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Evaluation of PHB Mid-Street Crossing System in Las Vegas, Nevada - Pedestrian Perspectives

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EVALUATION OF PHB MID-STREET CROSSING SYSTEM

IN LAS VEGAS, NEVADA – PEDESTRIAN PERSPECTIVES

by

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ABSTRACT

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by

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As the U.S. population ages and as more people choose to walk, it is critical to improve pedestrian safety. One of the best ways to encourage both pedestrians and vehicle drivers to behave safer is to make use of the most effective engineering traffic control systems. One such new technology is the Pedestrian Hybrid Beacon System (PHB), formerly known as the High-intensity Activated crosswalk (HAWK), a pedestrian-activated traffic-warning device. It features immediate activation of traffic warning lights from a dark state, a pedestrian countdown timer, and shorter pedestrian crossing times and traffic stoppage times compared to a traditional midblock traffic signal.

This study involves the evaluation of a PHB system installed in March 2012 at a midblock crossing on a large arterial street in Las Vegas, NV. Pedestrian and vehicle statistics were gathered several days before and after system installation and one year after installation. Evaluation of the observations indicate that the installed PHB system

enhances pedestrian safety after installation and that significant pedestrian safety benefits continue one year later.

This study evaluates only one particular site at three points in time, so the measures of effectiveness of the new PHB system are limited. The PHB system was proven effective in decreasing the unnecessary delay for the drivers, increasing the number of vehicles that stopped, and increasing pedestrian compliance in terms of pushing the activation button and avoiding jaywalking incidents. The result instills confidence that midblock crossings with installed PHB systems can achieve levels of pedestrian safety that exceed that of locations where traditional traffic signals are installed. One confusing aspect for those new to the system that needs to be improved is that both motorists and pedestrians seemed confused as to whether the system was operational when the lights were totally dark.

ACKNOWLEDGEMENTS

First and foremost, I want to thank God for the numberless blessings to help me reach this point in my life.

I would like to express my most sincere thanks to my advisor Dr. K (Dr. Moses Karakouzian) for his constant support and valuable advice at every step of my research and the long years I spent at UNLV. The patience and support of Dr. K has motivated me during many critical stages of my research and I can never forget this.

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UNLV became a second home with the long years that I spent there. The support and consideration from the Graduate College, the Department Chair, and the Engineering Dean all deserve special thanks in helping me to plod this way.

DEDICATION

I would like to dedicate my dissertation to my family. To my daughter Neethy Eapen and my husband George Eapen for all their support, in helping me attain my dream.

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CHAPTER 1

INTRODUCTION

In the United States, in the decade from 2003 through 2012, more than 47,000 people died walking on our streets, which is more than 16 times the number of Americans who died in natural disasters over the same time period (National Complete Streets Coalition, NCSC, 2014). There were 4,378 pedestrian fatalities and approximately 69,000 pedestrian injuries in 2008 (U.S. Department of Transportation, USDOT, 2008). In 2012, pedestrian fatalities increased to 4,743 and injuries to about 76,000 (USDOT, 2012). Of these reported pedestrian fatalities above, most occurred at non-intersection locations, 75 percent of the total in 2008 and 70 percent in 2012. This is in spite of the many traffic signal systems and signage installed to encourage safe motorist and pedestrian behavior.

Most state motor vehicle laws state that a motorist must use due care to avoid hitting pedestrians. Motor vehicles are large and heavy, so that they are hard to stop quickly and may cause severe injury if a pedestrian is struck. Although licensed drivers must have certain cognitive skills, this is not true for pedestrians. Pedestrians may include senior citizens, children, persons with mental challenges, and physical handicaps, which can include vision and hearing impairment. Consequently, to reduce pedestrian fatalities and injury it is important to implement safety systems that promote improved pedestrian and vehicle driver compliance.

