EFFECTIVENESS OF A PEDESTRIAN HYBRID BEACON AT MID-BLOCK PEDESTRIAN CROSSINGS IN DECREASING UNNECESSARY DELAY TO DRIVERS AND A COMPARISON TO OTHER SYSTEMS

by

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Abstract

Pedestrian signals, particularly at signalized, mid-block crossing can cause delay to drivers after pedestrians' have successfully crossed, which is termed "unnecessary delay" in this study. In many cases at a mid-block signal, a pedestrian pushes the button and then quickly crosses the street as soon as the walk signal appears and drivers still face several seconds of solid red ball and by law must remain stopped. On a busy street, a queue of vehicles waiting after all pedestrians have crossed can amount to hundreds of hours of unnecessary delay per year. The 'Pedestrian Hybrid Beacon' (Initially named a HAWK (High Intensity Activated Crosswalk)) Beacon was proven to be effective in decreasing this unnecessary delay when compared to standard signalized mid-blocks. The City of Lawrence, Kansas was interested in experimenting (as a HAWK beacon was considered experimental when they were installed) with a pedestrian hybrid beacon and they installed their first pedestrian hybrid beacon at a mid-block crossing on 11th street and a second pedestrian hybrid beacon at mid-block crossing on New Hampshire street, Lawrence, Kansas, which were the sites of interest for this research. A study was conducted at these sites to determine the effectiveness of the pedestrian hybrid beacon in decreasing the unnecessary delay to drivers by comparing it to a signalized mid-block crossing on Massachusetts Ave in Lawrence, Kansas. Apart from the delay measurements for these two sites, other parameters such as driver compliance rate to the signal, pedestrian compliance rate, and other driver and pedestrian characteristics were also studied. Video cameras were used to capture video at these sites and the effectiveness of the pedestrian hybrid beacon was analyzed from the video. The HAWK, now in the MUTCD as a Pedestrian Hybrid Beacon, proved to be effective in decreasing the unnecessary delay for drivers in this study. The City of Lawrence had a total of six pedestrian hybrid beacons in operation as per the information received in March 2010.

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Dedication

I would like to dedicate this thesis to my father, G. B. Franklin, who has been a great support to me by inspiring me since I was a kid, my mother M. Manorama, my sister G. Deepa and my brother G. Avinash.

CHAPTER 1 - Introduction

Pedestrians mostly prefer crossing the road at mid-block locations though intersections are well equipped for pedestrians (*1*). They will try to take the most direct route possible to get to their destination though it involves crossing several high speed lanes of traffic (*1*). To meet these pedestrians' needs, well designated and designed mid-block pedestrian crossings provide many safety benefits.

1.1 Non Intersection Crossings

Due to the advent of modern suburbs, the blocks are becoming longer and the increased vehicle speed puts pedestrians at higher risk at some intersections. Pedestrians tend to cross the street at random and unpredictable locations when convenient crossing points are not identified. Crossing at these random points may cause risk to pedestrians and also to drivers from the safety point of view (*1*).

To facilitate these random crossing points as designated non intersection crossing types, different techniques practiced are (*1*):

1. median and refuge islands,
2. grade separated crossings, and
3. mid-block crossings.

1.1.1 Median and Refuge Islands

A median and refuge island is a raised longitudinal space separating two main directions of traffic. Refuge islands are much shorter than medians with a length of 100ft – 200ft. Medians and refuge islands can be used to block side-street or driveway crossing of the main road. They also block left turn movements, therefore increasing the flow rate of the roadway and also increasing safety (*1*).

Generally, mid-block crossings are used on low volume, low speed (25-30 mph) streets such as short collectors through neighborhoods. Median and refuge islands are used when collectors are longer and handle more traffic and have higher speeds. Multilane minor and major arterials require refuge islands or raised medians to be used with great care (*1*).

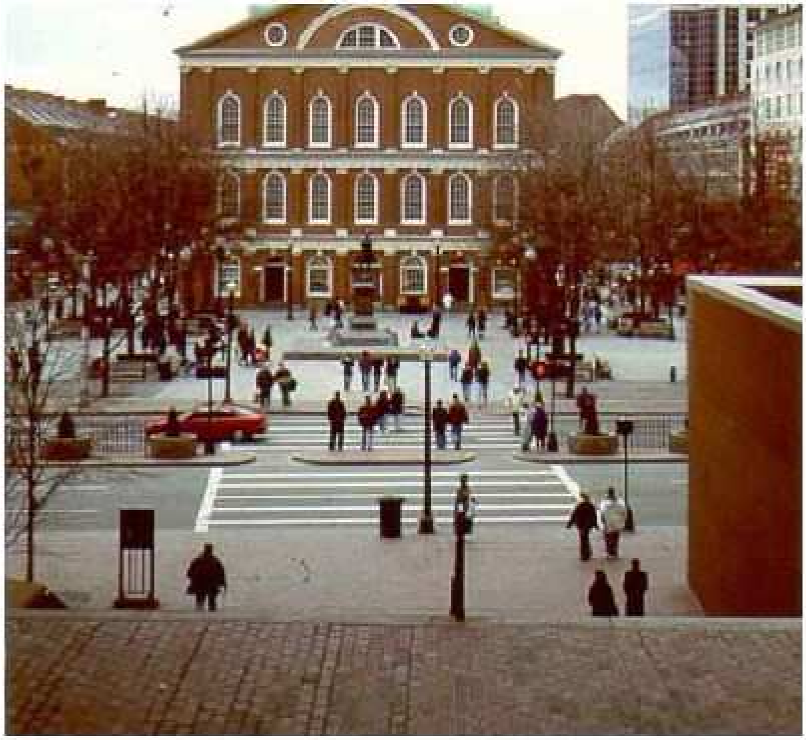

Figure 1.1: Picture of Refuge Islands with Crosswalks on a Major Collector with Higher Traffic Speeds

Source: *Federal Highway Administration University Course on Bicycle and Pedestrian Transportation (1)*

1.1.1.1 Advantage of Medians

Medians not only separate conflicts, but also create potential for acceptable gaps. A pedestrian facing many lanes of traffic in each direction needs to get a longer gap which can be a complex task. If a raised median is placed in the center, then a pedestrian can cross the roadway in stages with available small gaps (*1*).

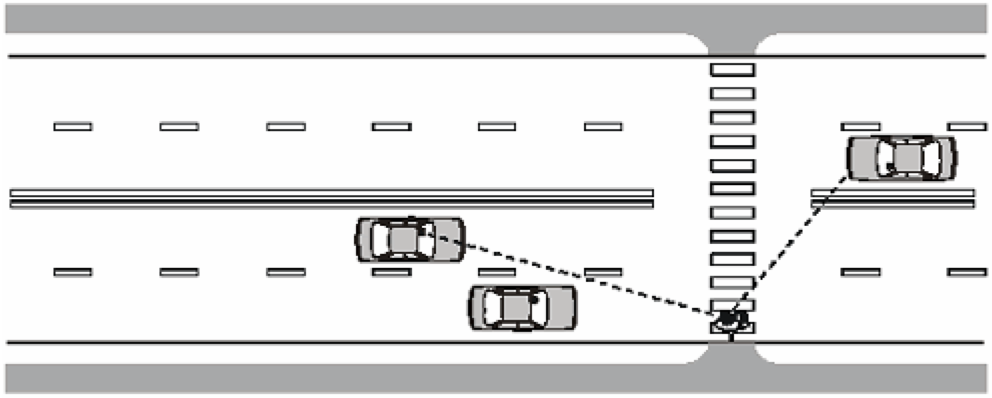

Figure 1.2: Pedestrian Requires a Long Time to Cross by Looking in Both Directions at a Mid-block Crossing without Median Refuge

Source: *Federal Highway Administration University Course on Bicycle and Pedestrian Transportation (1)*

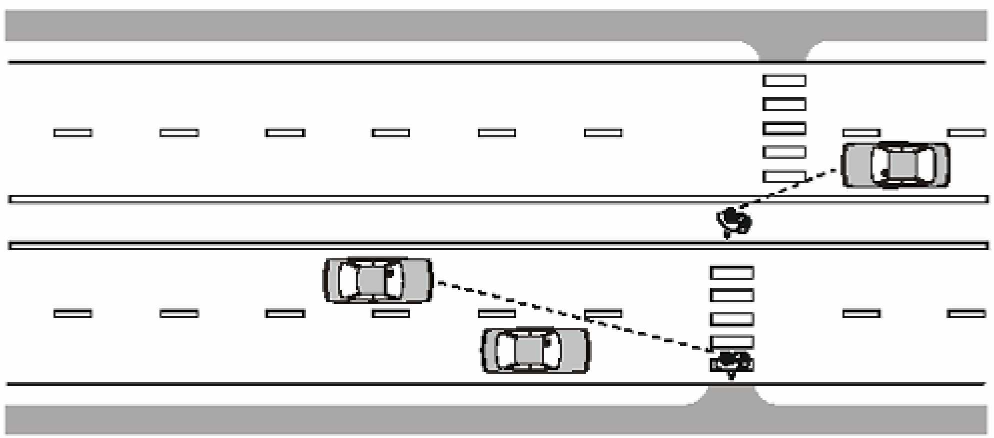

Figure 1.3: Mid-block with Median Refuge Allows the Pedestrian to Look for Gaps in Only One Direction at a Time

Source: *Federal Highway Administration University Course on Bicycle and Pedestrian Transportation (1)*

1.1.2 Grade-Separated Crossings

A grade separated crossings such as a bridge/overpass or a culvert/underpass (Figure 1.4) should be considered when a pedestrian facility meets a barrier like an active multitrack railroad, stream or freeway (*1*).

Figure 1.4: Picture of an Underpass Beneath a Four-lane Highway with High Traffic Volume

Source: *Federal Highway Administration University Course on Bicycle and Pedestrian Transportation (1)*

Some of the principle planning concerns with grade separated crossings are (*1*):

1. high cost for implementation,
2. lack of existence of the bicycle/pedestrian grade separation guidelines in the locally adopted greenway master plans by the time the construction is in an early stage of development,
3. lack of usage of overpass by bicyclists and pedestrians due to inconvenience, and
4. grade crossing should be accessible to all by considering different elements like ramps, handrails, landings, etc.

Some of the warrants for grade separated crossings to be present are (*1*):

1. high pedestrian volume and high demand to cross at the location,
2. larger numbers of younger school children regularly crossing,
3. high volume and high speed vehicles on the roadway,
4. no other convenient crossing places nearby,
5. sufficient funds and specific need for the overpass/underpass, and
6. an extreme hazard for pedestrians.

1.1.3 Mid-block Crossings

Mid-block crossings are locations between intersections where a marked crosswalk has been provided. Mid-block crossings are often installed in areas with heavy pedestrian traffic to provide more frequent crossing opportunities. They may also be added near major pedestrian destinations, such as schools, where people might otherwise cross at unmarked locations (*2*).

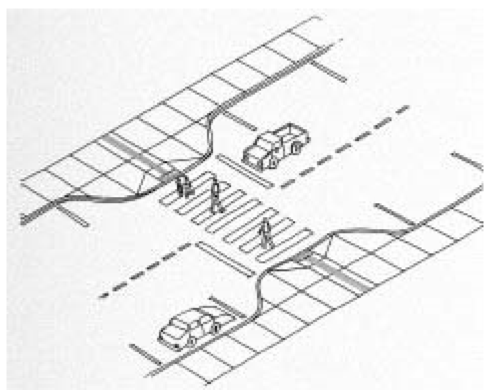

Figure 1.5: Curb Extensions and Highly Visible Crosswalks Improve Pedestrian Access at Mid-block Crossings

Source: Pedestrian Crossings (*2*)

1.1.3.1 Mid-block Crossings by Roadway Classifications

Median installations in mid-block crossings vary for different types of roadways because of a number of factors such as roadway width, traffic volume, traffic speed and type, desired lines for pedestrian movement, and adjacent land use. Mid-block crossing installations vary for different types of roadways as follows (*1*).

1.1.3.1.1 Local Roads

Mid-block crossings on local roads very rarely have median treatments due to their low traffic speed and volume. There might be some exceptions for installing medians with the presence of schools and hospitals (*1*).

1.1.3.1.2 Collector Roads

Two-lane collector roads occasionally have median or refuge islands to channel pedestrians to preferred crossing locations. Pedestrian crossings at the mid-block refuge islands with marked crosswalks achieve a good performance from motorists. Collector roads with four lanes might need raised medians (*1*).

1.1.3.1.3 Multi Lane Arterial Highway with Four Lanes

Multi-lane arterial highway with four lanes can be greatly improved with medians and mid-block crossings. Signalization is essential for these kinds of roads when roadway volume is higher, lack frequent gaps, have school zones, or have elderly and disabled pedestrians' at crossings, higher vehicle speed, etc., (*1*).

1.1.3.1.4 Multi-Lane Arterial Highway with Six or More Lanes

Multi-lane arterial highways with six lanes have a lot of merging and lane changing which makes pedestrian crossing conditions complex. Signalization is the only way to provide safer crossing conditions on high vehicle speed roads. However it is recommended not to allow higher vehicle speeds in urban areas which have higher density land use.

Large overhead signs, flashing beacons, bulb-outs and flashing overhead signs are successfully used in some locations (*1*).

1.1.3.2 Staggered Mid-block Crosswalks

Staggered crosswalks (or Z-crossings) are treatments in which the crosswalk is split by a median and is offset on either side of the median. This staggered crosswalk forces the pedestrians to face the oncoming traffic when they are on the median (Figure 1.6). Sometimes medians may also have attractive fencing to force the pedestrians' into the intended path (Figure 1.7) (*1*).

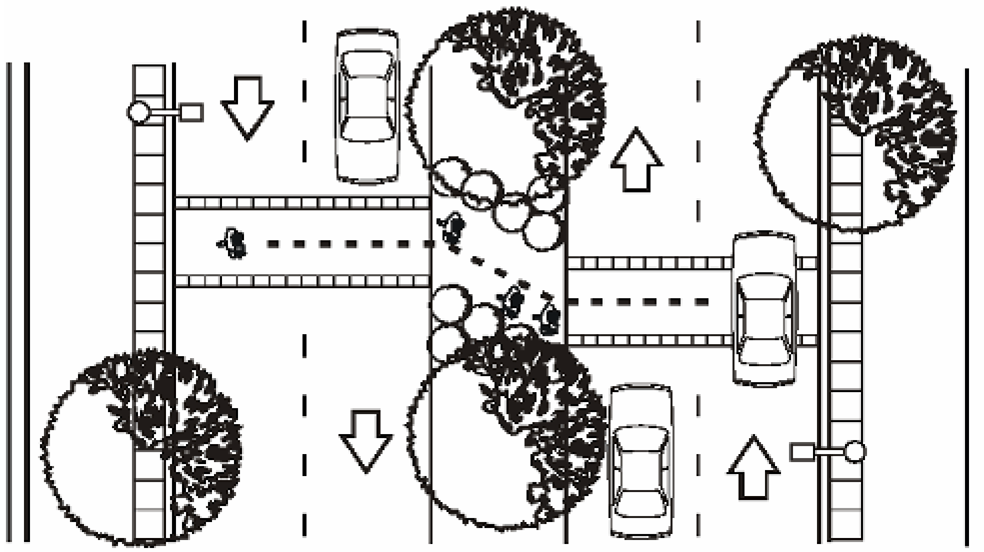

Figure 1.6: Staggered Crossing Configuration

Source: *Federal Highway Administration University Course on Bicycle and Pedestrian Transportation (1)*

Figure 1.7: Staggered Crosswalk with Fencing

Source: *Federal Highway Administration University Course on Bicycle and Pedestrian Transportation (1)*

1.2 Problem Statement

Signalizing a mid-block pedestrian crossing is one of the common treatments to enhance the safety of these pedestrian crossings. This type of treatment is most commonly selected on streets with heavy traffic where the gaps available for the pedestrians to cross the street are considered inadequate. This treatment is superior when compared with other mid-block crossing treatments because it results in better driver compliance and a safer crossing for pedestrians (*3*).

On the other hand, a signalized mid-block crossing can cause delay for the driver when they must remain stopped by a solid red ball even after all pedestrians have crossed. This delay has been termed “unnecessary delay” in this study. The Manual on Uniform Traffic Control Devices (MUTCD 2003)(*4*) used a walking speed of 4.0 ft/s (1.22 m/s) for designing the clearance time for pedestrians at traffic signals thereby accommodating different groups of pedestrians (Adults, senior citizens and physically challenging pedestrians) with different walking speeds. But in the real world, in many areas, the probability for a slow walking pedestrian is low and many times the pedestrians clear the street in the first few seconds of the walk phase without using the complete designed pedestrian clearance time. However, the drivers are required to remain stopped at the solid red ball for a designed time even though the pedestrians have cleared the lane, causing them unnecessary delay. Sometimes the pedestrians press the push button and cross the street even before they are given walk signal. This is the extreme case with maximum unnecessary delay for the drivers in which they need to stop for no pedestrians for the entire designed pedestrian clearance time. This situation often occurs in areas where there are students or other young pedestrians.

A Pedestrian Hybrid Beacon (PHB), when used at mid-block pedestrian crossing can overcome this unnecessary delay to motorists by its special signal phasing with a flashing red ball. A study conducted by Fitzpatrick et al. (2006) (*3*), also concluded that it achieves a high driver compliance rate (97%).

The City of Lawrence was interested in experimenting with the Pedestrian Hybrid Beacon. The PHB was not included in the 2003 MUTCD when it was decided to install the signal. So, the city of Lawrence got permission from Federal Highway Administration (FHWA) for experimental testing at one of their mid-block crossings (at 11th street between New York street and new Jersey street) on a route used by elementary school children. Previously there was a yellow flashing beacon at that site that parent teacher organizations thought was inadequate.

The parents wanted a traffic signal and the city wished to minimize vehicular traffic delay on the street. It was decided to implement a PHB. This beacon was then studied for its effectiveness in decreasing unnecessary delay to the drivers in this study.

1.3 Objective of the Study

The objective of this research was to study the safety benefits to pedestrians and the reduction of unnecessary delay to motorists using PHBs in the city of Lawrence. The city staff wanted the research to evaluate the benefits of the signal. For this purpose, two different mid-block pedestrian crossings (one on 11th street between New York street and New Jersey street and the other on New Hampshire street between 9th street and 10th street) with PHBs installed were selected to for comparison to a signalized mid-block pedestrian crossing on Massachusetts street between north park street and south park street. Video cameras were used to collect the data on driver delay and pedestrian characteristics at the PHB sites and the comparison site. A survey of a sample of motorists was also conducted to evaluate their understanding and acceptance of a PHB.

1.4 Pedestrian Hybrid Beacon (PHB) / HAWK Beacon Signal

HAWK beacon was the most common name of the Pedestrian Hybrid Beacon till December 16th, 2009. HAWK is an acronym derived from *H*igh intensity *A*ctivated cross *W*al*K*. The PHB was not included in the 2003 MUTCD. So, when the PHB was installed at City of Lawrence, Kansas, they had to get a permission to experiment from the FHWA for the installation.