1.1 Background

Las Vegas is one of the most dangerous places to be a pedestrian. The NCSC created a Pedestrian Danger Index (PDI) to indicate "the likelihood of a person on foot being hit by a vehicle and killed." From 2003-2012, the national PDI was 52.2 and the average annual pedestrian (APD) fatality rate was 1.56 per 100,000 people. The numbers for the Las Vegas metropolitan area were a PDI of 102.7 and an APD of 1.85, which ranked it 13th worst in the country (NCSC, 2014). The report also ranked Las Vegas 9th worst in America in terms of the percentage of all traffic deaths that were pedestrians, 20.2 percent. It also noted that more than 60 percent of pedestrian fatalities were on arterial roads with a speed limit of 40 mph or higher. Adults aged 65 and older had the highest PDI of all population segments, comprising 21 percent of all pedestrian fatalities in the study period, and 57 percent died on arterial roadways (NCSC, 2014).

Midblock (non-intersection) locations account for more than 70 percent of pedestrian fatalities (USDOT, 2012). This is partly because, between intersections, vehicle speeds are higher. If vehicles are moving at 40 mph or faster when they hit a pedestrian, 80 percent of them will die, while less than 10 percent die when vehicles are moving 20 mph or less.

1.2 Description of a Pedestrian Hybrid Beacon System (PHB)

In the late 1990s, Richard Nassi, transportation administrator for the City of Tucson, Arizona, developed the High-Intensity Activated Crosswalk, or HAWK, pedestrian beacon. The Manual on Uniform Traffic Control Devices (MUTCD) calls the device the Pedestrian Hybrid Beacon (MUTCD, 2012).The PHB is designed to make pedestrian crossings safer, particularly for arterial streets with minor street intersections, wide streets, and streets with posted speed limits more than 40 mph. When a pedestrian arrives, a button is pushed which instantaneously activates the PHB flashing sequences to vehicles. When vehicles are stopped with steady double-red lights, the pedestrian crosses the roadway with a visible countdown. However, after several seconds the PHB system switches to alternating red flashing lights, meaning vehicle drivers are free to proceed as soon as the pedestrians have crossed (Figure 1-1). Newly arriving vehicles are required to stop before proceeding if the red lights are flashing.

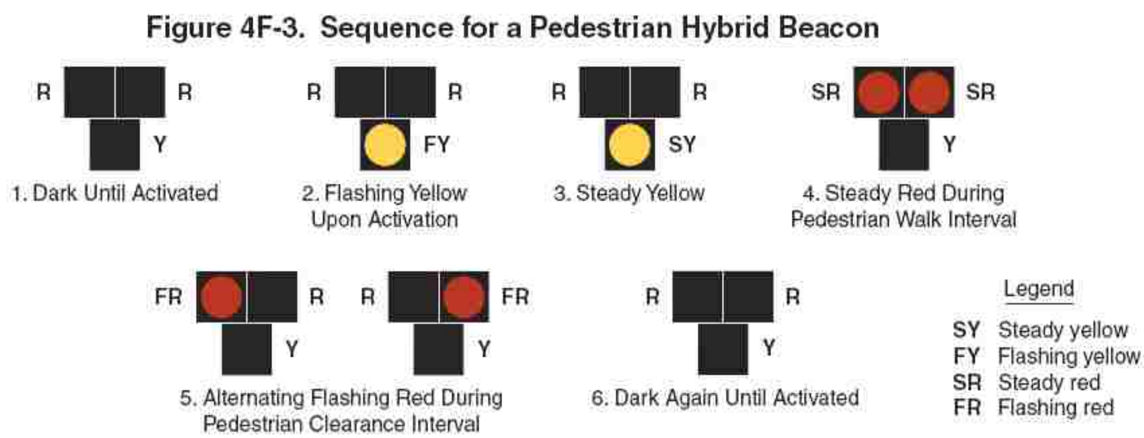


Figure 1-1.Sequence for a Pedestrian Hybrid Beacon Crossing System (MUTCD, 2012)

One early study sponsored by FHWA found that PHB systems result in a 69 percent reduction in crashes involving pedestrians, a 15 percent reduction in sever crashes that result in injury, and a 29 percent reduction in total crashes (Fitzpatrick and Park, 2010). The study also showed that compared with traditional traffic signal crossings, the PHB system results in faster pedestrian crossing times and less delay to motorists.

1.3 Statement of the Problem and Hypothesis

A number of new roadway crossing technologies are being developed, installed, and tested, but only a few are appropriate for high-speed conditions or for wide crossings. One that show significant promise is the PHB system, however, there have not been too many studies conducted showing how effective the system is. A PHB system was installed along an arterial roadway in Las Vegas, NV where a traditional traffic signal was previous operating. This study is intended to evaluate whether pedestrian safety and other traffic indicators improved after installation.

A number of metrics can be used to quantify pedestrian safety. In general, if pedestrian and vehicle driver awareness is increased, then pedestrian safety is enhanced. Compared to pedestrian vehicle driver behavior with the original traffic signal, it is expected that all pedestrian safety metrics will show that the new PHB system improves pedestrian safety.

1.4 Research Scope and Purpose

Placing some type of traffic signal midblock for pedestrian crossing is a common treatment to enhance pedestrian crossing safety. The PHB system was designed to improve safety, particularly for streets with heavy traffic and high speeds where traffic gaps are often not available for the pedestrians to safely cross the street. On the other hand, midblock traffic signals of any type create delays for traffic. For traditional signals, vehicles must remain stopped for the entire pedestrian WALK time, which is calibrated long for the safety of slower-walking elderly or physically handicapped pedestrians. The PHB system allows vehicles to proceed as soon as pedestrians clear.

This research studies the effects from installing a PHB system at a busy midblock crossing in Las Vegas, NV, where formerly a traditional signal operated. Observed video data from mounted cameras covers three periods of time: several days prior to removal of the old system, several days of data immediately after the PHB system is installed, and several days of data one year after PHB installation. The data was collected over 24-hour periods. This research evaluates changes in pedestrian and vehicle compliance in these three periods. The purpose of this research is to determine the safety effectiveness of the PHB installation at this Las Vegas location.

1.5 Organization of the Report

Chapter 2 comprises a literature review related to this research. The scope of the review covers relevant definitions, pedestrian crossing safety, common engineering traffic control systems, evaluation of engineering traffic control countermeasures, and studies focused on Pedestrian Hybrid Beacon traffic systems.

Chapter 3 describes the Las Vegas site where the PHB system was installed together with operational and environmental conditions. Chapter 4 discusses the data collection and general methodology used in categorizing and analyzing the data. Chapter 5 presents the statistical analysis and plots of the data together with conclusions and discussion. Chapter 6 gives conclusions from this study of a PHB installation effectiveness. Recommendations for future research are also suggested in this chapter.

The Appendix describes the raw data and calculation spreadsheets used to summarize and analyze the raw observational data.

CHAPTER 2

LITERATURE REVIEW

2.1 General Definition of Terms

A number of standard terms and definitions are used in this report. The definitions cited below are taken from the *Highway Safety Manual* (AASHTO, 2010) unless otherwise indicated.

accident/crash - a set of events not under human control that results in injury or property damage, due to the collision of at least one motorized vehicle and may involve collision with another motorized vehicle, a bicyclist, a pedestrian or an object. The terms accident and crash are used interchangeably in this report.

accident severity - the most severe injury sustained in an accident (e.g., in a fatal accident, two fatalities and three severe injuries were reported).

arterial highway - a general term denoting a highway primarily used by through traffic, usually on a continuous route or a highway designated as part of an arterial system. (MUTCD, 2012)

beacon - a highway traffic signal with one or more signal sections that operates in a flashing mode. (MUTCD, 2012)

bicycle - a pedal-powered vehicle upon which the human operator sits. (MUTCD, 2012)

bus lane - a highway or street lane designed for bus use during specific periods.

countermeasure - a roadway based strategy intended to reduce the crash frequency or severity, or both at a site.

crosswalk - (a) that part of a roadway at an intersection included within the connections of the lateral lines of the sidewalks on opposite sides of the highway measured from the curbs or in the absence of curbs, from the edges of the traversable roadway, and in the absence of a sidewalk on one side of the roadway, the part of a roadway included within the extension of the lateral lines of the sidewalk at right angles to the center line; (b) any portion of a roadway at an intersection or elsewhere distinctly indicated as a pedestrian crossing by pavement marking lines on the surface, which might be supplemented by contrasting pavement texture, style, or color. (MUTCD, 2012)

dark mode - the lack of all signal indications at a signalized location. (The dark mode is most commonly associated with power failures, ramp meters, hybrid beacons, beacons, and some movable bridge signals.) (MUTCD, 2012)

day - from 6 a.m. to 5:59 p.m.