The geometry of the PHB is triangular with one yellow lens on the bottom and two red lenses above it. This PHB for the vehicular traffic was coordinated with a traditional walk/don't walk signal for pedestrians. When not activated, the PHB is blanked out. The PHB is activated by a pedestrian push button. Once the pedestrian activates a PHB, the overhead signal begins flashing yellow, followed by solid yellow, advising drivers to prepare to stop. The signal then displays a solid red to drivers and the pedestrian gets the walk indication; however after a few seconds into the pedestrian walk phase, the red ball facing the driver goes to flashing red for the final seconds of the walk phase (when pedestrians are given flashing don't walk indication) and the driver may proceed on flashing red if the crosswalk is clear, thereby decreasing the unnecessary delay which is present in a conventionally signalized mid-block crossing. Figure 1.8 shows the sequence of operation of PHB.

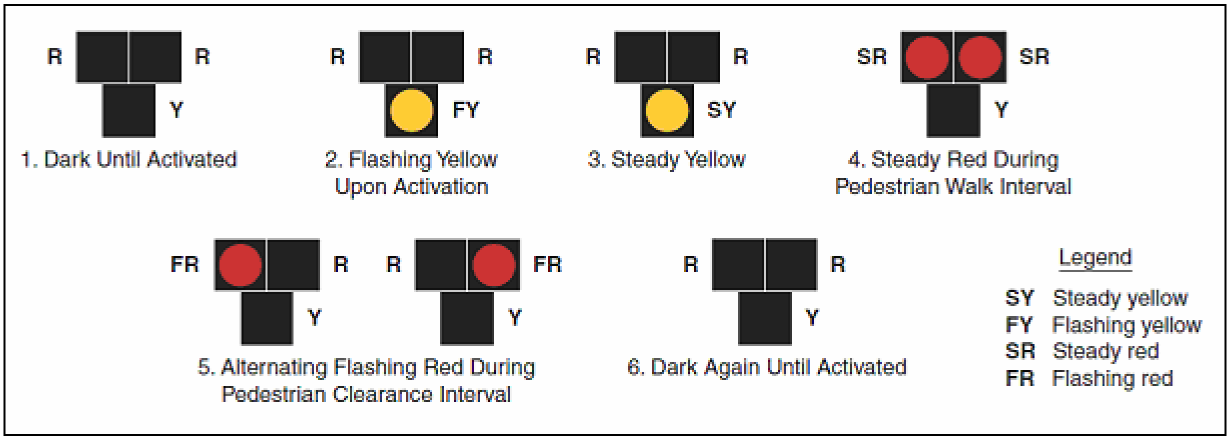

Figure 1.8: Sequence of Operation for a Pedestrian Hybrid Beacon

Source: MUTCD 2009 (*5*)

Understanding of Different Phases of a PHB for a Driver from Figure 1.8:

1. Dark; drive as usual.
2. Flashing Yellow; caution. pedestrians want to cross.
3. Steady Yellow; be prepared to stop for pedestrians.
4. Steady Red; must stop and remain stopped
5. Flashing Red; you can proceed after the pedestrians have cleared the street.
6. Dark again; drive as usual.

In 2004, the Tucson Department of Transportation installed five PHBs around the city for the first time in US. They found them to be very effective and there are currently over 66 PHBs in operation. These special signals were placed at intersections where there were frequent crashes with pedestrians near a university, a shopping center and a high school. The PHBs have greatly improved pedestrian safety in Tucson which led to an increase in usage in the US and finally, being added to MUTCD 2009 (*5*).

1.4.1 Measuring of Unnecessary Delay

Unnecessary delay has been defined in this paper as the time for which vehicles are stopped at a signalized mid-block crossing after all pedestrians have cleared the crosswalk but still need to remain stopped for a solid red ball according to law. It is measured as the time taken from when all pedestrians reach the other curb until the vehicles legally resume.

When measuring the unnecessary delay for each signal actuation, the delay of the first vehicle which starts moving first in any of the lanes was considered.

1.4.2 Pedestrian Hybrid Beacons at Lawrence, Kansas

The City of Lawrence was interested in experimenting with the PHB to make use of its advantages.

The first PHB was installed on a mid-block pedestrian crossing on 11th street in between New York street and New Jersey street at Lawrence, Kansas in August 2007. A second PHB was installed on a mid-block pedestrian crossing on New Hampshire street between 9th street and 10th street in March 2009.

These two PHBs were compared with a signalized mid-block pedestrian crossing on Massachusetts street between north park street and south park street in Lawrence to determine their effectiveness when compared to the signalized mid-block crossing.

1.5 Organization of this Thesis

Chapter 2 of this thesis reviews the results from different studies that provide a background that concentrates on studies conducted for determining the effectiveness of different pedestrian crossing treatments, pedestrian characteristics, pedestrian walking speed, and literature available on PHBs.

Chapter 3 of this thesis describes a preliminary study conducted in Manhattan, Kansas to find the effectiveness of four different mid-block pedestrian crossing treatments. The sites selected for this study, methodology selected for data collection and data analysis, and their results will be discussed in detail in this chapter.

Chapter 4 of this thesis starts with giving a brief description of the PHB followed by presenting the PHB section now included in the 2009 MUTCD(*3*).

Chapter 5 of this thesis deals with the study methodology carried out at the two selected mid-block pedestrian crossing treatments equipped with PHBs and their comparison site which is a conventionally signalized mid-block pedestrian crossing. Description of the site, methodology followed for data collection and data analysis, and different results that were required from this study are described for the three sites of interest in this chapter.

Chapter 6 of this thesis includes the results of a survey conducted with Lawrence drivers providing information on the operation and asking for their opinion on the PHB newly installed in their city. The results were based on the 35 survey responses among the 250 distributed survey forms.

Chapter 7 of this thesis starts with describing the concepts required for an Independent Group t-test which was chosen to test the statistical significance of reduction in unnecessary delay to drives by using a PHB when compared to the conventionally signalized mid-block crossing. Finally, the Independent Group t-test results were presented.

Chapter 8 of this thesis summarizes all results obtained from preliminary study, primary study, survey with drivers, and statistical analysis.

Chapter 9 of this thesis discusses the conclusions of the unnecessary delay results for using signals and PHBs at mid-block pedestrian crossings. Recommendations and future research are also suggested in this chapter.

CHAPTER 2 - Literature Review

There is limited published information available on PHBs. However to better understand their benefits, this thesis will review various issues of different crossing treatments and pedestrian safety, including the PHB, from a recent, comprehensive study.

2.1 Different Pedestrian Crossing Treatments

A study was conducted by Fitzpatrick et al. (2006) (*3*) for motorist compliance rates at 42 study sites that included 9 different kinds of crossing treatments. This report was reviewed regarding different crossing treatments and their effectiveness. Driver compliance rates for crosswalks with different treatments was one of the basic findings from this report. Every state has its own state laws defining driver yielding behavior at crosswalks. State law defining pedestrians right-of-way in crosswalks was the main criteria used to define and measure driver compliance in different states. State laws for pedestrian right-of-way varies among the 50 US states. Appendix A reviews the 50 state laws for pedestrian right-of-way at crosswalks. The Kansas state law for pedestrian right-of-way at a crosswalk is:

"*When traffic-control signs are not in place or not in operation, the driver of a vehicle shall yield the right-of-way, slowing down or stopping if need be or yield, to a pedestrian crossing a roadway within a crosswalk when the pedestrian is upon the half of the roadway upon which the vehicle is traveling, or when the pedestrian is approaching so closely from the opposite half of the roadway so as to be in danger*"

2.1.1 Traffic Signals and Red Beacon Displays

Traffic signals, half signals and displays with solid or flashing red beacons fall into this category. PHBs are an example of a solid or flashing red beacon.

Half signals are used in a few cities (eg., Seattle, WA and Portland, OR). A traditional traffic signal head is used on the major streets, but not the minor or side streets. During the red signal indication for the vehicles, traditional pedestrian walk/ don't walk signals are used for pedestrians' crossing the major street. When a pedestrian activates a half signal, the signal to traffic changes from steady green to steady yellow and then to steady red. The operation of a half signal may be different at different places.

The city of Tucson developed the PHB for the first time in the United States (US). They are dark until activated by a pedestrian. Upon activation they cycle through flashing yellow, steady yellow, steady red and then flashing red. During the red signal indication for the vehicles, traditional pedestrian walk/ don't walk signals are used for pedestrians crossing the major street. During the flashing don't walk interval for pedestrians, drivers see a flashing red indication which means they can proceed if the crosswalk is not occupied.

The steady red signal display treatment provides a regulatory message that results in a good response from drivers. The field studies from the study done by Fitzpatrick et al. (2006) and several other studies cited in Fitzpatrick at al. concluded that red signals or beacon devices were most effective in achieving motorist yielding (90-100%) on high volume, high speed streets (*3*).

2.1.2 Flashing Beacons

Flashing beacons are very commonly used in the US. The different kinds of flashing beacons operation include:

1) continuous flashing mode,
2) pedestrian operated manual push button,
3) passive pedestrian detecting using automated sensors, and
4) different flash rates, sequences or strobe effects.

The study conducted by Fitzpatrick et al. (2006) (*3*) has shown that motorist yielding for all flashing beacons has an average value of 58 percent (values ranging from 25 to 73 percent for different sites). It is stated in the Fitzpatrick et al. (2006) (*3*) report(*3*) that several other studies concluded intermittent (activated using manual pushbutton or automated sensors) flashing beacons have a more effective driver response than continuously flashing beacons.

2.1.3 In-Roadway Warning lights

The use of in-roadway warning lights originated in the states of California and Washington and then spread to various other places in the United States (*3*). They are mounted in the pavement near the crosswalk markings such that they protrude above the pavement less than 0.5 in (1.3cm).

Some of the problems encountered by in-roadway warning lights are:

1) snow plows damaging the flashing light enclosures,
2) light lenses becoming dirty from road grit which requires regular cleaning, and
3) inefficient operation of automatic pedestrian detection.

It is stated in the Fitzpatrick et al. (2006) (*3*) that some studies with in-roadway warning light installations have reported increased driver yielding to the 50 to 90 percent range. They also mentioned that several other studies proved that the in-roadway warning signs are effective in increasing driver recognition of the crosswalk, i.e., sooner, and are more effective during the nighttime during which the in-roadway warning signs are highly visible.

It is reported by Fitzpatrick et al. (2006) (*3*) that in some studies, cities preferred overhead flashing beacons instead of in-roadway lights because of poor visibility when traffic is queued. Another concern is that the in-roadway flashing lights are hardly visible in very bright sunlight.

The Fitzpatrick et al. (2006) (*3*) research team did not include the in-roadway signs in their field studies and hypothesized that these installations are inappropriate and that other crossings treatments would be more effective.

2.1.4 Motorists Warning Signs and Pavement Markings

These pedestrian crossing treatments may be of various types:

1) animated or roving eyes,
2) advanced yield or stop lines,
3) crossing flags carried by pedestrians,
4) yield to pedestrians and stop here for pedestrian signs, and
5) internally illuminated crosswalk signs.

These kinds of treatment send out a warning message like “watch out for pedestrians” or “avoid pedestrians”. The Fitzpatrick et al. (2006) (*3*) research team, (*3*) hypothesized in their study that drivers comply to these warning messages as a courtesy. For high-speed, high-volume roadways they hypothesize that the motorists are less willing to extend this courtesy to pedestrians.

Among these crossing treatments, the Fitzpatrick et al. (2006) (*3*) field studies indicated that in-street signs had relatively high motorist yielding (average of 87% from different sites). The study also concluded that high visibility signs and marking treatments had different yielding rates for sites with different posted speed limits (61% yielding rate for 25mph posted speed limit and an average of 17% yielding rate for sites with 35mph posted speed limit).

Field studies conducted by Fitzpatrick et al. (2006) (*3*) also found pedestrian crossing flags to be moderately effective with an average yielding rate of 65 percent (ranged from 46 to 79% for all the sites).

2.1.5 Summary of the Fitzpatrick, et al. (2006) Study

Fitzpatrick et al. (2006) (*3*) in their study found that red signals or red beacon devices have the highest compliance rates (> 90%) on high-volume, high-speed streets when compared to other crossing treatments. The summary of their results were shown in Figure 2.1. The HAWK (as the PHB was called in their study) was observed to have a driver compliance rate of 97%.

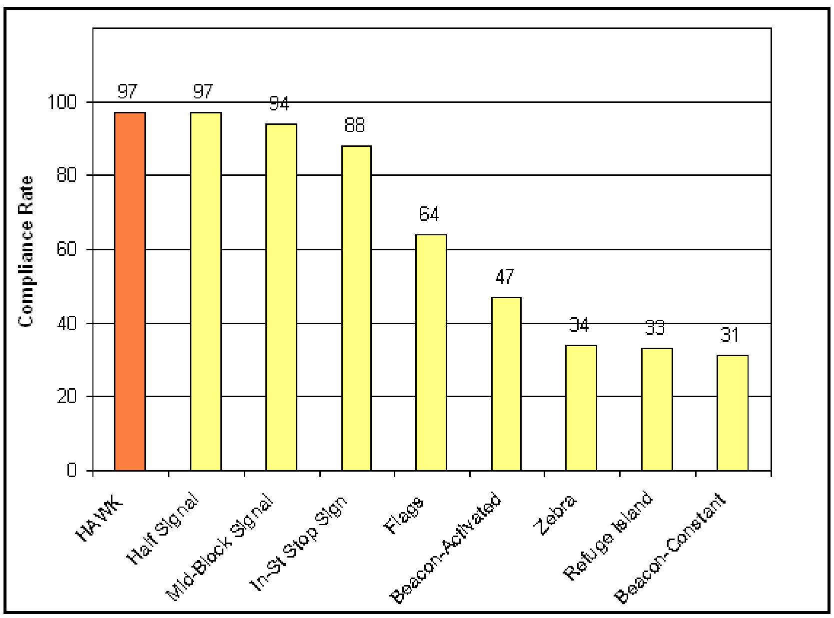

Figure 2.1: Driver Compliance Rates for Different Crossing Treatments from Fitzpatrick et al. Study

2.2 Pedestrian Characteristics

During the process of designing a roadway, a wide range of needs and pedestrian capabilities of different pedestrian groups must be accommodated. Age and functional disabilities play a major role for the reduction of a person’s mobility, sight or hearing. These situations warrant good engineering with good decision to accommodate different categories of pedestrians on the roadway.

2.2.1 Characteristics of Different Age Groups

Table 2.1 shows some common characteristics of pedestrians in different age groups. This table was extracted from FHWA University Course on Bicycle and Pedestrian Transportation (*1*).

Table 2.1: Walking Characteristics and Abilities of Different Pedestrian Age Groups

Infants and Toddlers (ages 0 to 4)

At this age, walking skills are just being developed and the children require constant parental supervision. Infants and toddlers are very limited in ability and are:

- Learning to walk.
- Developing peripheral vision and depth perception.
- Impulsive and unpredictable.

Young Children (ages 5 to 12)

At a young age, children have unique abilities and needs. Since children this age vary greatly in ability, it is important for parents to supervise and make decisions on when their child is ready for a new independent activity. Children in this age range tend to be:

- Impulsive and unpredictable.
- Limited in their peripheral vision (a sound source is not easily located).
- Limited in training/lacking in experience.
- Thrilled or excited by close calls.
- Short and hard to see by drivers.
- Susceptible to darting or dashing out into the intersection.
- Likely to copy the behavior of older people.

Preteens (ages 13 to 14)

By middle school years, children have many of their physical abilities but still lack experience and training. Now there is greater desire to take risk. Preteens generally:

- Lack experience.
- Walk and bicycle more and at different times (have a higher crash exposure).
- Ride more frequently under risky conditions (in high traffic).
- Lack positive role models.
- Walk across more risky roadways (collectors and above).
- Get involved in more intersection dash collisions.
- Have a sense of invulnerability that makes them more willing to take chances.

High School Aged (ages 15 to 18)

By high school and college age, exposure changes and new risks are assumed. Many walk and bicycle under low light conditions. Other characteristics of this age group are that they:

- Are very active, can go long distances, and visit new places.
- Feel invincible.
- Still lack experience and training.
- Are capable of traveling at higher speeds.
- Will overestimate their abilities on hills, curves, etc.
- Attempt to use bicycles, in-line skates, etc., based on practices carried over from youth.
- Are willing to experiment with alcohol and drugs.

Table 2.1: Walking Characteristics and Abilities of Different Pedestrian Age Groups – Continued

Adults (19 to 40)

These adults are highly competent in traffic and capable of perceiving and dealing with risk in most circumstances. Some use bicycles for commuting and utilitarian trips, while others use bicycles primarily for recreation. This group generally:

- Is active and fully aware of the traffic environment.
- Comprises only 1–4 percent of bicycling population in most communities.
- Tends to be very vocal and interested in improving conditions.
- Has members interested in serving as instructors or task force leaders.

Middle-Aged Adults (41 to 65)

During this stage of life, many pedestrians experience a slowing of the reflexes necessary to observe, assess, and respond to traffic conditions.

Senior Adults (65+)

Senior adults, ages 65 and up, begin a gradual decline in physical and physiological performance, with a rapid decline after age 75. Many are incapable of surviving serious injuries. These changes affect their performance. Seniors:

- Walk more in older years, especially for exercise/independence.
- May have reduced income and therefore no car.
- All experience some reduction in vision, agility, balance, speed, and strength.
- May have further problems with hearing, extreme visual problems, and concentration.
- Have the tendency to focus on only one object at a time.
- Have difficulty hearing vehicles approaching from behind.
- All have greatly reduced abilities under low light/night conditions.
- May overestimate their abilities.
- Have a higher fatality rate than other pedestrians involved in collisions with motor vehicles.

Source: *Federal Highway Administration University Course on Bicycle and Pedestrian Transportation (1)*

2.2.2 Other Pedestrian Types and Characteristics

Table 2.2 gives some other types of pedestrians that can be grouped by their walking characteristics.

Table 2.2: Characteristics of Other Pedestrian Groups

Impaired For those of us fortunate to live to an older age, 85 percent will have a permanent disability that limits our range of mobility. Disabilities are common through all ages, and the permanently disabled constitute at least 15 percent of our population. Those with permanent physical disabilities, often kept away from society in the past, are now walking and bicycling on a regular basis. Many others have temporary conditions, including pregnancy, and broken or sprained limbs that may restrict their mobility. The disabled group includes: • Those who are visually impaired, hearing impaired, mobility impaired, mentally/emotionally impaired, or other. • Many older adults who have reduced abilities. • People who were previously institutionalized and are not trained to walk the streets. • Those dependent on alcohol or drugs who may be hard to recognize.
Inexperienced Adults who have not walked and bicycled regularly as children, and who have not received training are not prepared to take on the challenges of an unfriendly urban environment. This group presents a particular challenge because: • Ninety-five percent of adults are novice bicyclists. • Many are unskilled in urban walking. • Drinking can influence their abilities. • Many assume they have higher skills and abilities than they actually have. • Most carry over sloppy habits from childhood. • Many new immigrants are unprepared for urban auto traffic.
Ethnic/Cultural Diversity/Tourism America is rapidly becoming a nation with no clear majority population. All groups need access and mobility in order to fully participate in society. Transportation officials must pay close attention to communication, the creation of ethnic villages, and subcultural needs and practices. Most of these people depend heavily on walking and transit to get around. Some newly arriving groups lack urban experience, and many are used to different motorist behavior.
Transportation Disadvantaged In most States, 30 to 40 percent of the population does not own a car because they are not able to drive, they choose not to drive, or they cannot afford to purchase or operate a car. Even though this group typically does not have special needs, these men, women, and children are highly dependent on walking, transit, and bicycling for their basic freedom, access, and mobility.