delay - the additional travel time experienced by a driver, passenger, or pedestrian in comparison to free flow conditions.

driver expectancy - the likelihood that a driver will respond to common situations in predictable ways that the driver has found successful in the past. Expectancy affects how drivers perceive and handle information and affects the speed and nature of their responses.

flashing - an operation in which a light source, such as a traffic signal indication, is turned on and off repetitively. (MUTCD, 2012)

human factors - the application of knowledge from human sciences such as human psychology, physiology, and kinesiology in the design of systems, tasks, and environments for effective and safe use.

hybrid beacon - a special type of beacon that is intentionally placed in a dark mode (no indications displayed) between periods of operation and, when operated, displays both steady and flashing traffic control signal indications. (MUTCD, 2012)

intersection - general area where two or more roadways or highways meet, including the roadway, and roadside facilities for pedestrian and bicycle movements within the area.

intersection related accident - an accident that occurs at the intersection itself or an accident that occurs on an intersection approach within 250 ft. (as defined in the HSM) of the intersection and is related to the presence of the intersection.

jaywalking - the illegal or reckless crossing of a roadway by a pedestrian. Examples include a pedestrian crossing outside of marked crosswalks and starting to cross a crosswalk at a signalized intersection without waiting for a permissive indication to be displayed. In the United States, state statutes generally reflect the Uniform Vehicle Code in requiring drivers to yield the right of way to pedestrians at crosswalks; at other locations, crossing pedestrians are either required to yield to drivers or, under some conditions, are prohibited from crossing. (*Uniform Vehicle Code*, National Committee on Uniform Traffic Laws and Ordinances, NCUTLO, 2000)

median - the portion of a divided highway separating the traveled ways from traffic in opposite directions.

median refuge island - an island in the center of a road that physically separates the directional flow of traffic and that provides pedestrians with a place of refuge and reduces the crossing distance of a crosswalk.

minor street - the lower volume street controlled by stop signs at a two-way, or four-way stop-controlled intersection; also referred to as a side street. The lower volume street at a signalized intersection.

multilane highway - a highway with at least two lanes for the exclusive use of traffic in each direction, with no control, partial control, or full control of access, but that may have periodic interruptions to flow at signalized intersections.

night - from 6 p.m. to 5:59 a.m.

operating speed - the 85th percentile of the distribution of observed speeds operating during free-flow conditions.

pedestrian - a person traveling on foot or in a wheelchair.

pedestrian clearance time - the time provided for a pedestrian crossing in a crosswalk, after leaving the curb or shoulder, to travel to the far side of the traveled way or to a median. (MUTCD 2012)

pedestrian crosswalk - pedestrian roadway crossing facility that represents a legal crosswalk at a particular location.

pedestrian signal - a device that communicates information about pedestrian signal timing in non-visual format such as audible tones, speech messages, and/or vibrating surfaces. (MUTCD, 2012)

pedestrian traffic control - traffic control devices installed particularly for pedestrian movement control at intersections; it may include illuminated push buttons, pedestrian detectors, countdown signals, signage, pedestrian channelization devices, and pedestrian signal intervals.

peripheral vision - the ability of people to see objects beyond the cone of clearest vision.

phase - the part of the signal cycle allocated to any combination of traffic movements receiving the right-of-way simultaneously during one or more intervals.

pushbutton - a button to activate a device or signal timing for pedestrians, bicyclists, or other road users. (MUTCD, 2012)

roadside - the area between the outside shoulder edge and the right-of-way limits. The area between roadways of a divided highway may also be considered roadside.

rural areas - places outside the boundaries of urban growth boundary where the population is less than 5,000 inhabitants.

safety - the number of accidents, by severity, expected to occur on the entity per unit of time. An entity may be a signalized intersection, a road segment, a driver, a fleet of trucks, etc.

shoulder - a portion of the roadway contiguous with the traveled way for accommodation of pedestrians, bicycles, stopped vehicles, emergency use, as well as lateral support of the sub base, base, and surface courses.

sign - any traffic control device that is intended to communicate specific information to road users through a word, symbol, and/or arrow legend. Signs do not include highway traffic signals, pavement markings, delineators, or channelization devices. (MUTCD, 2012)

speed limit - the maximum (or minimum) speed applicable to a section of highway as established by law or regulation. (MUTCD, 2012)

stop line - a solid white pavement marking line extending across approach lanes to indicate the point at which a stop is intended or required to be made. (MUTCD, 2012)

traffic barrier - a device used to prevent a vehicle from striking a more severe obstacle or feature located on the roadside or in the median or to prevent crossover median accidents. As defined herein, there are four classes of traffic barriers, namely, roadside barriers, median barriers, bridge railings, and crash cushions.

traffic control device - a sign, signal, marking, or other device used to regulate, warn, or guide traffic, placed on, over, or adjacent to a street, highway, private road open to public travel, pedestrian facility, or shared-use path by authority of a public agency or official having jurisdiction, or, in the case of a private road open to public travel, by authority of the private owner or private official having jurisdiction. (MUTCD, 2012)

urban environment - an area typified by high densities of development or concentrations of population, drawing people from several areas within a region.

volume - the number of persons or vehicles passing a point on a lane, roadway, or other traffic-way during some time interval, often one hour, expressed in vehicles, bicycles, or persons per hour.

volume, annual average daily traffic - the average number of vehicles passing a point on a roadway in a day from both directions, for all days of the year, during a specified calendar year, expressed in vehicles per day.

walk interval - an interval during which the WALKING PERSON (symbolizing WALK) signal indication is displayed. (MUTCD, 2012)

2.2 Pedestrian Crossing Safety

Walking, as a means of transportation, is done by everyone: children, teenagers, adults, seniors, drunken people, physically and mentally impaired people, and so on. Walking carries a high risk of injury or death when it occurs on streets and highways due to the massive weight and speed of cars and trucks compared to pedestrians. For this reason, all societies have developed crossing safety guidelines, signage, and engineered systems.

How should pedestrian safety be measured? Pedestrian crash statistics are taken from government reports related to pedestrian collisions with vehicles. All numbers tabulated are estimates and vary based the definitions used. For instance, regarding traffic collision fatalities, the National Safety Council counts as a traffic fatality as any crash death that occurs within 1 year after the collision, whereas the National Highway Traffic Safety Administration only counts deaths that occur within 30 days (Campbell, Zegeer, Huang, & Cynecki, 2004). If a fatality were defined to be those who died at the crash scene or within a day or two, then other statistical totals would result. Similarly, the definitions for "injury" can vary, and many may not even be reported.

When do pedestrian collisions occur? The FHWA sponsored Campbell et al., 2004 to summarize research on pedestrian safety in the U.S. They concluded that (p. 24):

- Fatal pedestrian crashes tend to occur at night.
- Non-fatal pedestrian crashes tend to occur during the day.
- Pedestrian crashes are more frequent on Friday and Saturday and less frequent on Sunday.
- Child-pedestrian crashes occur more often in the summer.
- Adult pedestrian crashes occur more often in the winter.
- Type of pedestrian crashes also varies with the time of day, day of week, and season. Type includes classifications such as walking along road, midblock dart/dash, intersection dash, driver violation at intersection, bus related, backing vehicle, disabled vehicle, etc.

Who is involved in pedestrian crashes? Again, the large survey performed by Campbell et al., 2004 (p. 31) reports that:

- The largest percentage of pedestrian fatalities falls into the 25-44 age category.
- However, when fatalities per 100,000 population is calculated, the oldest age category stands out higher than the rest.
- Nevertheless, compared with their proportion in the U.S. population, children and young adults ages 2-22 are overrepresented in terms of pedestrian deaths and injuries.
- More male than female fatalities are seen in every age category.
- Alcohol is an important factor in pedestrian crashes. A North Carolina study showed that between 42 and 61 percent of fatally-injured pedestrians had blood-alcohol concentration levels of 0.10 or greater. Statistics indicate that drunken pedestrians pose a greater threat to pedestrian safety than do drunk drivers.