Source: *Federal Highway Administration University Course on Bicycle and Pedestrian Transportation (1)*

2.2.3 Mobility-Impaired Pedestrians

Mobility-impaired pedestrians include those with wheelchairs, crutches, canes, walkers, guide dogs, prosthetic limbs, orthotics, or other assistive devices. Table 2.3 contains a list of design features that help accommodate mobility-impaired pedestrians.

Table 2.3: Design Needs of Mobility-impaired Pedestrians

Wheelchair Users • Wider path and larger maneuvering space. • Surfaces with low cross slopes, low grades, smooth surfaces, and level terrains. • Firm, stable surfaces and structures such as ramps or beveled edges to negotiate changes in level. • Gradual rate of change of cross slope in such places as driveways and aprons.
Walking-Aid Users • No grates and cracks which could catch or hinder the walking-aid. • Longer pedestrian signal cycles at intersections and the presence of passing spaces to allow others to travel around them. • No rapid change in cross slope that could cause people with walkers to stumble.
Prosthesis Users • Extended signal timing at wide intersections. • Low grades and cross slopes.
People with Visual Impairments • Detectable warnings (surfaces that can be detected underfoot and by a person using a cane through texture, color, and resilience). • Wayfinding information that provides orientation information to the user. • Visual cues, tactile surfaces, or audible pedestrian signals that can make information about traffic flow and street crossings more accessible.
People with Hearing Impairments • Areas with long sight distances relatively free of visual obstructions such as landscaping.
People with Cognitive Impairments • Signs that use pictures, universal symbols, and colors rather than words to convey meaning to a broad range of people.

Source: *Federal Highway Administration University Course on Bicycle and Pedestrian Transportation(1)*

2.3 Pedestrian Walking Speed

As shown in section 2.2 above, different categories of pedestrians have a wide range of needs and abilities. Walking speed is the main criteria used in designing the pedestrian clearance time at traffic signals. Generally the 85th percentile walking speed for all groups of pedestrians is used while designing the pedestrian clearance time. This generally includes the low speed, walking pedestrians. So, in cases like this, the faster pedestrians would be using only a portion of a designed clearance time at the signals and the crosswalk would be unoccupied for the remaining portion of time. The 2003 MUTCD (*4*) which was in effect during this study, adopted a walking speed of 4.0 ft/s (1.22 m/s) for designing the pedestrian clearance time for traffic signals. It also includes a comment that where pedestrians who walk slower than normal, or pedestrians who use wheelchairs, routinely use the crosswalk, a walking speed of less than 4.0 ft/s (1.22 m/s) should be considered in determining the pedestrian clearance times.

Fitzpatrick et al. (2006) (*3*) in their study determined the 15th percentile walking speeds for younger and older people to be 3.77 ft/s (1.15 m/s) and 3.03ft/s(0.92 m/s) respectively. They recommended a walking speed of 3.5 ft/s (0.07 m/s) and 3.0 ft/s (0.92 m/s) for general population and senior citizens or less able population. This speed would require longer walk times and would likely increase unnecessary delay. Also in their report, they cited Coffin and Morrall (1995) (*6*), as recommending a walking speed of 3.3 ft/s (1.01 m/s) at crossings with large numbers of seniors, on the basis of their observations of speeds of older pedestrians at three types of crossings. They also mentioned that according to the report ‘Guidelines and Recommendations to Accommodate Older Drivers and Pedestrians’ (2001) (*7*), a walking speed of 2.5 ft/s (0.76 m/s) is recommended for less capable older pedestrians. These speeds, if adopted for special areas could greatly increase unnecessary delay.

2.3.1 Senior Citizens

In the US, the Census Bureau estimates that the 65-year and older population will grow by over 50% between the period 2000 to 2020. This rapid change in demographics should be properly accommodated into transportation systems in a safe manner.

In the report, ‘Guidelines and Recommendations to Accommodate Older Drivers and Pedestrians’(*7*), an assumed walking speed of 2.8 ft/s (0.9 m/s) was recommended for less capable (15th percentile) older pedestrians.

In the Fitzpatrick et al. study, (2006) (3) mean startup time was 2.5sec for older pedestrians, compared to 1.9s for younger ones. Also they stated that older pedestrians are more likely to make incorrect decisions about the length of a critical gap if compelled to make a quick decision, which can lead to higher rates of crashes, injuries and fatalities in older pedestrians.

2.4 Literature on the Pedestrian Hybrid Beacon / HAWK beacon signal

Fitzpatrick and Park (2008) (*8*) conducted a study to evaluate the safety effectiveness of a PHB (referred to as a HAWK in their study) in the City of Tucson, AZ. Their goal was to select two un-signalized intersections and two signalized intersections as reference sites for each PHB in their study. They studied 71 reference sites (35 un-signalized intersections and 36 signalized intersections) for the 21 PHBs of interest in this study. Crash data was used from two datasets to evaluate the effectiveness of a PHB for a before and after study. When comparing the 21 PHB intersections with 35 unsignalized intersections, they found that PHB intersections had slightly greater number of crashes (0.222 crashes/million entering vehicles and pedestrians (MEV&P)) when compared to nearby unsignalized intersections (0.090 crashes/MEV&P). However, the research team did not conclude that the installations at unsignalized crossings increased crashes because the before crash rate for the PHB locations when they were unsignalized was greater (0.328 crashes/MEV&P). PHB intersections were found to have fewer crashes (0.222 crashes/MEV&P) when compared to nearby signalized intersections (0.713 crashes/MEV&P). Different types of crashes that were categorized in this study are: All crashes (all identified crashes), Pedestrian crashes, Rear-end crashes, Angle-crashes and Severe crashes (includes all the crashes with an injury severity code of possible injury, non-incapacitating injury, incapacitating injury, or fatal injury). In their study, the before and after Empirical Bayes method was used for crash prediction to conclude that the PHB was statistically significant in decreasing crashes. For all intersection crashes a 28 percent reduction in all crashes and a 58 percent reduction in pedestrian crashes were observed at the 95 percent confidence interval.

CHAPTER 3 - Study of Mid-block Pedestrian Crossing Treatments in Manhattan, Kansas

To gain a better understanding of several pedestrian crossing treatments, an initial study of effectiveness of different mid-block pedestrian crossing treatments was conducted in Manhattan, Kansas.

Four different mid-block pedestrian crossing treatments in Manhattan were studied such that the effectiveness of these different crossing treatments could be determined. These results were subjectively compared to the results of the PHB on New Hampshire street, Lawrence.

Different types of mid-block pedestrian crossing treatments that were selected in Manhattan, Kansas for the study are:

1) signalized mid-block pedestrian crossing on Anderson Avenue,
2) mid-block pedestrian crossing with yellow flashers on Denison Avenue,
3) mid-block pedestrian crossing with in-roadway pedestrian crossing signs on Poyntz Avenue, and
4) mid-block pedestrian crossing with warning signs on N 17th street.

3.1 Signalized Mid-block Pedestrian Crossing on Anderson Avenue

3.1.1 Site Selected

The conventional signalized mid-block on Anderson Avenue, Manhattan, Kansas was selected for study of unnecessary delay computations. Other parameters were also computed at this site which will be explained in the next sections. Figures 3.1 and 3.2 give the plan and details of this signalized mid-block crossing. The characteristics of the site selected are that it is a street with two-way traffic with two lanes in each direction and a left turn lane for east bound traffic. It has no parking on either side of the street, and it has no median or curb in the center.

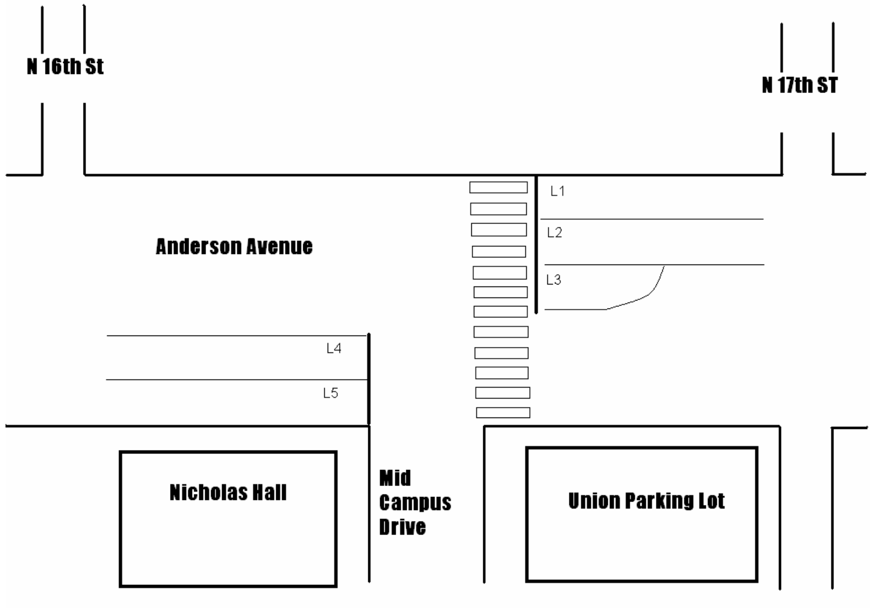

Figure 3.1: Plan of Signalized Mid-block Crossing on Anderson Avenue.

Figure 3.2: Picture of the Signalized Mid-block Crossing on Anderson Avenue.

3.1.2 Methodology for the Manhattan Study

Different parameters of interest in this study were unnecessary delay to drivers, percentage of pedestrians who don't push the call button before crossing the crosswalk, percentage of pedestrians who push the call button but don't wait until the walk signal is given, and percentage of pedestrians who start walking after flashing don't walk.

Data was collected manually at the site at different times in a particular week in October 2007. The times for which the observations were carried out were 11:00am-12:00pm, 12:00pm-2:00pm, 4:00pm-5:30pm and 6:00pm-8:00pm.The designed pedestrian clearance time was 30 seconds at the selected site.

Every time a pedestrian arrived at the crosswalk, he/she is categorized as pressing the call button or not. If he/she presses the call button, he/she is again categorized as waiting for the walk signal to cross the road or not. If the pedestrian crosses the street on walk signal, different parameters like walking time of all the pedestrians together, unnecessary delay and pedestrians who start walking after flashing don't walk were observed. Figures 3.3, 3.4, 3.5, and 3.6 summarize the results from the data collected.

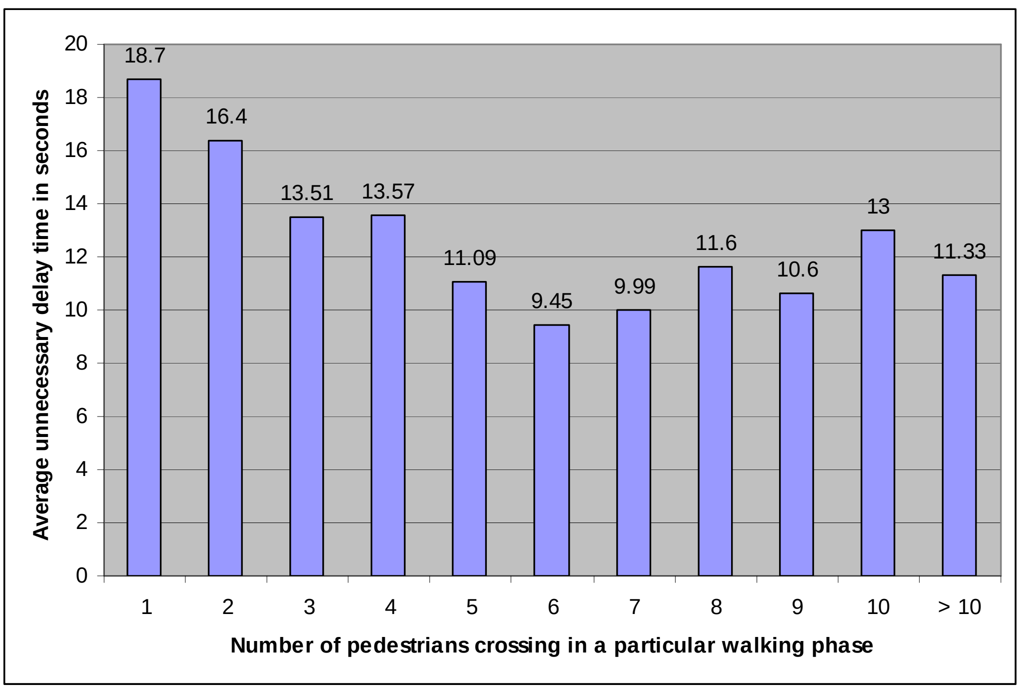

Figure 3.3: Average Unnecessary Delay Caused by Signalized Mid-block on Anderson Avenue for Different Number of Pedestrians Crossing the Road in a Walk Phase

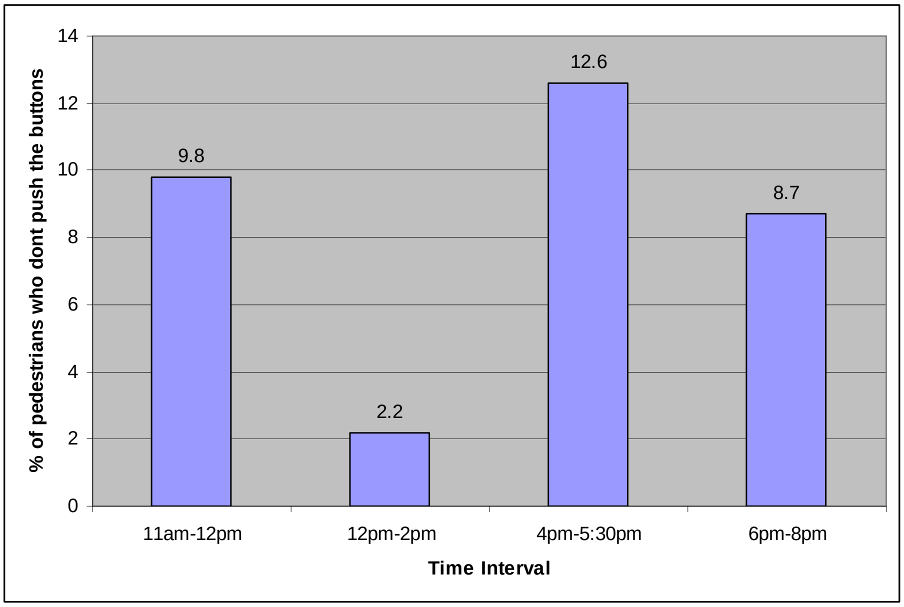

Figure 3.4: Percentage of Pedestrians who Don't Push the Button and Cross the Road for Different Observed Time Intervals.

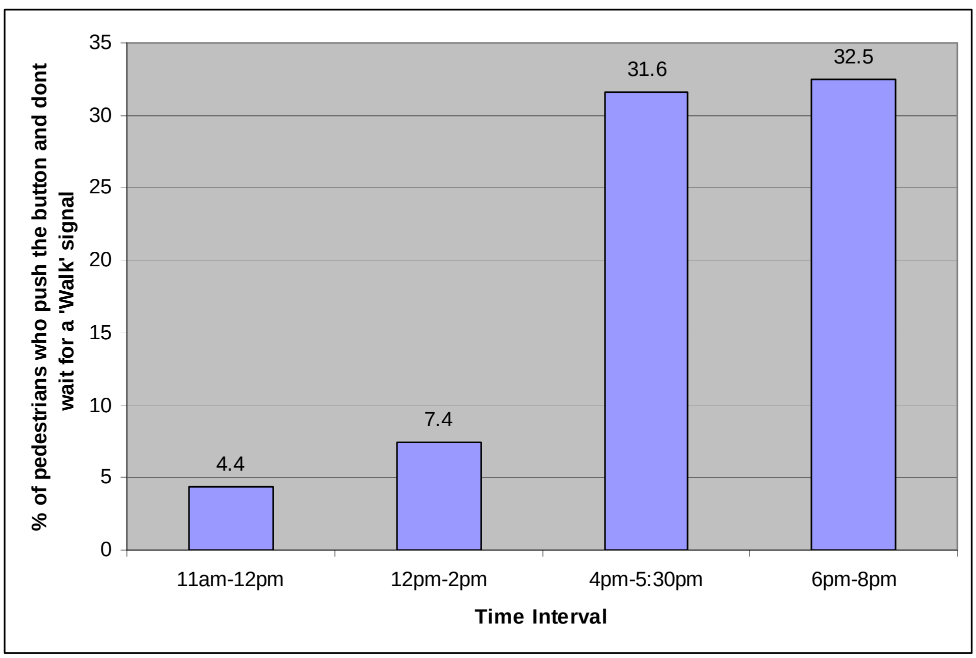

Figure 3.5: Percentage of Pedestrians who Push the Button but Don't Wait for Walk Sign to Cross the Road for Different Observed Time Intervals.

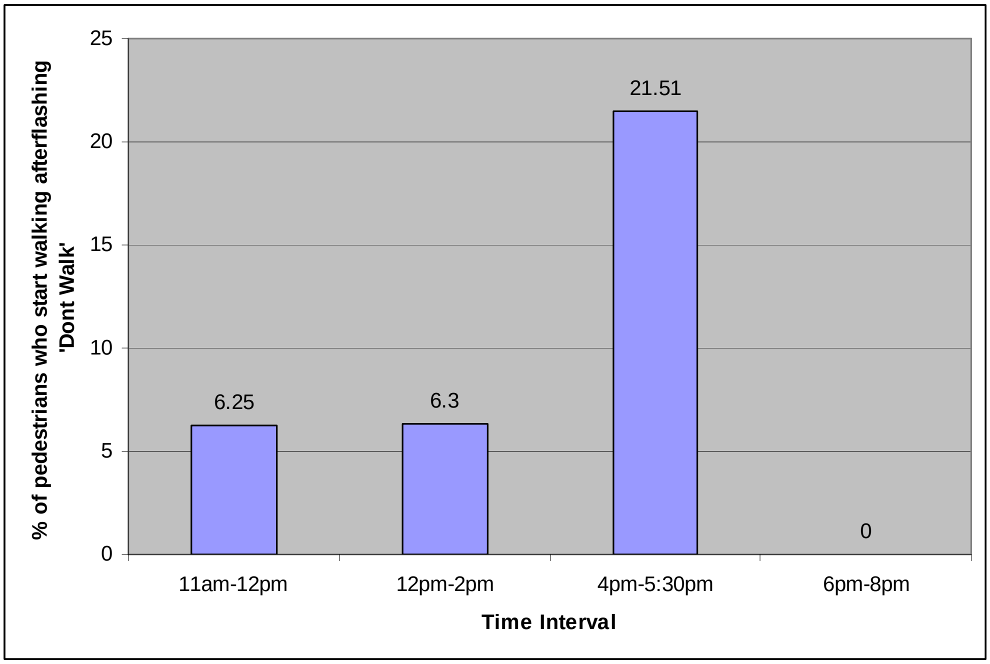

Figure 3.6: Percentage of Pedestrians who Start Walking After Flashing Don't Walk for Different Observed Time Intervals.