Where do pedestrian collisions occur? The Campbell et al., 2004 (p. 37) report concludes that:

- Studies show that 70-85 percent of pedestrian collisions occur in urban areas rather than rural areas.
- Overall, 74 percent of pedestrian crashes occur where there is no traffic control, 7 percent where there is a stop sign, and 17 percent in the presence of a traffic signal. However, this breakdown greatly varies by crash type.

- With respect to speed limits, most pedestrian crashes occur where speed limits are low or moderate.

- Though most pedestrian crashes occur in urban areas, 60 percent of all these pedestrian crashes (and 75 percent of child pedestrian crashes) occur at non-intersections. The majority of the senior pedestrian crashes occur at intersections.

How do pedestrian collisions occur? Standard contributing factors are considered to be pedestrian-contributing factors, roadway/environment factors, driver-contributing factors, and vehicle factors. Statistical tabulation is uncertain, however, since people are hesitant to acknowledge culpability. The Campbell et al., 2004 report indicates that:

- One important study tabulated contributing factors for 5,073 pedestrian crashes. With respect to “Pedestrian Factors”, the largest single category is “ran into road.” Yet this category accounts for only 15 percent of collisions. The largest specific “Roadway Factor” is "vision obstruction"(11 percent). For drivers, the largest category is "failure to yield right-of-way." (p. 38)

- When the pedestrian alone is at fault (43 percent of cases overall), the situation varies by crash type. When a vehicle is backing, the pedestrian is judged to be at fault only 10 percent of the time, but in an intersection or midblock dash, the pedestrian is considered to be at fault 91 percent of the time (p. 40). Drivers are solely responsible for causing 35 percent of vehicle-pedestrian collisions. The remaining 22 percent of collisions have multiple or unknown causes. (p. 46).

- One 1985 study of the causes of pedestrian collisions in Arizona found that urban pedestrian collisions and fatalities tended to occur on wide, high-speed arterial streets. Most pedestrian collisions were caused by failure to yield by the driver or pedestrian and failure to use the crosswalk. The authors concluded that there was little in the way of engineering countermeasures that would be useful. They indicated that public education, particularly for children under 14 years of age, appeared to be the most useful countermeasure. (p. 46)

2.3 Common Engineering Traffic Control Systems

Non-intersection or midblock pedestrian crossings are a safety concern, since often, no crosswalk or signals are present. There are a number of types of engineered pedestrian crossing systems designed and employed to improve pedestrian safety.

Figure 2-1. Pedestrians Crossing Midblock, Safety Concern (Turner, Fitzpatrick, Brewer, & Park, 2006)

High visibility crosswalks (Figure 2-2) are one of the first options tried since they are cheap. However, as noted above, studies show that crosswalk markings alone do not significantly improve midblock pedestrian crossing safety. Marked crosswalks should be paired with other safety technologies. In-pavement lights can be activated or pedestrian-activated traffic signals are commonly used.