3.1.3 Results and Discussion

The unnecessary delay caused at the signalized mid-block on Anderson Avenue on average for pedestrians crossing the crosswalk was 12.65seconds. Out of the 30 seconds of the total designed pedestrian clearance time, 12.65 seconds was observed as the average unnecessary delay. These results infer that 42% of the total time designed as pedestrian clearance time is unnecessary delay. A different crossing treatment which reduces this unnecessary delay would be of a great value to motorists for this crossing.

Pedestrians found crossing the street without pressing the call button were 8.32% of the total pedestrians observed.

Pedestrians who don't wait for the walk signal to cross the street after pressing the call button were 18.87% of the total pedestrians observed.

Pedestrians entering the crosswalk after flashing don't walk were 8.51% of the total pedestrians observed.

The average unnecessary delay (12.65 seconds) at the signalized mid-block on Anderson Avenue, Manhattan, Kansas should be decreased by using a PHB. The average unnecessary delay at the PHB on New Hampshire street in Lawrence, Kansas was 0.62 seconds. Reducing unnecessary delay is a main benefit of PHB.

3.2 Mid-block Pedestrian Crossing with Yellow Flashers on Denison Avenue

3.2.1 Site Selected

Yellow Flashers was the crossing treatment at a mid-block pedestrian crossing on Denison Avenue in front of Kansas State University's Ackert Hall, Manhattan, Kansas. It is on a university campus; therefore, most of the pedestrians using this pedestrian crossing are college students. The students rarely activated these flashers to cross the road. A study was conducted to determine the percentage of pedestrians activating the flashers before crossing the road. Figures 3.7 and 3.8 show the plan and Google map of the site selected. The characteristics of the site selected are that it is a street with two-way traffic with one lane in southbound traffic and two lanes northbound. It doesn't have parking on both sides of the street, and it has no median or curb at the center of the street.

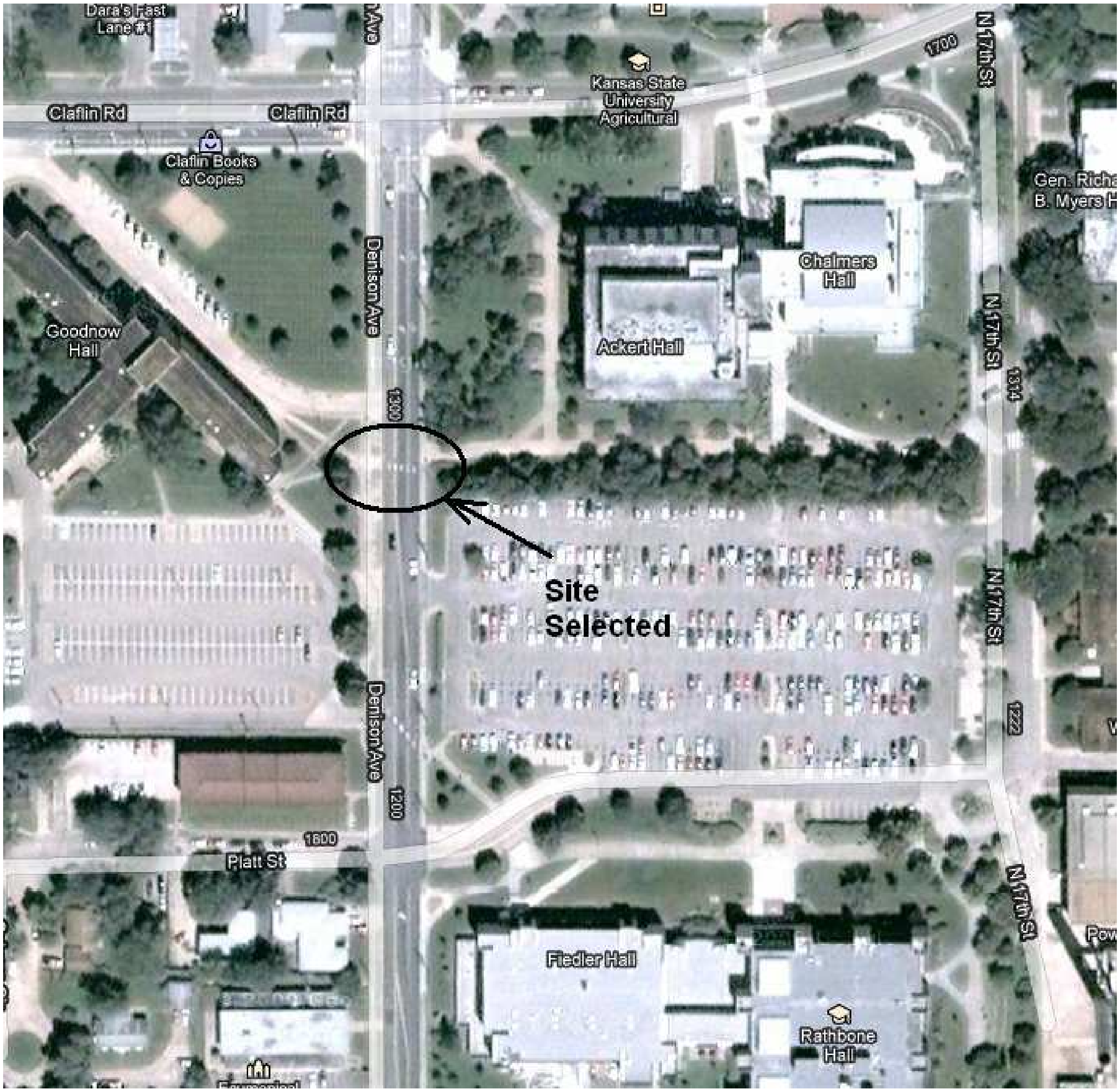

Figure 3.7: Google Map Showing Site Selected on Denison Avenue

Figure 3.8: Photo of Site Selected on Denison Avenue

3.2.2 Methodology of Study Conducted

Data was conducted manually at the site for different times in November 2007. The times for which the observations were made are 7:45am-8:45am, 8:45am-9:45am, 11:00am-12:00pm, 12:00pm-1:00pm, 4:00pm-5:30pm, 6:00pm-7:00pm, and 7:00pm-8:00pm.

The total number of pedestrians who were crossing the road, and the total number of pedestrians who were activating the flashers were counted. The ratio of the percentage of people actuating the flashers to the total pedestrians observed at a particular time interval gives the percentage of pedestrians using the flashers for crossing the road for that particular time interval. This method was carried out for all the time intervals observed. Figure 3.9 summarizes the results from the observations.

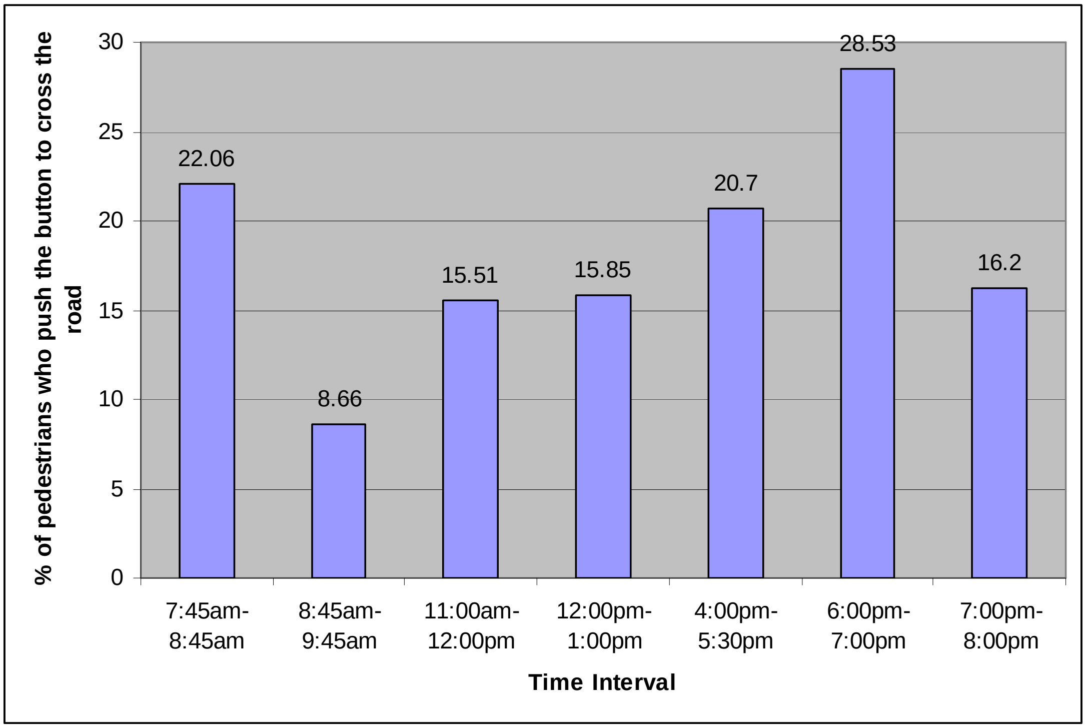

Figure 3.9: Percentage of Pedestrians who Push the Button for Crossing the Road on Denison Avenue.

3.2.3 Results and Discussions

Only 16.20% of the total pedestrians observed were activating the flashers for crossing the road and the remaining pedestrians crossed the road without activating the flashers.

The yellow flasher usage on Denison Avenue resulted in a very low compliance rate. Therefore, other treatments could possibly increase signal compliance rate. However, there is no known accident problem and, subjectively, drivers appear to respect crossing pedestrians.

3.3 Mid-block Pedestrian Crossing with In-Roadway Pedestrian Crossing Signs on Poyntz Avenue

3.3.1 Poyntz Avenue Site

Two in-roadway, pedestrian crossing signs were installed at two different crosswalks on Poyntz Avenue, Manhattan, Kansas. One between 3rd Street and 4th street and the other between 4th street and 5th street. Figure 3.10 shows the satellite view of these two Poyntz Avenue locations and Figure 3.11 shows the picture of the in-road way sign on Poyntz Avenue. These two sites were installed with in-roadway sign stating ‘State Law, Yield to Pedestrians within Crosswalk’. The crosswalk with in-roadway sign between 3rd street and 4th street was selected for this study. The characteristics of the site selected were that it is a street with two-way traffic and with one lane in each direction. It has parking on both sides of the street, and it has no median or curb at the center of the street. The motorists compliance rate towards the pedestrians was determined at this crossing according to the Kansas state law which states that:

“*When traffic-control signs are not in place or not in operation, the driver of a vehicle shall yield the right-of-way, slowing down or stopping if need be or yield, to a pedestrian crossing a roadway within a crosswalk when the pedestrian is upon the half of the roadway upon which the vehicle is traveling, or when the pedestrian is approaching so closely from the opposite half of the roadway so as to be in danger*”

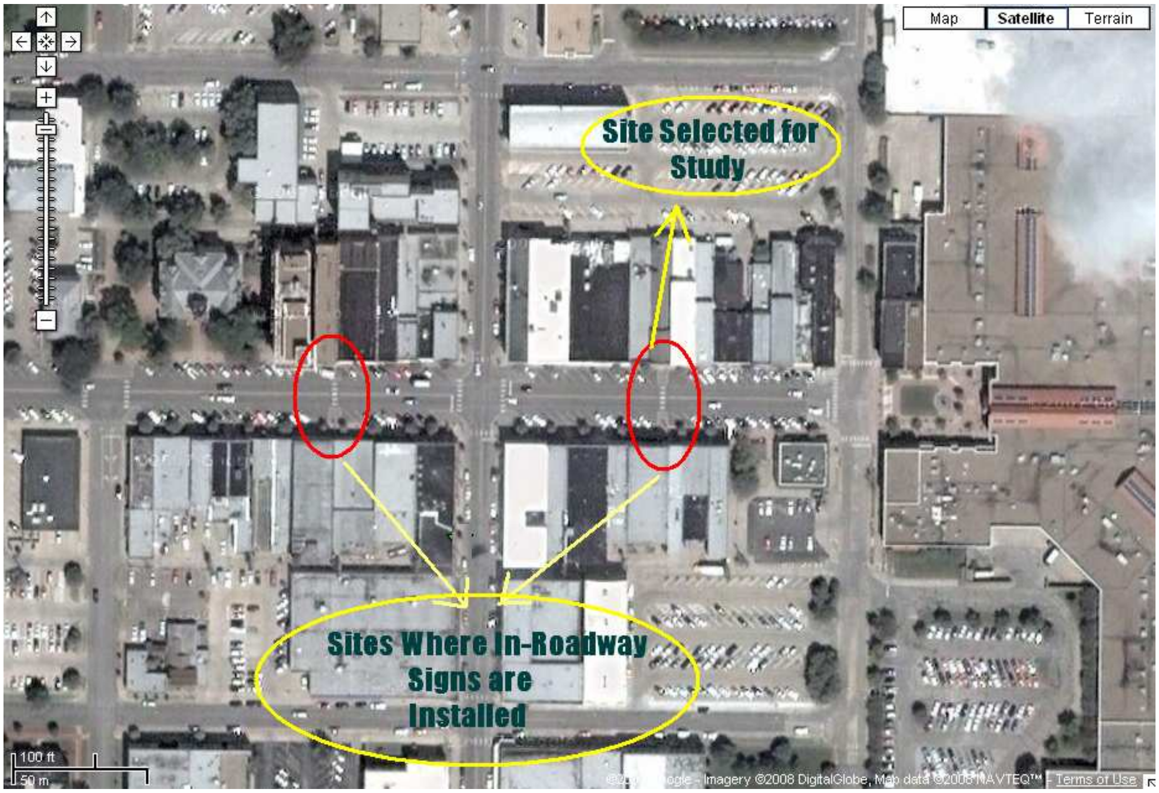

Figure 3.10: Satellite View of Crosswalks Installed with In-Roadway Signs on Poyntz Avenue

3.3.2 Methodology of Study Conducted

Actions of the pedestrians crossing the street and the vehicle yielding behavior were manually recorded at this site. Pedestrian compliance rate and vehicle compliance rate were the parameters of interest in this study.

Data was conducted manually at the site at different times during week in November 2007. The times for which the observations are carried out were 8am-9am, 9am-10am, 4pm-5pm, 5pm-6pm, and 8:30pm-9:30pm.

Figure 3.11: Crosswalk with In-Roadway Sign on Poyntz Avenue

3.3.3 Results and Discussions

The driver compliance rate was observed as 85% for the selected site. The percentage of pedestrians using the crosswalk for crossing the road for the observed time intervals is 80.6%.

This site had very low pedestrian volume so the pedestrian compliance results could be unreliable.

3.4 Mid-block Pedestrian Crossing with Warning Signs on N 17th Street

3.4.1 17th Street Site

The crosswalk on N 17th Street near the Kansas State University (KSU) Student Union, Manhattan, Kansas was equipped with warning signs for motorists which states that “STOP, When Occupied”. The motorists compliance rate towards the pedestrians was determined at this crossing according to the Kansas state law stated previously in section 3.3.1.

Pedestrian compliance rate was also studied. The characteristics of the site selected were that it is a street with two-way traffic with one lane in each direction. It has no parking on either sides of the road, and it has no median or curb at the center of the road.

Figure 3.12: Picture of the Crosswalk of Site Selected with a Warning Sign for Motorists

3.4.2 Study Methodology

Data was collected manually at the site for different times during a week in November 2007. The total number of pedestrians crossing the road at the crosswalk, away from crosswalk, and the vehicle compliance rate was measured at this crosswalk.

3.4.3 Results

The vehicle compliance rate was observed as 75% at this site with warning signs. Only 60% of the total pedestrians crossing the street in this area used the crosswalk for crossing the street.

CHAPTER 4 - Pedestrian Hybrid Beacons

4.1 Pedestrian Hybrid Beacon in MUTCD 2009

The 2009 version of MUTCD has allocated a separate chapter "CHAPTER 4F. PEDESTRIAN HYBRID BEACONS". It has three sections, Section 4F.01 through Section 4F.03 describing the application, design and operation of pedestrian hybrid beacons. The three sections Section 4F.01 through Section 4F.03 are presented below (*5*).

Section 4F.01 Application of Pedestrian Hybrid Beacons
Support:
01 A pedestrian hybrid beacon is a special type of hybrid beacon used to warn and control traffic at an unsignalized location to assist pedestrians in crossing a street or highway at a marked crosswalk.
Option:
02 A pedestrian hybrid beacon may be considered for installation to facilitate pedestrian crossings at a location that does not meet traffic signal warrants (see Chapter 4C), or at a location that meets traffic signal warrants under Sections 4C.05 and/or 4C.06 but a decision is made to not install a traffic control signal.
Standard:
03 If used, pedestrian hybrid beacons shall be used in conjunction with signs and pavement markings to warn and control traffic at locations where pedestrians enter or cross a street or highway. A pedestrian hybrid beacon shall only be installed at a marked crosswalk.

Section 4F.02 Design of Pedestrian Hybrid Beacons
Standard:
01 Except as otherwise provided in this Section, a pedestrian hybrid beacon shall meet the provisions of Chapters 4D and 4E.
02 A pedestrian hybrid beacon face shall consist of three signal sections, with a CIRCULAR YELLOW signal indication centered below two horizontally aligned CIRCULAR RED signal indications.
03 When an engineering study finds that installation of a pedestrian hybrid beacon is justified, then:
A. At least two pedestrian hybrid beacon faces shall be installed for each approach of the major street,
B. A stop line shall be installed for each approach to the crosswalk,
C. A pedestrian signal head conforming to the provisions set forth in Chapter 4E shall be installed at each end of the marked crosswalk, and
D. The pedestrian hybrid beacon shall be pedestrian actuated.

Section 4F.03 Operation of Pedestrian Hybrid Beacons

Standard:

01 Pedestrian hybrid beacon indications shall be dark (not illuminated) during periods between actuations.

02 Upon actuation by a pedestrian, a pedestrian hybrid beacon face shall display a flashing CIRCULAR yellow signal indication, followed by a steady CIRCULAR yellow signal indication, followed by both steady CIRCULAR RED signal indications during the pedestrian walk interval, followed by alternating flashing CIRCULAR RED signal indications during the pedestrian clearance interval (see Figure 4F-3). Upon termination of the pedestrian clearance interval, the pedestrian hybrid beacon faces shall revert to a dark (not illuminated) condition.

03 Except as provided in Paragraph 4, the pedestrian signal heads shall continue to display a steady

UPRAISED HAND (symbolizing DONT WALK) signal indication when the pedestrian hybrid beacon faces are either dark or displaying flashing or steady CIRCULAR yellow signal indications. The pedestrian signal heads shall display a WALKING PERSON (symbolizing WALK) signal indication when the pedestrian hybrid beacon faces are displaying steady CIRCULAR RED signal indications. The pedestrian signal heads shall display a flashing UPRAISED HAND (symbolizing DONT WALK) signal indication when the pedestrian hybrid beacon faces are displaying alternating flashing CIRCULAR RED signal indications. Upon termination of the pedestrian clearance interval, the pedestrian signal heads shall revert to a steady UPRAISED HAND (symbolizing DONT WALK) signal indication.
”

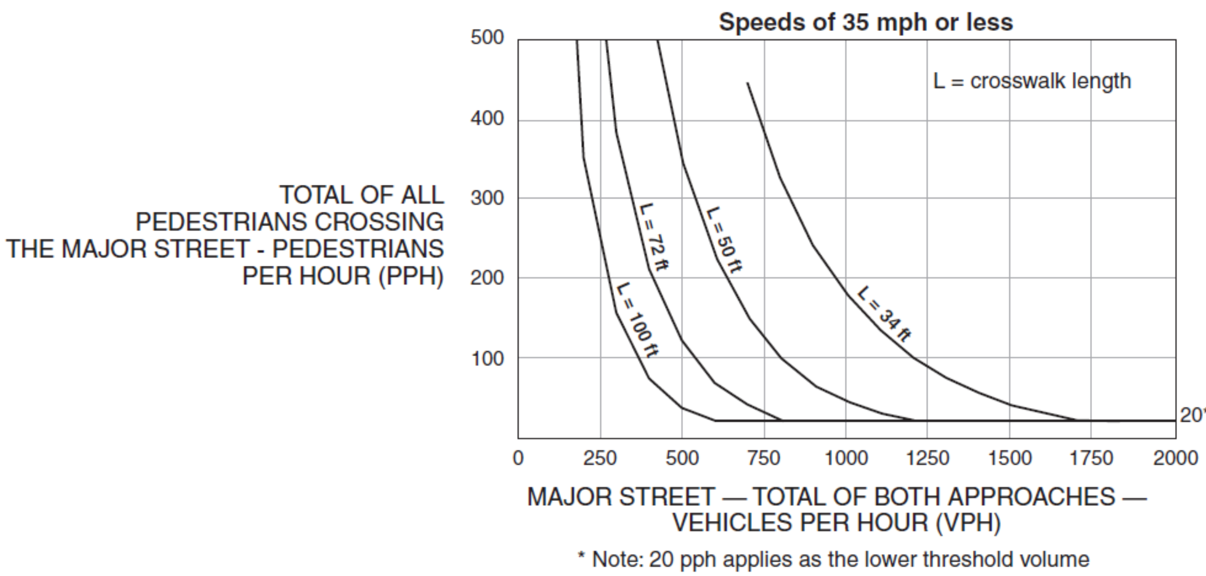

Figure 4.1: Guidance for the Installation of Pedestrian Hybrid Beacons on Low Speed Roadways

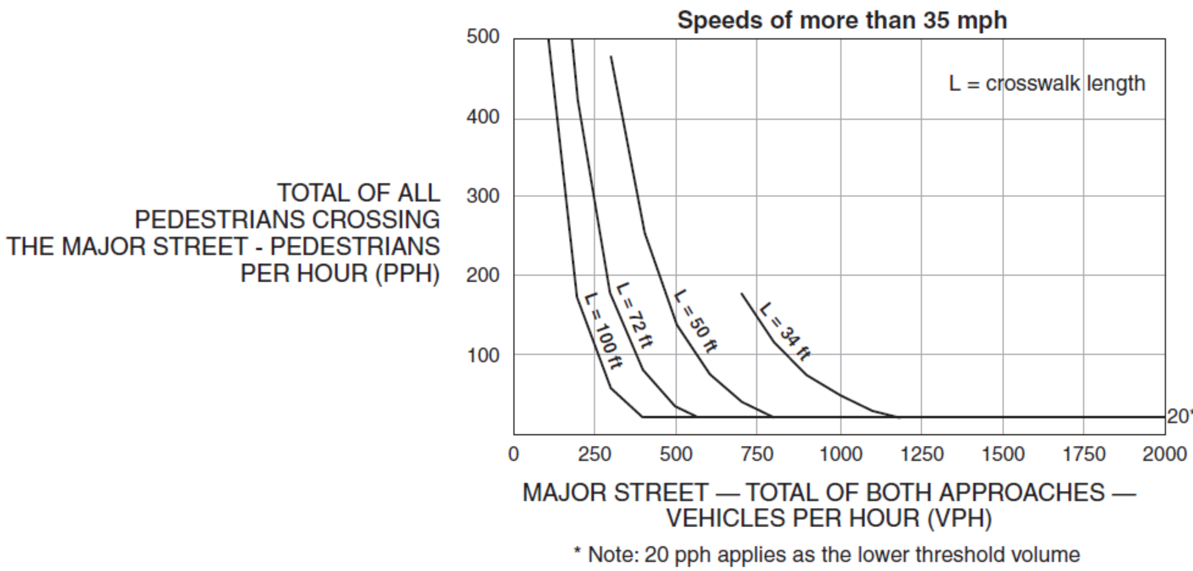

Figure 4.2: Guidance for Installation of Pedestrian Hybrid Beacons on High-Speed Roadways

CHAPTER 5 - PHB Data Collection and Study Methodology

5.1 Study Methodology

Lawrence, Kansas installed two mid-block, PHBs in their city. The first beacon was installed on 11th street between New York street and New Jersey street. The second beacon was installed on New Hampshire street between 9th street and 10th street. These PHBs were compared with a standard mid-block signal on Massachusetts street between North Park street and South Park street to observe the effectiveness of PHBs in decreasing unnecessary delay to the drivers. Further, driver compliance rate, pedestrian compliance rate and pedestrian characteristics were also observed in this study.

A survey was also conducted with the drivers of Lawrence after the installation of the first PHB to determine their understanding and opinion of the beacon and if they were comfortable with this new kind of the signal.

5.2 Pedestrian Hybrid Beacon on 11th Street, Lawrence, Kansas

5.2.1 Site Selected

A PHB was installed at a mid-block pedestrian crossing on 11th street between New York Street and New Jersey Street in Lawrence, Kansas in August 2007. This was the first PHB installed in Lawrence. This PHB was installed on a street having two-way traffic with one lane in each direction and no parking on either side near the crossing. Figure 4.1 shows the picture of the mid-block pedestrian crossing equipped with a PHB. The signal timing of each phase of the PHB installed at this site is shown in Figure 5.2.

Figure 5.1: Photo of a Pedestrian Hybrid Beacon on 11th street, Lawrence, Kansas

5.2.2 Phasing of the Pedestrian Hybrid Beacon on 11th Street

When a pedestrian activates this PHB, the overhead signal begins flashing yellow for 7 seconds, and then followed by solid yellow for 4 seconds advising drivers to prepare to stop. The signal then displays a solid red to drivers for 7 seconds and simultaneously pedestrian gets a walk signal for 7 seconds. This solid red is followed by flashing red for the drivers for 15 seconds and simultaneously the walk signal is followed by flashing don’t walk for the pedestrians for 14 seconds. Figure 5.2 gives an explanation of the phasing arrangement of the PHB, coordinated with the pedestrian phases.

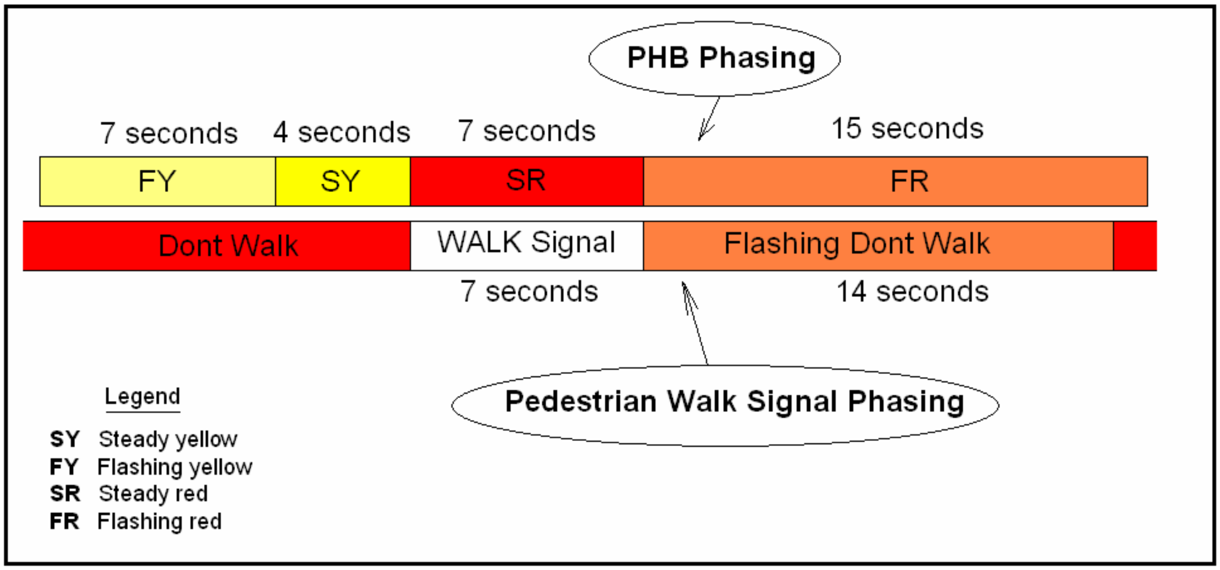

Figure 5.2: Designed Signal Timings for Pedestrian Hybrid Beacon Coordinating with Pedestrian Walk Signals on 11th Street, Lawrence, Kansas

5.2.3 Video Data Recording and Reduction

A fish eye camera was used to record the video at this crosswalk with the PHB to observe how the pedestrians and vehicles were behaving to the PHB operation. The camera was fixed to the mast arm of the signal such that it covered the crosswalk and also the vehicles on both sides of the crosswalk for a certain distance as it recorded video.

A total of 60 hours of video was recorded for 10 days, with 6 hours of video for each day. The video was recorded on VHS tapes with each tape having 6 hours of video data. This compromised the data for each day. The video was recorded for the time intervals 7am-9am and 2pm- 6pm for each day for all the 10 VHS tapes. This video data was later reduced and analyzed to measure different parameters of interest.

5.2.4 Video Data Analysis

From the video data recorded at the mid-block pedestrian crossing equipped with the PHB on 11th street, the different parameters of interest in this study were: unnecessary delay to drivers, PHB understandability, driver compliance rate, and pedestrian characteristics.

It was observed from the video data that some of the drivers did not appear to understand the usage of the PHB and did not move forward on flashing red after pedestrians had cleared. In these cases, when the flashing red phase of the PHB was not understood, the PHB would not have any advantages over a conventional signal as the unnecessary delay is still present. If a lead driver did not move forward three seconds after flashing red, with no pedestrians present in his lane , it was assumed he/she did not understand that they could legally proceed. It was observed that 42% of the drivers appeared to understand the operation of the PHB (flashing red phase) and the remaining 58% did not understand, i.e., remained stopped on flashing red when no pedestrians were present. It was then decided to try an education program for drivers by conducting survey and distributing handouts which explained the sections below in detail.

Unnecessary Delay to the Drivers Defined:

Unnecessary delay to drivers was defined in this study as the time for which the vehicles are stopped at a signalized, mid-block crossing when pedestrians have cleared the crosswalk in the drivers' lane but drivers need to remain stopped for a solid red ball according to law. It is measured as the time taken from when all pedestrians reach the other curb until the vehicles can legally resume.

When measuring the unnecessary delay for each signal actuation, the delay of the first vehicle which started moving first in any of the lanes was considered.

Driver Compliance Rate Defined:

Driver compliance to the PHB was based on the assumption that the driver should stop when the signal turns to the steady red phase for the drivers and remain stopped for pedestrians who are still present in the crossing using the clearance interval, i.e. the flashing red phase for the drivers.

Pedestrian Characteristics

Pedestrian compliance is very important towards better operation of any proposed signal. It applies very well to the PHB because any crossing signal or beacon becomes less safe with lower pedestrian compliance rates. Different characteristics at this PHB site such as percentage of pedestrians activating the walk signal for crossing the street, percentage of pedestrians who don't use the walk signal for crossing the street, and the percentage of pedestrians who cross the street other than at the crosswalk, were also observed from the video data.

5.3 Pedestrian Hybrid Beacon on New Hampshire Street, Lawrence, Kansas

5.3.1 Site Selected

This second PHB in Lawrence was installed at a mid-block pedestrian crossing on New Hampshire street between 9^{th} street and 10^{th} street in March 2009. This beacon was installed on a street having three lanes, one lane in each direction and a middle buffer lane for left turn movements. The street has parking on both sides. Figure 5.3 shows the picture of the site equipped with a pedestrian hybrid beacon.

Figure 5.3: Photo of a Pedestrian Hybrid Beacon on New Hampshire Street, Lawrence, Kansas

5.3.2 Phasing of the Pedestrian Hybrid Beacon on New Hampshire Street

The pedestrian signal has a maximum wait time of 29 seconds for pedestrians to get the walk signal after pressing the call button at this site. When a pedestrian activates the PHB, the overhead signal flashes yellow for 6 seconds followed by solid yellow for 4 seconds advising drivers to prepare to stop. The signal then displays a solid red to drivers for 7 seconds and simultaneously, pedestrians get a walk signal for 7 seconds. This solid red is followed by flashing red for the drivers for 14 seconds and simultaneously, the walk signal is followed by flashing don't walk for the pedestrians for 14 seconds. Figure 5.4 shows the phasing arrangement of the PHB coordinated with the pedestrian phases.

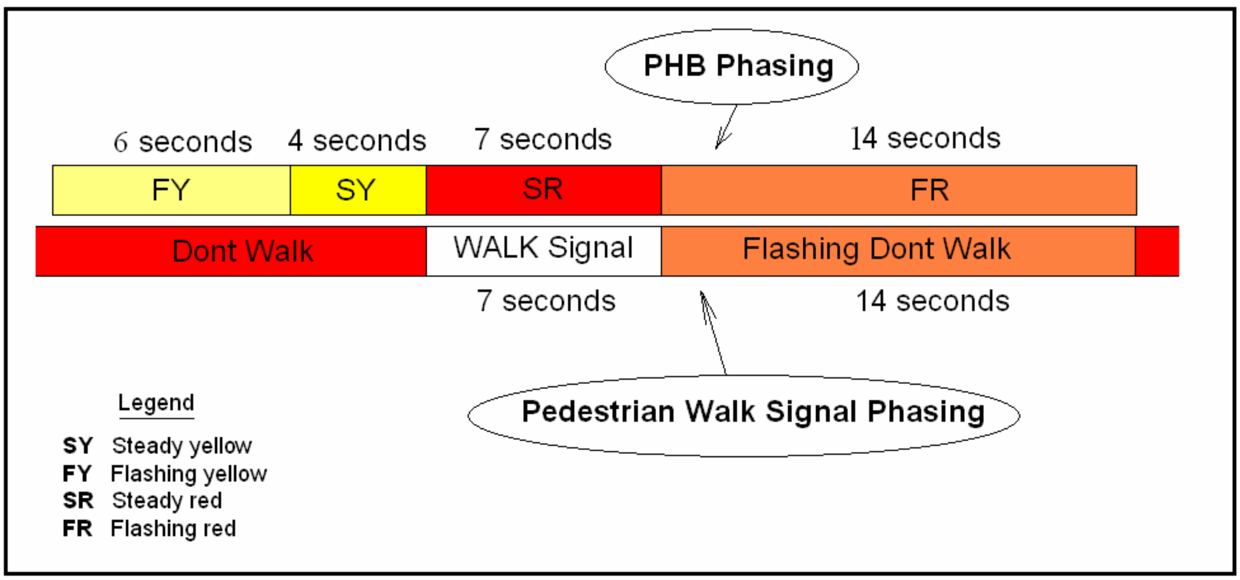

Figure 5.4: Designed Signal Timings for Pedestrian Hybrid Beacon Coordinating with Pedestrian Walk Signals on New Hampshire Street.

5.3.3 Video Data Recording, Reduction, and Analysis

An intersection camera was used to record the video data at this site for 100 hours. The recorded video data was used to analyze unnecessary delay to drivers, PHB understandability, driver compliance rate, and pedestrian characteristics. Out of the 100 hours of video data analysis, only 60 hours of video data analysis at this site was used for comparison to the signalized mid-block, which had 60 hours of video analysis.

From the video data recorded at the mid-block pedestrian crossing equipped with the PHB on New Hampshire street, the parameters of interest in this study were: unnecessary delay to drivers, PHB understandability, driver compliance rate, and pedestrian characteristics. The pedestrian characteristics studied at this PHB site included: percentage of pedestrians activating the walk signal for crossing the street, percentage of pedestrians who don't use walk signal for crossing the street, and percentage of pedestrians who cross the street other than at the crosswalk.

The understandability of the PHB (flashing red phase) increased to 50.34% at this site when compared to the first PHB, which had 42% understandability

5.4 Comparison Site: Signalized Mid-block Crossing on Massachusetts Street, Lawrence, Kansas

5.4.1 Site Selected

A conventional signalized mid-block pedestrian crossing was used as a comparison site for the two PHBs on 11th street and New Hampshire street to compare the effectiveness of the two PHBs. A conventional, signalized, mid-block pedestrian crossing on Massachusetts street between North Park street and South Park street in Lawrence was selected by the city traffic engineer for comparison with the two PHBs. The signalized mid-block crossing is on a street having two-way traffic with two lanes in one direction, with the other direction having one lane and there is parking on the street. Subjectively, it was determined by the city traffic engineer to be functionally similar to the PHB sites. Figure 5.5 shows the picture of the signalized mid-block on Massachusetts street. The signal timing of each phase of the signal is shown in Figure 5.6.

Figure 5.5: Picture of Signalized Mid-block on Massachusetts Street

5.4.2 Phasing of a Signalized Mid-Block on Massachusetts Street

The signalized mid-block signal has a pedestrian waiting time of 5 sec to turn to yellow from green once a pedestrian pushes the call button. The signal for traffic shows yellow for 4 seconds and then red for 22 seconds and then goes back to green for the traffic. One minute after the signal changes to red for traffic, pedestrians are given a walk signal for 7 seconds followed by flashing don’t walk for 8 seconds and then steady don’t walk. Figure 5.6 shows the phasing arrangement of the signal and coordination with pedestrian phases.

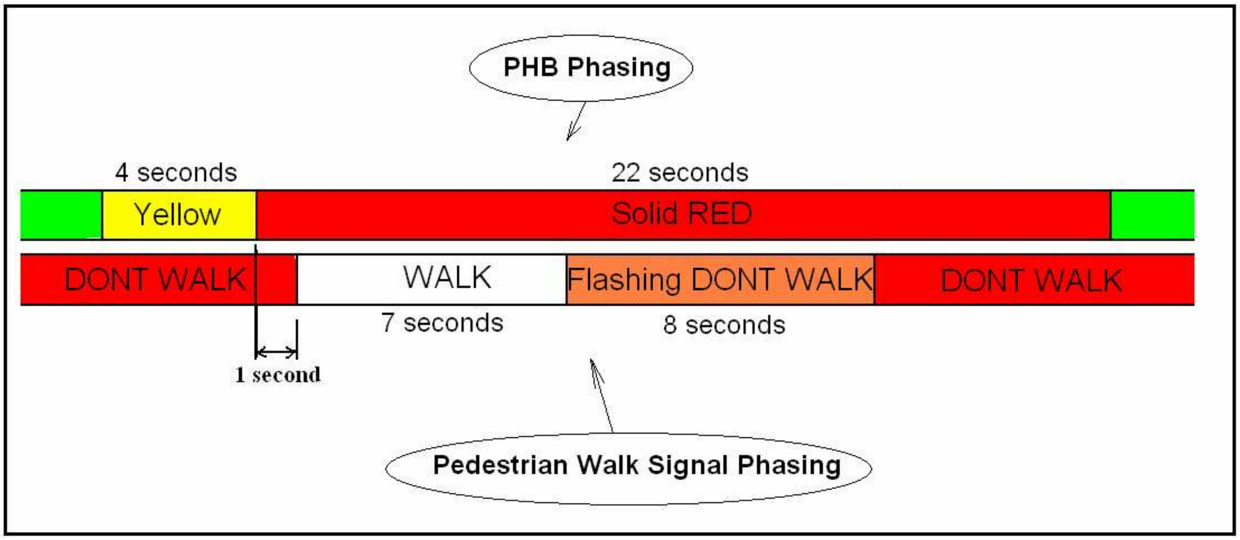

Figure 5.6: Designed Signal Phasing Times for Signalized Mid-block Coordinating with Pedestrian Walk Signals on Massachusetts Street

5.4.3 Video data Recording, Reduction and Analysis

A video camera was installed at this site to record the activity of vehicles and pedestrians. A total of 60 hours of video was recorded for 10 days with 6 hours of video for each day. The videos were recorded for the days August 5th to August 9th and August 11th to August 15th of the year 2008 for the period 9:00 am -3:00 pm. Six hours of video was recorded on each day on one VHS tape. All10 VHS tapes were reduced and analyzed to determine the parameters of interest for this study.