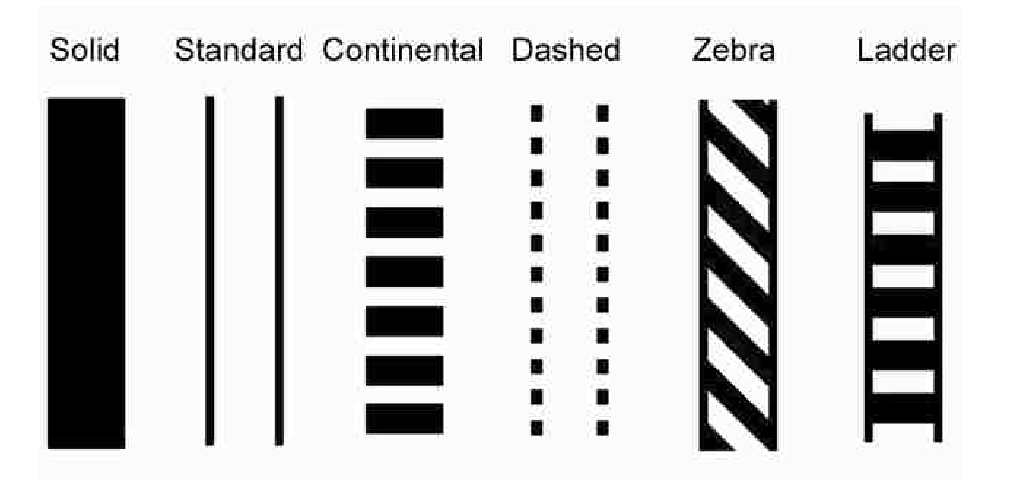


Figure 2-2. High Visibility Crosswalk Marking Patterns (Campbell et al., 2004, p. 58)

Median and refuge islands (Figures 2-3 and 2-4) consist of a dedicated and raised area located between lanes of traffic. Pedestrians can use the islands for safely waiting until vehicular traffic clears, allowing them to cross a street. Refuge islands are commonly found along wide, multilane streets where adequate pedestrian crossing time cannot be provided without adversely affecting the traffic flow. These islands are particularly useful to those who use wheelchairs, the elderly, or who are otherwise unable to completely cross an intersection within the provided signal time.

Figure 2-3. Refuge Islands Provide A Safety Zone While Crossing (Turner et al., 2006)