From the video data recorded at Massachusetts street, parameters of interest in this study were: unnecessary delay to drivers, driver compliance rate, and pedestrian characteristics. Pedestrian characteristics studied at this signalized, mid-block site included percentage of pedestrians activating the walk signal for crossing the street, percentage of pedestrians who don't use the walk signal for crossing the street, and percentage of pedestrians who cross the street other than at crosswalk.

CHAPTER 6 - Survey of Lawrence Drivers

The first PHB in Lawrence, Kansas was installed on 11th street on August 2007. After this PHB was in operation for a year and it was determined from the recorded video data and onsite observation that many of the drivers did not appear to understand the operation of a PHB (flashing red phase in particular).

The PHB had been installed because the parent-teacher association was concerned that the students were not safe at that crosswalk with an existing flashing light treatment for the crosswalk. The parents wanted a traffic signal and the city wished to minimize vehicular traffic delay on the street. It was decided to implement a PHB. Without good understanding of all the phases of a PHB, it is not possible to achieve the desired decrease in unnecessary delay to the drivers

Therefore, a survey was conducted in October 2008 near the first PHB site to determine how well drivers understood the PHB and also if they felt comfortable with this new kind of signal. The survey handouts included information to help understand the operation of the PHB.

Handouts explaining different phases of a PHB were distributed with the survey forms to the drivers. Figure 6.1 shows the survey form and handouts that were distributed. Figure 6.2 and Figure 6.3 shows the front side and back side of the survey form that was used for this survey. Appendix B contains the survey form that was distributed and Appendix C contains the informational handouts.

Figure 6.1: Photo Showing the Survey Form and Handout Distributed to Drivers in Lawrence

EFFECTIVENESS STUDY OF A HAWK BEACON
CITY OF LAWRENCE

Dear Motorist:

The City of Lawrence needs your help in a special study of a new pedestrian beacon. This Pedestrian Hybrid Signal on 11th street between New York St and New Jersey St is a new concept to reduce vehicular delay. Material handed out with this survey explains the new signal operation. The city needs your opinion to determine driver understanding and acceptance. Please take a couple of minutes to complete this survey on the back.

In appreciation for completing and returning this survey, we would like to send you a free State of Kansas highway map. To receive your map, please provide your mailing address where indicated.

PROF EUGENE R. RUSSELL
DEPARTMENT OF CIVIL ENGINEERING
2118 FIEDLER HALL
KANSAS STATE UNIVERSITY
1700 ANDERSON AVENUE
MANHATTAN KS 66502-9909

Figure 6.2: Figure Showing the Front Side of the Survey Form

Survey Regarding your Opinion about the HAWK Pedestrian Beacon.

We are conducting this survey to find out your opinion about the HAWK Pedestrian Beacon on 11th Street between New York Street and New Jersey street at Lawrence.

Are you aware that there is a HAWK Pedestrian Beacon on 11th Street between New York Street and New Jersey Street?
☐ Yes ☐ No

Have you ever had a chance to drive by this HAWK Pedestrian Beacon while driving in the city?
☐ Yes ☐ No

If you have passed by this HAWK Pedestrian Beacon, did you understand all the phases of this beacon well? (see phases below)
☐ Yes ☐ No

- Please check the phases which you understood and those you didn't

Phase 1: Blank Signal (which means 'move as usual')
☐ Understood ☐ Not understood
Phase 2: Flashing Yellow (which means 'Caution, Pedestrians want to cross')
☐ Understood ☐ Not understood
Phase 3: Steady Yellow (which means 'Be prepared to Stop for pedestrians')
☐ Understood ☐ Not understood
Phase 4: Steady Red (which means 'Must Stop and Remain Stopped')
☐ Understood ☐ Not understood
Phase5: Flashing Red (which means 'You can proceed after pedestrians have cleared')
☐ Understood ☐ Not understood
Phase 6: Blank Signal again (which means 'drive as usual')
☐ Understood ☐ Not understood

Did you feel comfortable while driving through this HAWK Pedestrian Beacon?
☐ Yes ☐ No

The HAWK Pedestrian Beacon is intended to decrease the delay for drivers at mid-blocks. Did you observe any decrease in delay at this site while driving when compared to other conventional signalized mid-block crossings?
☐ Yes ☐ No

Would you be in favor of this HAWK Pedestrian Beacon to be installed at other places in your city?
☐ Yes ☐ No

If you were acting as a pedestrian at this crossing with the HAWK Pedestrian Beacon, would you feel comfortable while crossing?
☐ Yes ☐ No

Comments: Please add your comments here.
…………………………………………
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…………………………………………
…………………………………………
…………………………………………
…………………………………………
Name/Address…………………………
…………………………………………
…………………………………………

Please fold, tape (or staple) and put in return mail

Figure 6.3: Figure Showing the Back Side of the Survey Form

6.1 Survey Methodology

A total of 250 survey forms were printed and distributed in Lawrence on October 16th, 2008 (from 10:00am – 12:00pm) at the intersection of 11th street and New Jersey street. This intersection was selected as a major spot for distributing the survey forms along with the handouts to the drivers. Survey forms were also distributed.

At the four-way stop controlled intersection of 11th street and New Jersey street, four people were allocated to each direction of traffic to distribute the survey forms and handouts to stopped traffic. Also, the PHB was frequently activated by the survey team to distribute the survey forms and handouts to the stopped traffic. Figure 6.4 shows the satellite view of the PHB on the 11th street. The red spots in this figure shows the spots selected for distributing the survey forms.

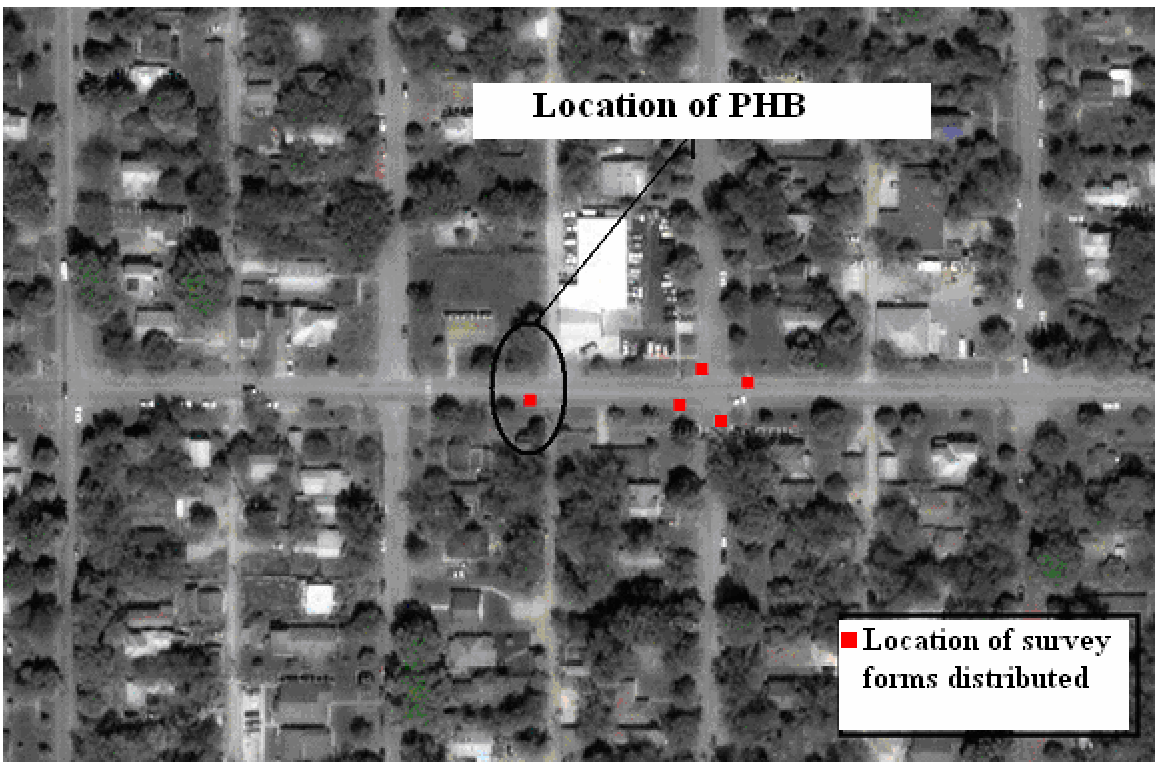

Figure 6.4: Satellite View of Pedestrian Hybrid Beacon Site on 11th Street and Locations where Survey Forms were Distributed.

6.2 Survey Results

Out of the 250 survey forms distributed, 35 of them were returned. The response rate of this survey was 14%. Based on the responses from these 35 survey forms, results were synthesized as shown below. Table 6.1 below summarizes the survey responses. Based on the low response rate, these results could be biased and/or of limited value.

Table 6.1: Summary of Survey Responses

Q. No	Question	Frequency	Percentage
1	Are you aware that there is a HAWK Pedestrian Beacon on 11th Street between New York Street and New Jersey Street?		
	Yes	24	68.6%
	No	11	31.4%
2	Have you ever had a chance to drive by this HAWK Pedestrian Beacon while driving in the city?		
	Yes	29	82.9%
	No	6	17.1%
3	If you have passed by this HAWK Pedestrian Beacon, did you understand all the phases of this beacon well?		
	Yes	11	34.4%
	No	21	65.6%
4	Please check the phases which you understood and those you didn't		
	Phase 1: Blank Signal		
	Understood	31	93.9%
	Not understood	2	6.1%
	Phase 2: Flashing Yellow		
	Understood	25	75.8%
	Not understood	8	24.2%
	Phase 3: Steady Yellow		
	Understood	22	66.7%
	Not understood	11	33.3%
	Phase 4: Steady Red		
	Understood	30	90.9%
	Not understood	3	9.1%

Table 6.1: Summary of Survey Responses - Continued

	Phase5: Flashing Red		
	Understood	14	42.4%
	Not understood	19	57.6%
	Phase 6: Blank Signal again		
	Understood	31	93.9%
	Not understood	2	6.1%
5	Did you feel comfortable while driving through this HAWK Pedestrian Beacon?		
	Yes	21	75%
	No	7	25%
6	The HAWK Pedestrian Beacon is intended to decrease the delay for drivers at mid-blocks. Did you observe any decrease in delay at this site while driving when compared to other conventional signalized mid-block crossings?		
	Yes	3	11.1%
	No	24	88.9%
7	Would you be in favor of this HAWK Pedestrian Beacon to be installed at other places in your city?		
	Yes	16	50%
	No	16	50%
8	If you were acting as a pedestrian at this crossing with the HAWK Pedestrian Beacon, would you feel comfortable while crossing?		
	Yes	19	54.3%
	No	16	45.7%

CHAPTER 7 - Statistical Analysis

An independent group t-test was the statistical model selected for this study to determine if there is a statistically significant decrease in unnecessary delay to the drivers when using a PHB at mid-block pedestrian crossings, over conventionally signalized mid-block crossings. The statistical concepts involved in this independent group t-test are explained below and then the statistical analysis conducted for the PHB is described.

7.1 Independent Group t-test

An independent group t-test was the test statistic selected for this statistical hypothesis testing. An independent group t-test is used for comparing means of two groups. It determines if the means of the two groups are statistically significant or not. The null hypothesis and alternative hypothesis will be assumed as follows: Null Hypothesis H_0: There is no difference between the means of the two groups. Alternative Hypothesis H_a: The difference between the means of the two groups is statistically significant. The t-statistic can be computed from the data by using the formula described in the equation 1 (*9*).

Equation 1: t-value for Equal Variance

$$t = \frac{(x_1 - x_2)}{\sqrt{s^2\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

Where,

t = Calculated t-value

x_1 = Mean value of the first group

x_2 = Mean value of the second group

s^2 = Pooled variance

n_1 = number of observations of the first group

n_2 = number of observations of the first group

The degrees of freedom for the pooled method of equal variance are ($n_1 + n_2$ -2). Equation 2 shows the formula for pooled variance computation.

Equation 2: Formula for Pooled Variance

$$s^2 = \frac{(n_1 - 1)s_1^{\,2} + (n_2 - 1)s_2^{\,2}}{(n_1 + n_2 - 2)}$$

Where,

s_1^2 = Variance of the first group

s_2^2 = Variance of the second group

For unequal variances, t-value is calculated by using the equation 3

Equation 3: t-value for Unequal Variances

$$t = \frac{(x_1 - x_2)}{\sqrt{\frac{s_1^{\,2}}{n_1} + \frac{s_2^{\,2}}{n_2}}}$$

The critical t-value is obtained from the standard t-distribution table corresponding to a level of significance (generally 0.05) and degrees of freedom ($n_1 + n_2 – 2$). The acceptance or rejection of the null hypothesis is based on the magnitude of the estimated and critical t-value. If the estimated t-value from equation 1 or equation 3 is greater than the critical t-value from t-distribution table, the null hypothesis is rejected and alternative hypothesis is accepted.

The t-test was performed both manually and also using a Statistical Analysis Software (SAS). SAS has predefined library functions for performing various statistical tests. In this case, the probability value (p-value) associated with the t-test is used in validating a null hypothesis and alternative hypothesis. When the t-test results in p-value greater than 0.05, the null hypothesis is accepted and alternative hypothesis is rejected. If the t-test results in p-value lesser than 0.05, the alternative hypothesis is accepted and null hypothesis is rejected.

7.2 Statistical Analysis for Comparing the Conventionally Signalized and PHB Mid-block Crossing Treatments

The t-test was conducted both to determine if the unnecessary delay generated at the two PHB sites (for the drivers who appeared to understand its usage) is equal or not to that of the unnecessary delay generated for drivers at the signalized mid-block crossing. The PHB on 11th street and the PHB on New Hampshire street were individually tested for statistical significance compared to the conventionally signalized mid-block on Massachusetts street. The mean and standard deviation of delays for the PHB actuations on 11th street when flashing red phase was understood are 0.94 seconds and 2.39 seconds, respectively. Similarly the mean and standard deviation of delays for the PHB actuations on New Hampshire street when flashing red phase was understood are 0.62 seconds and 2.10 seconds, respectively. The mean and standard deviation of delays for the signalized mid-block on Massachusetts street are 10.1 seconds and 3.76 seconds, respectively.

The results from the t-test showed that the unnecessary delay generated at the two PHB sites for the drivers who understood its usage is not equal to that of the unnecessary delay for drivers at the signalized mid-block, i.e. there is a statistically significant difference. Table 7.1 and 7.2 shows the results of the independent sample t-tests.

The PHB on 11th street had a very low delay sample size (from Table 7.1) when compared to the signalized mid-block on Massachusetts street which might make the statistical analysis less reliable. However, the second PHB on New Hampshire street had an approximately similar delay sample size to that of the signalized mid-block on Massachusetts street. Therefore, the results obtained by comparing the second PHB with the signalized mid-block can be considered comparatively more reliable.

Table 7.1: Results of Independent Sample t-test Conducted for the PHB on 11th Street and Signalized Mid-block on Massachusetts Street.

Description	Delay Sample Size	Mean Delay (sec)	Std. Dev. (sec)	t-value	p-value
Signalized mid-block on Massachusetts street	355	10.1	3.76	-8.36	<0.0001
PHB on 11th street	12	0.94	2.39		

Table 7.2: Results of Independent Sample t-test Conducted for the PHB on New Hampshire Street and Signalized Mid-block on Massachusetts Street.

Description	Delay Sample Size	Mean Delay (sec)	Std. Dev. (sec)	t-value	p-value
Signalized mid-block on Massachusetts street	355	10.1	3.76	-8.2	<0.0001
PHB on New Hampshire street	443	0.62	2.1		

CHAPTER 8 - Discussion of Results

8.1 Pedestrian Hybrid Beacon on 11th Street, Lawrence

Many drivers did not appear to understand the operation of the PHB. Only 42% of the total drivers stopped at the PHB seemed to understand the flashing red phase of the PHB very well, i.e. they could proceed on flashing red if no pedestrians remained in the crosswalk. If drivers did not start on flashing red with no pedestrians in the crosswalk in their lane, it was assumed they did not understand the PHB operation, i.e that they could legally proceed on flashing red. Only “driver understood” cases were considered for determining the average unnecessary delay to the drivers at the PHBs; assuming that with usage, some portion of the remaining 58% of the drivers eventually would understand the operation.

Pedestrian characteristics were determined by considering all cases as they have nothing to do with driver understandability.

Summary of these results are shown in Table 8.1.

8.1.1 Unnecessary Delay Findings

The average unnecessary delay for the drivers was 0.94 seconds for the PHB on 11th street when the flashing red phase of a PHB was understood.

The average unnecessary delay for the drivers was 13.3 seconds for drivers when the flashing red phase was not understood at the PHB on 11th street. This unnecessary delay due to lack of PHB understandability should decrease with the increase of understanding the PHB.

8.1.2 Pedestrian Characteristics

The PHB on 11th street, a residential area with several grade school pedestrians, had very low pedestrian compliance.

Only 46% of the total pedestrians crossing the street activated the walk signal for crossing the street. The remaining 54% of pedestrians crossed the street without activating the walk signal.

Forty percent of the total pedestrians crossed the street other than at the crosswalk. Fourteen percent of the total pedestrians used the crosswalk but didn’t use the walk signal for crossing.

8.1.3 Driver Compliance Rate

The driver compliance rate was observed to be 90% for the PHB on 11th street. This unexpected, relatively low compliance rate (reported in the Fitzpatrick et al. study (*3*) to be 97%) can be attributed to drivers attempting to use all the yellow time but end up running the beginning of the red phase, and possibly to the fact that a signal at this location was new and it was a new type of signal.

8.2 Pedestrian Hybrid Beacon on New Hampshire Street, Lawrence

This second PHB was installed in Lawrence approximately two years (March 2009) after the first PHB had been installed. This PHB was installed at a mid-block pedestrian crossing on New Hampshire street between 9th street and 10th street. This second PHB was a good site for the PHB installation compared to the first PHB because of the heavy vehicle flow, which is when the reduction of unnecessary delay should be high. The understandability of the PHB was higher for this PHB location as it was determined to be 50.34%. The understandability still needs to be improved for these PHBs in Lawrence in order to get its maximum advantages.

Summary of these results are shown in Table 8.1.

8.2.1 Unnecessary Delay Findings

The average unnecessary delay for the drivers was 0.62 seconds for the PHB on New Hampshire street when the flashing red phase of the PHB was understood.

8.2.2 Pedestrian Characteristics

Only 68% of the total pedestrians crossing the street activated the walk signal for crossing the street. The remaining 32% of pedestrians' crossed the street without activating the walk signal.

Ten percent of the total pedestrians cross the street other than at crosswalk. Twenty two of the total pedestrians used the crosswalk but didn't use the walk signal for crossing.

8.2.3 Driver Compliance Rate

The driver compliance rate increased to 95.2% for the second PHB. The results obtained for the second PHB should be more reliable because the second site had greater volumes of both vehicles and pedestrians.

8.3 Signalized Mid-block on Massachusetts Street, Lawrence

This conventionally signalized mid-block on Massachusetts street between North Park street and South Park street was used as a comparison site for the two mid-block PHBs. The driver and pedestrian characteristics at this site are presented below.

Summary of these results are shown in Table 8.1.

8.3.1 Unnecessary Delay

The average unnecessary delay for the drivers was 11.21 seconds for the conventionally signalized mid-block crossing on Massachusetts Street.

8.3.2 Pedestrian Characteristics

Pedestrians crossing the street by activating the walk signal were 77.8% of the total pedestrians observed.

Pedestrians who didn't wait for the walk sign to cross the street after pressing the call button were 2.63% of the total pedestrians observed.

8.3.3 Driver Compliance Rate

The driver compliance rate for the conventional signal was observed to be 98.8%.

8.4 Statistical Analysis

An independent group t-test conducted to compare the unnecessary delay generated at 11th street to that of the unnecessary delay generated at the conventionally signalized mid-block crossing on Massachusetts street showed that there is a statistically significant difference (t-value = -8.36, p-value = <0.0001) for the unnecessary delays generated at these two sites. This leads to the conclusion that the PHB on 11th street is effective in decreasing the unnecessary delay to drivers when compared to the conventionally signalized mid-block on Massachusetts street.

Similarly, an independent group t-test conducted to compare the unnecessary delay generated at New Hampshire street to that of the unnecessary delay generated at the conventionally signalized mid-block crossing on Massachusetts street showed that there is a statistically significant difference (t-value = -8.2, p-value = <0.0001) for the unnecessary delays generated at these two sites. This again leads to the conclusions that the PHB on New Hampshire street is effective in decreasing the unnecessary delay to the drivers when compared to the conventionally signalized mid-block crossing on Massachusetts street.

8.5 Survey Results

Based on 35 (14%) survey responses returned from the drivers of Lawrence, the important results were:

Only 34.40% of the drivers understood all the phases of a PHB very well. Figure 8.1 summarizes the results.

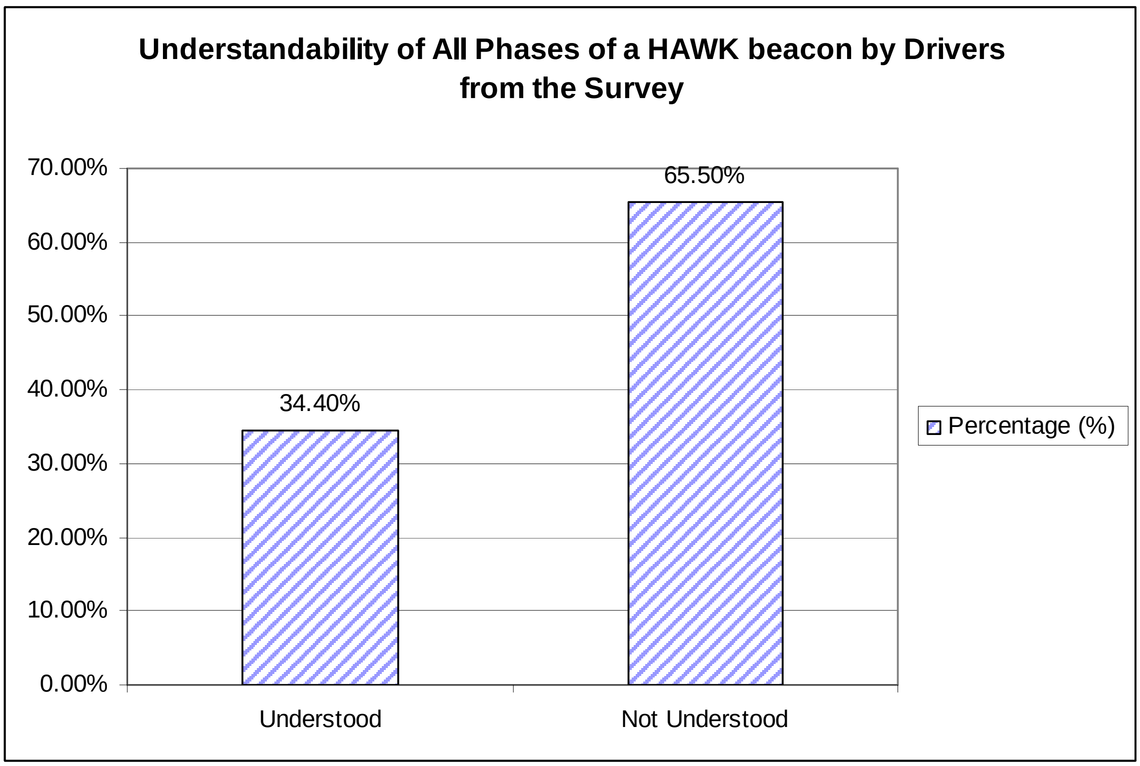

Figure 8.1: Understandability of All Phases of a Pedestrian Hybrid Beacon

The flashing red phase was not understood by 57.6% of the drivers. The steady yellow phase was not understood by 33.3% of the drivers. The flashing yellow phase was not understood by 24.2% of the drivers. Other than these phases, the remaining were understood by most of the survey respondents. Figure 8.2 summarizes the results.

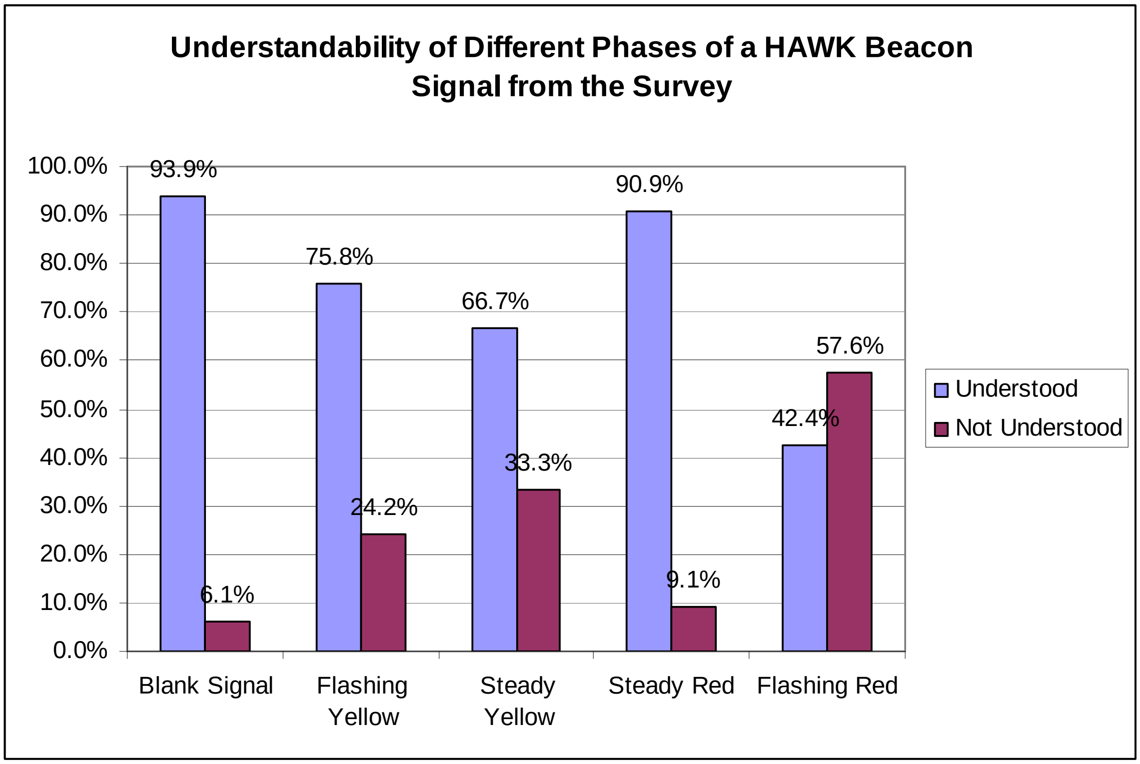

Figure 8.2: Understandability of Different Phases of a Pedestrian Hybrid Beacon

The percentage of drivers who didn't feel that the PHB decreases delay to them when compared to a conventionally signalized mid-block was 88.9%. However the video data showed there is a decrease in delay to the drivers due to the PHB. The results from the survey might be attributed to the drivers' misconception as they didn't experience a conventionally signalized mid-block on the same street to make a correct judgment of the PHBs effectiveness.

Fifty percent of the drivers were in favor of PHB to be installed at other places and fifty percent were not.

Seventy five percent of the drivers answered that they were comfortable driving where there is a PHB.

Table 8.1: Overall Summary of Study Results

Description	Signalized Mid-block on Massachusetts Street	PHB on 11th Street	PHB on New Hampshire Street
PHB understandability determined from video analysis	NA	42%	50.34%
PHB understandability determined from survey with Lawrence drivers	NA	34.40%	NA
Average unnecessary delay determined at the site	11.21 seconds	0.94 seconds	0.62 seconds
Independent group t-test results: Statistical significance of unnecessary delay generated at PHB to that of the unnecessary delay generated at signalized mid-block on Massachusetts street	NA	Statistically a significant reduction in unnecessary delay	Statistically a significant reduction in unnecessary delay
Driver compliance rate determined at the site	98.80%	90%	95.20%
Percentage of pedestrians' activating walk signal for crossing the street	77.80%	46%	68%
Legend: PHB: Pedestrian Hybrid Beacon NA: Not Applicable			

8.6 Comparison of the Pedestrian Hybrid Beacon in Lawrence with Different Mid-block Crossing Treatments in Manhattan, Kansas

The PHB on New Hampshire street in Lawrence was subjectively compared to different mid-block crossing treatments in Manhattan; namely, conventionally signalized mid-block signals, yellow flashers, in-roadway signs, and crosswalk with warning signs.

This comparison indicates that the use of a red beacon or a red signal (as in Lawrence) resulted in a greater driver compliance rate and the use of the push buttons by pedestrians crossing the street had the highest pedestrian compliance rate. This is consistent with a major conclusions in the Fitzpatrick et al. (2006) (*3*) study.

CHAPTER 9 - Conclusions and Recommendations

The use of a PHB at mid-block pedestrian crossings was found effective in decreasing the unnecessary delay to the drivers. The average unnecessary delay generated by the drivers at a conventionally signalized mid-block crossing on Massachusetts street in Lawrence was found to be 11.21 seconds per vehicle. For a designated 22 seconds pedestrian clearance time at this site, this average 11.21 sec means that 50.9% of the pedestrian clearance time was not used by pedestrians. Thus 50.9% of the designed pedestrian clearance time is seen as unnecessary delay. On the other hand, the average unnecessary delay per vehicle generated by the drivers at the PHB on 11th street and on New Hampshire street was found to be 0.94 seconds and 0.62 seconds, respectively. This is 4.3% of the designed pedestrian clearance time shown as unnecessary delay. These results showed that the unnecessary delay to the drivers is significantly less with the PHBs, and pedestrian clearance time is more effectively used. The comparison may have been more convincing if a before after study was possible at the same site with a conventionally signalized mid-block as the before treatment, and a PHB as the after treatment.

An independent group t-test leads to the conclusion that the unnecessary delay to the drivers at both the PHBs installed in Lawrence is statistically less than the unnecessary delay caused at the conventionally signalized mid-block pedestrian crossings.

The driver compliance rate was observed to be 98.8% for the conventionally signalized mid-block crossing on Massachusetts street and 90% and 95.2% at the PHBs on 11th street and New Hampshire street, respectively. Again, the results would have been more appropriate and convincing if a before after study was done at the same site with a signalized mid-block as before treatment and PHB as after treatment. Difference in site characteristics could have affected some results. Also, the 11th street PHB was the first in Lawrence; and the one on New Hampshire was installed two years after. This could have effected driver understanding and compliance rate due to more experience with the second PHB.

About 77.8% of the total pedestrians crossing at Massachusetts street activated the walk signal for crossing the street. Forty six percent of the total pedestrians crossing at 11th street activated the walk signal for crossing the street. Sixty eight percent of the total pedestrians crossing at New Hampshire street activated the walk signal for crossing the street. The pedestrian characteristics are variable at the conventionally signalized mid-block and at the two PHBs. This can be attributed to the fact that the site characteristics and the crossing behaviors of pedestrians at each of the site were not same.

Due to the observed lack of driver understandability from the video data, a survey was conducted with the drivers of Lawrence. The survey results were summarized from the 35 (14%) returned survey responses among the 250 distributed survey forms. The survey showed that only 34.40% of the responding drivers understood all the phases of a PHB well. Flashing red phase was not understood by 57.6% of drivers responding drivers. Steady yellow phase was not understood by 33.3% of the responding drivers. Flashing yellow phase was not understood by 24.2% of the responding drivers. Other than these phases, the remaining were understood by most of the responding drivers. It should be noted that these above values are the result of respondents' self reporting. About 88.9% of the survey respondents didn't feel that the PHB decreases their delay when compared to a conventional signal. Fifty percent of the survey respondents were in favor of PHBs to be installed at other locations and fifty percent were not. Seventy five percent said they are comfortable driving through a PHB site.

The comparison of the PHB on New Hampshire street, Lawrence, with different mid-block pedestrian crossing treatments in Manhattan has subjectively shown that the use of red beacon or red signal, likely increases the driver compliance rate and the use of the walk signal increases the pedestrian compliance rate.

9.1 Data Limitations and Future Research

The PHBs selected for this study were installed at the mid-block pedestrian crossing in Lawrence when the beacon was not included in the 2003 MUTCD. Due to this reason, the first PHB was installed at a site which didn't appear to warrant a PHB. This PHB was compared to a conventionally signalized mid-block with only subjectively determining that it has comparable pedestrian, driver and geometric characteristics. Though the study provided results indicating that the pedestrian hybrid beacon (PHB) is effective in decreasing unnecessary delay to drivers, it would be more convincing if a before after study was at the same site to observe the driver and pedestrian benefits.

The understandability of the first PHB on 11th street was observed to be low and so drivers didn't take advantage of the PHB. Although it appeared to increase at the second PHB on Massachusetts, intensive educational programs to the drivers in a city should increase driver understandability of the PHB, especially when they are new, and eventually, less unnecessary delay.

References

1. Federal Highway Administration University Course on Bicycle and Pedestrian Transportation. http://www.tfhrc.gov/safety/pedbike/pubs/05085/ Accessed January 2, 2010.
2. Pedestrian crossings. http://www.fhwa.dot.gov/environment/sidewalk2/sidewalks208.htm Accessed January 18, 2010.
3. Kay Fitzpatrick, Shawn Turner, Marcus Brewer, Paul Carlson, Brooke Ullman, Nada Trout, Eun Sug Park, Jeff Whitacre, Nazir Lalani., and Dominique Lord. *Improving Pedestrian Safety at Unsignalized Crossings*. Publication TCRP report 112/NCHRP report 562, Transportation Research Board of the National Academies, Washington, D.C, 2006.
4. *Manual on Uniform Traffic Control Devices for Streets and Highways*. U.S. DOT, FHWA, Washington, DC, 2003. Available online at http://mutcd.fhwa.dot.gov/pdfs/2003/pdf-index.htm Accessed January 8, 2010.
5. *Manual on Uniform Traffic Control Devices for Streets and Highways*. U.S. DOT, FHWA, Washington, DC, 2003. Available online at http://mutcd.fhwa.dot.gov/kno_2009.htm Accessed May 18, 2010.
6. Coffin, A., and J.Morrall. *Walking Speeds of Elderly Pedestrians at Crosswalks*. Transportation Research Record 1497, TRB, Washington, DC, 1995.
7. Staplin, L., K. Lococo, S. Byington, and D. Harkey. *Guidelines and Recommendations to Accommodate Older Drivers and Pedestrians*. Report No FHWA-RD-01-051, FHWA, McLean, VA, October 2001.
8. Kay Fitzpatrick and Eun Sug Park. Safety Effectiveness of the HAWK Pedestrian Treatment. CD-ROM. Transportation Research Board of the National Academies, Washington, D.C., 2009.
9. Steel, R.G.D., and Torrie, J.H., *Principles and Procedures of STATISTICS.* Mc-Graw-Hill Book Company, Inc., New York, 1960.
10. NHTSA, PedBikeLaws, http://www.nhtsa.dot.gov/people/injury/pedbimot/bike/resourceguide/ Accessed January 8, 2010.

Appendix A - Pedestrian Right of Way State Laws

Driver yielding behavior at crosswalks is defined in a particular way for each of the 50 states in USA. This law is called ‘Pedestrians right of way in crosswalks [Yield to pedestrian in crosswalk]’. This defined yielding behavior was used to determine the driver compliance rate in this study. The states’ laws for pedestrian right of way in crosswalks are summarized below for all the 50 states. Initially, a standard state law which is used in most of the states was defined. If there is any deviation of the pedestrian right of way law in crosswalks for any state, a table below explains it.

Standard:

UVC § 11- 502(a) Pedestrians' right of way in crosswalks [Yield to pedestrian in crosswalk]

When traffic-control signals are not in place or not in operation, the driver of a vehicle shall yield the right of way, slowing down or stopping if need be to yield to a pedestrian crossing the roadway within a crosswalk when the pedestrian is upon the half of the roadway upon which the vehicle is traveling, or when the pedestrian is approaching so closely from the opposite half of the roadway as to be in danger.

Table 9.1: State Laws for Pedestrian Right of Way in Crosswalk

State	State Law Exact, or Equivalent, or Variation	If Equivalent or Variation
Alaska	Variation	It omits the words "slowing down or stopping if need be to so yield." It inserts the words "who is on a sidewalk, vehicular way or area or who is" after the first mention of the word "pedestrian."
Alabama	Exact	
Arkansas	Variation	However, no mention is made in the Arkansas law of the location of the pedestrian when crossing.
Arizona	Variation	It replaces the word "when" with "if," adds the word "are" in the phrase "or are not in operation," and replaces the word "upon" with the word "on."
California	Variation	This law states that "the driver of a vehicle shall yield the right-of-way to a pedestrian crossing the roadway within any marked crosswalk or within any unmarked crosswalk at an intersection, except as otherwise provided in this chapter". No mention is made that traffic control signals are not in place or not in operation. In addition, no mention is made of the location of the pedestrian in the roadway.
Colorado	Exact	
Connecticut	Variation	It accepts procedures required for emergency vehicles. Unless otherwise directed by police officers or traffic control signals, vehicles must yield to pedestrians in a crosswalk provided the pedestrian "steps to the curb at the entrance to a crosswalk" or is crossing the roadway either within the half of the roadway in which the driver is traveling or from that half of the roadway in which the driver is not traveling.
Delaware	Variation	In addition to traffic control signals not being in place or in operation, Delaware law states that the pedestrian has the right of way "when the operator of a vehicle is making a turn at an intersection."

Source: NHTSA PedBikeLaws (*10*)

State	State Law Same, or Equivalent, or Variation	If Equivalent or Variation
Florida	Variation	Florida law states "signals are not in place or in operation" instead of "signals are not in place or not in operation."
Georgia	Variation	Georgia makes no mention of traffic control signals not being in place or in operation. It states that "the driver of a vehicle shall stop and remain stopped to allow a pedestrian to cross the roadway within a crosswalk when the pedestrian is upon the half of the roadway upon which the vehicle is traveling, or when the pedestrian is approaching and is within one lane of the half of the roadway on which the vehicle is traveling or onto which it is turning."
Hawaii	Exact	
Iowa	Variation	Iowa state code contains several minor word changes, and replaces "within a crosswalk" with "within any marked crosswalk or within any unmarked crosswalk at an intersection." The state code omits "when the pedestrian is upon the half of the roadway upon which the vehicle is traveling, or when the pedestrian is approaching so closely from the opposite half of the roadway as to be in danger," and adds "except as otherwise provided in this chapter."
Idaho	Variation	Idaho makes no mention of the pedestrian being "upon the half of the roadway upon which the vehicle is traveling, or when the pedestrian is approaching so closely from the opposite half of the roadway as to be in danger." It uses the word "highway" instead of "roadway" and makes other minor word changes.
Illinois	Exact	

State	State Law Same, or Equivalent, or Variation	If Equivalent or Variation
Indiana	Variation	It uses the words "a person who drives a vehicle" instead of "the driver of a vehicle." Indiana requires the driver to yield to a pedestrian "approaching closely from the opposite half of the roadway" instead of "approaching so closely from the opposite half of the roadway as to be in danger." There are other minor changes in wording.
Kansas	Exact	
Kentucky	Variation	This law replaces the word "driver" with "operator" and uses the words "upon which the vehicle is traveling" instead of "upon the half of the roadway upon which the vehicle is traveling." There are other minor changes in wording.
Louisiana	Equivalent	Instead of the words "so closely as to be in danger," Louisiana states "closely as to be in danger."
Massachusetts	Variation	When traffic control signals are not in place or not in operation the driver of a vehicle shall yield the right of way, slowing down or stopping if need be so to yield, to a pedestrian crossing the roadway within a crosswalk marked in accordance with standards established by the department of highways if the pedestrian is on that half of the traveled part of the way on which the vehicle is traveling or if the pedestrian approaches from the opposite half of the traveled part of the way to within 10 feet of that half of the traveled part of the way on which said vehicle is traveling.
Maryland	Variation	The UVC states that "when traffic control signals are not in place or not in operation the driver of a vehicle shall yield the right of way, slowing down or stopping if need be to so yield," while Maryland only states that "the driver of a vehicle shall come to a stop."

State	State Law Same, or Equivalent, or Variation	If Equivalent or Variation
Maine	Variation	Maine code specifies when "traffic-control devices are not in operation" and does not mention "when traffic control signals are not in place." In such cases, "an operator must yield the right-of-way to a pedestrian crossing within a crosswalk when the pedestrian is on the same half of the way or approaching so closely as to be in danger."
Michigan	Not Located	Not Located
Minnesota	Variation	With regard to § 11-502(a), where traffic- control signals are not present (i.e., "in place or in operation"), "the driver of a vehicle shall stop to yield the right-of-way to a pedestrian crossing the roadway within a marked crosswalk or within any crosswalk at an intersection."
Missouri	Exact	
Mississippi	Variation	Mississippi law replaces the phrase "within a crosswalk" with "within any marked crosswalk or within any unmarked crosswalk at an intersection." Mississippi law does not specify that the pedestrian is on the same side of the roadway as the approaching vehicle or is approaching from the opposite side of the roadway.
Montana	Variation	This law covers UVC § 11-502(a), (b) and (c). With regard to 11-502(a), the law specifies that the driver shall yield to the pedestrian within a marked or unmarked crosswalk at an intersection. It excepts a subsection of the law that permits a driver to make a right-hand turn "if the pedestrian is in the opposite half of the roadway and is not in danger."

State	State Law Same, or Equivalent, or Variation	If Equivalent or Variation
North Carolina	Variation	North Carolina makes no mention of the pedestrian being upon the half of the roadway upon which the vehicle is traveling or approaching so closely from the opposite half of the roadway as to be in danger. North Carolina states that the pedestrian crossing can be "within any marked crosswalk or within any unmarked crosswalk at or near an intersection
North Dakota	Exact	
Nebraska	Variation	With regard to § 11-502(a), the law requires that the driver yield to a pedestrian "who is in the lane in which the driver is proceeding or is in the lane immediately adjacent thereto." The UVC states that the "pedestrian is upon the half of the roadway upon which the vehicle is traveling, or when the pedestrian is approaching so closely from the opposite half of the roadway as to be in danger." Nebraska requires the vehicle to come "to a complete stop"
New Hampshire	Exact	
New Jersey	Variation	With regard to § 11-502(a), it states that "the driver of a vehicle shall yield the right-of-way to a pedestrian crossing the roadway within a marked crosswalk or within any unmarked crosswalk at an intersection, except at crosswalks when the movement of traffic is being regulated by police officers or traffic control signals, or where otherwise prohibited by municipal, county, or State regulation." No mention is made that traffic control signals are not in place or not in operation, of slowing or stopping or of the location of the pedestrian in the roadway.

State	State Law Same, or Equivalent, or Variation	If Equivalent or Variation
New Mexico	Exact	
Nevada	Variation	It replaces the word "roadway" with "highway." It uses the words "official traffic control devices" instead of "traffic control signals" and makes other minor changes in wording.
New York	Variation	It used identical wording.
Ohio	Variation	In addition to traffic signals not being in place or in operation, this law applies when signals "are not clearly assigning the right-of-way."
Oklahoma	Exact	
Oregon	Variation	It requires the driver to "stop" (not slow down or stop). It states that the pedestrian is "approaching so closely to the half of the roadway along which the driver is proceeding so as to be in a position of danger by closely approaching or reaching the center of the roadway" in place of "approaching so closely from the opposite half of the roadway as to be in danger."
Pennsylvania	Variation	Pennsylvania states that "when traffic-control signals are not in place or not in operation, the driver of a vehicle shall yield the right-of-way to a pedestrian crossing the roadway within any marked crosswalk or within any unmarked crosswalk at an intersection." No mention is made of "slowing or stopping if need be to so yield" or that the law applies "when the pedestrian is upon the half of the roadway upon which the vehicle is traveling, or when the pedestrian is approaching so closely from the opposite half of the roadway as to be in danger."
Rhode Island	Variation	Used identical wording.
South Carolina	Equivalent	South Carolina omits the word "so" in the phrase "if need be to so yield."

State	State Law Same, or Equivalent, or Variation	If Equivalent or Variation
South Dakota	Not Located	Not Located
Tennessee	Exact	
Texas	Equivalent	
Utah	Variation	It uses wording equivalent to that provided in the UVC except that it adds "except as provided under Subsection (2)" [stopping requirements when approaching school crosswalks].
Virginia	Not Located	Not Located
Vermont	Variation	Vermont uses the words "if traffic-control signals are not in operation" in place of "when traffic control signals are not in place or not in operation," uses the words "stopping if necessary" in place of "stopping if need be to so yield," and does not mention that the driver shall yield when"the pedestrian is upon the half of the roadway upon which the vehicle is traveling, or when the pedestrian is approaching so closely from the opposite half of the roadway as to be in danger."
Washington	Variation	Washington states that "the operator of an approaching vehicle shall stop and remain stopped to allow a pedestrian to cross the roadway within an unmarked or marked crosswalk when the pedestrian is upon or within one lane of the half of the roadway upon which the vehicle is traveling or onto which it is turning. For purposes of this section ‘half of the roadway' means all traffic lanes carrying traffic in one direction of travel, and includes the entire width of a one-way roadway." No mention is made that traffic control signals are not in place or not in operation.

State	State Law Same, or Equivalent, or Variation	If Equivalent or Variation
Wisconsin	Variation	Wisconsin applies this law to intersections not controlled "by a traffic officer" as well as those not controlled by a traffic control signal. It uses the word "operator" in place of "driver." It requires the operator to stop for a pedestrian or "a person riding a bicycle in a manner which is consistent with the safe use of the crosswalk by pedestrians" who is crossing in a crosswalk. It does not mention the location of the pedestrian or bicyclist in the roadway.
West Virginia	Variation	Used identical wording.
Wyoming	Variation	Wyoming uses the words "to yield, to any pedestrian within or entering a crosswalk at either edge of the roadway" in place of "to so yield, to a pedestrian crossing the roadway within a crosswalk when the pedestrian is upon the half of the roadway upon which the vehicle is traveling, or when the pedestrian is approaching so closely from the opposite half of the roadway as to be in danger."

Appendix B - Survey Form

A survey was conducted with the Lawrence drivers to get their opinion about the newly installed Pedestrian Hybrid Signal in their city. Two hundred and fifty survey forms were distributed in a single day. The survey form is shown below.

Front side of the survey form:

EFFECTIVENESS STUDY OF A HAWK BEACON
CITY OF LAWRENCE

Dear Motorist:

The City of Lawrence needs your help in a special study of a new pedestrian beacon. This Pedestrian Hybrid Signal on 11th street between New York St and New Jersey St is a new concept to reduce vehicular delay. Material handed out with this survey explains the new signal operation. The city needs your opinion to determine driver understanding and acceptance. Please take a couple of minutes to complete this survey on the back.

In appreciation for completing and returning this survey, we would like to send you a free State of Kansas highway map. To receive your map, please provide your mailing address where indicated.

Back side of the survey form:

Survey Regarding your Opinion about the Pedestrian Hybrid Beacon (HAWK).

We are conducting this survey to find out your opinion about the HAWK Pedestrian Beacon on 11^{th} Street between New York Street and New Jersey street at Lawrence.

Are you aware that there is a HAWK Pedestrian Beacon on 11^{th} Street between New York Street and New Jersey Street?

☐ Yes ☐ No

Have you ever had a chance to drive by this HAWK Pedestrian Beacon while driving in the city?

☐ Yes ☐ No

If you have passed by this HAWK Pedestrian Beacon, did you understand all the phases of this beacon well? (see phases below)

☐ Yes ☐ No

- Please check the phases which you understood and those you didn't

Phase 1: Blank Signal (which means 'move as usual')

☐ Understood ☐ Not understood

Phase 2: Flashing Yellow (which means 'Caution, Pedestrians want to cross')

☐ Understood ☐ Not understood

Phase 3: Steady Yellow (which means 'Be prepared to Stop for pedestrians')

☐ Understood ☐ Not understood

Phase 4: Steady Red (which means 'Must Stop and Remain Stopped')

☐ Understood ☐ Not understood

Phase5: Flashing Red (which means 'You can proceed after pedestrians have cleared')

☐ Understood ☐ Not understood

Phase 6: Blank Signal again (which means 'drive as usual')

☐ Understood ☐ Not understood

Did you feel comfortable while driving through this HAWK Pedestrian Beacon?

☐ Yes ☐ No

The HAWK Pedestrian Beacon is intended to decrease the delay for drivers at mid-blocks. Did you observe any decrease in delay at this site while driving when compared to other conventional signalized mid-block crossings?

☐ Yes ☐ No

Would you be in favor of this HAWK Pedestrian Beacon to be installed at other places in your city?

☐ Yes ☐ No

If you were acting as a pedestrian at this crossing with the HAWK Pedestrian Beacon, would you feel comfortable while crossing?

☐ Yes ☐ No

Comments: Please add your comments here.

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…………………………………………………………………………………………

Name/Address………………………………………………………………………

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Appendix C - Handouts Explaining PHB (HAWK) Operation

Handouts were prepared and decided to be distributed with the survey forms when the drivers were observed not understanding all the phases of the PHB very well. The below figures shows the front and back of the handouts distributed.

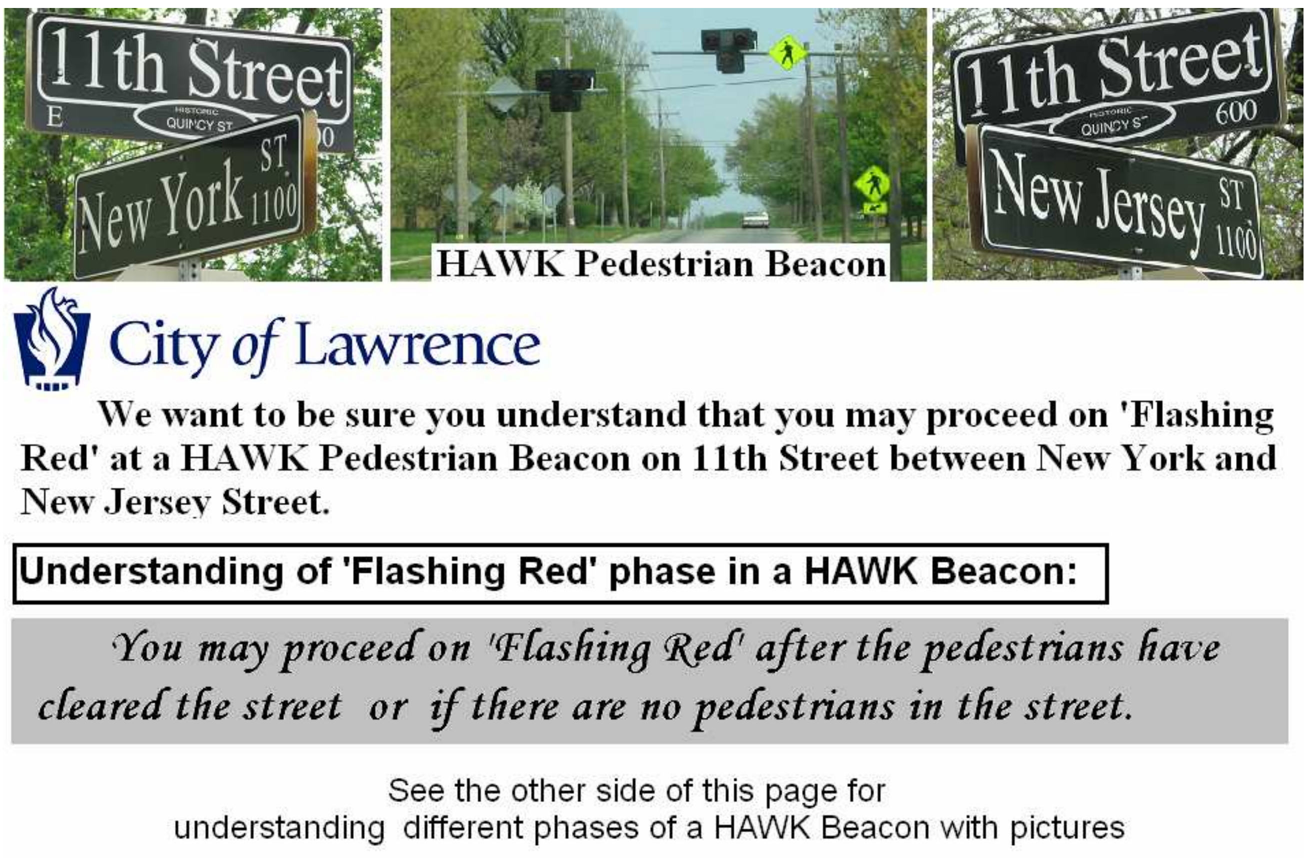

Figure 9.1: Picture Showing the Front Side of the Handout Prepared

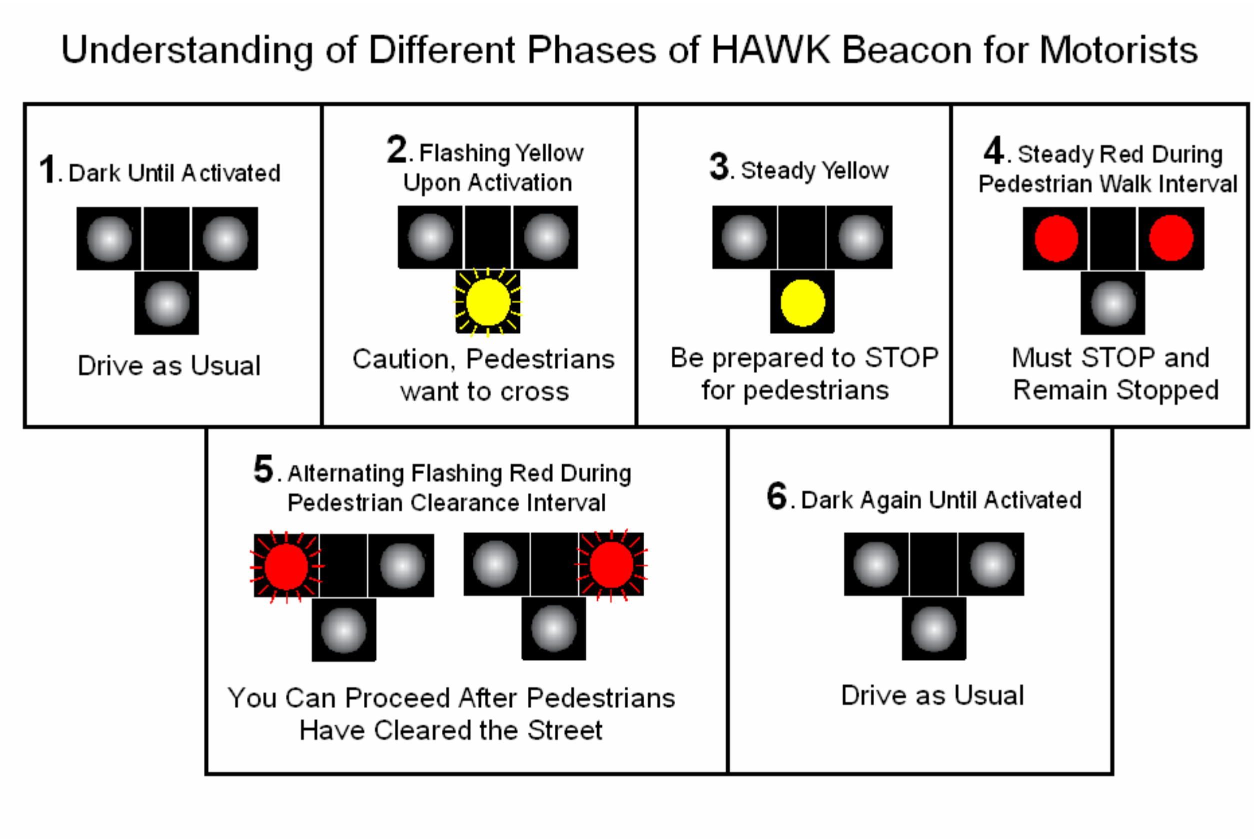

Figure 9.2: Picture Showing the Back Side of the Handout Prepared