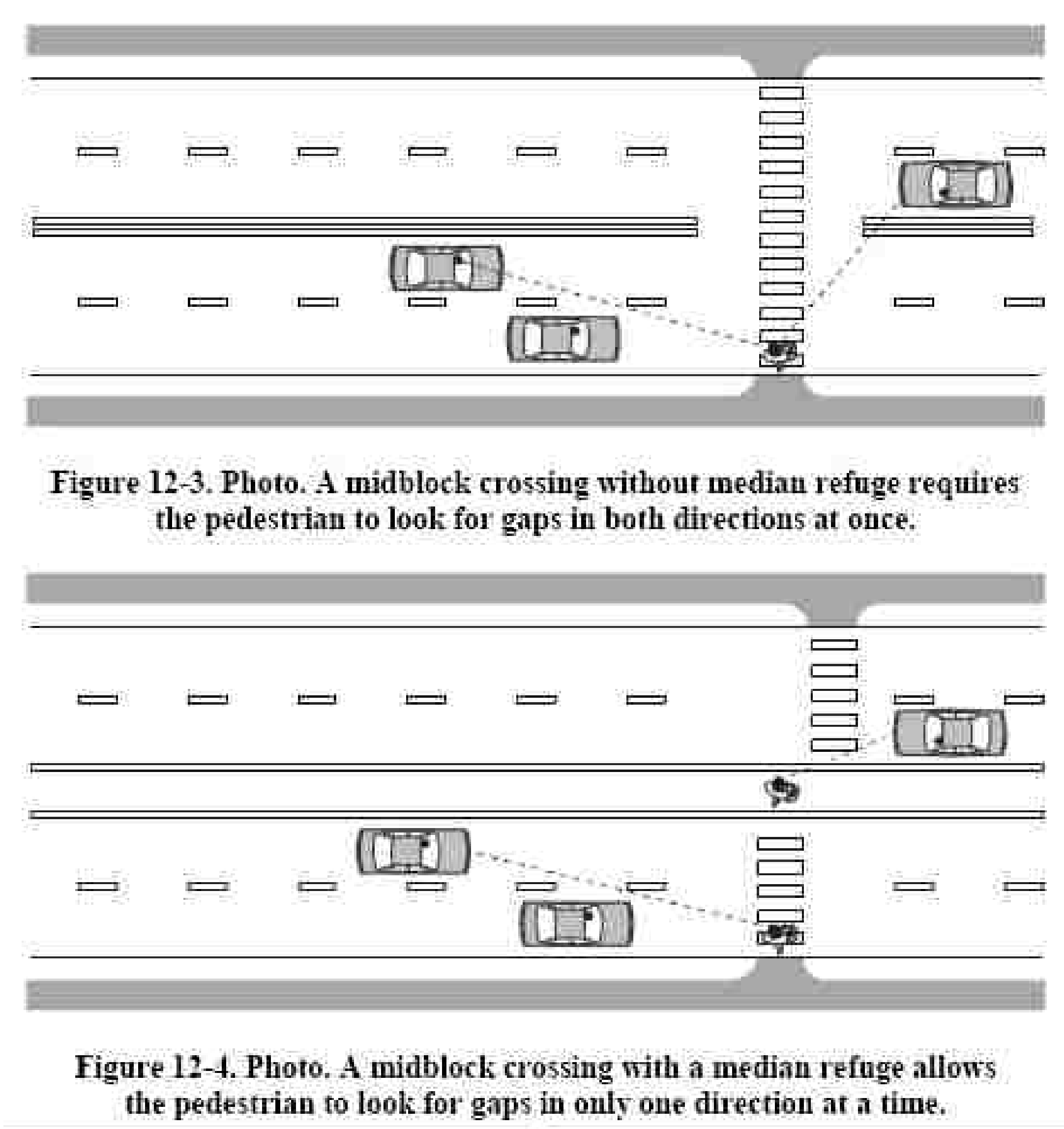


Figure 2-4. Difference With and Without a Refuge Island (Turner et al., 2006)

Grade separated crossings (Figure 2-5) such as a bridge/overpass or tunnel/underpass are useful when engineers do not want arterial traffic to be disrupted by crossing pedestrians. Pedestrians love these facilities, but they are expensive to construct. Many bicyclists and pedestrians will not use an overpass that is inconvenient. Instead, pedestrians may choose a timesaving and sometimes more hazardous crossing. Fencing or other controls may be required to reinforce the safe crossing point.

Figure 2-5. Underpass Pedestrian Crossing Below a Highway (Turner et al., 2006)

Suburban crossings of two- to four-lane roadways are greatly improved when medians and midblock crossings (Figure 2-6) are used. On lower-volume roadways, it is best not to use traffic signals. Midblock crossing curb extensions provide better visibility for motorists and pedestrians.

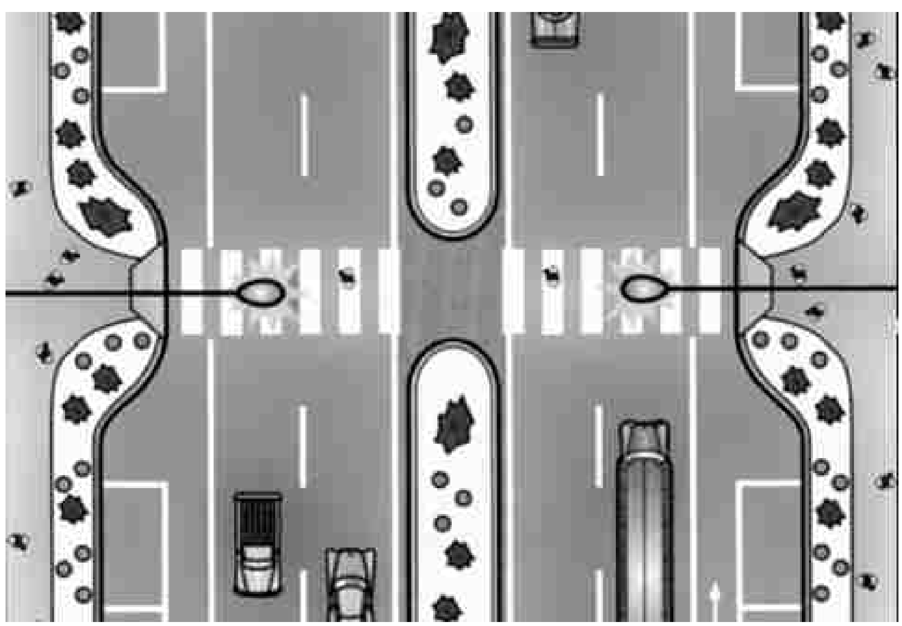


Figure 2-6. Midblock Crossing Curb Extensions (Turner et al., 2006)

On multilane arterials with six or more lanes, motorists frequently change lanes, change speed, and allow for merging traffic. These conditions may be difficult to interpret by the pedestrian who wants to cross. Moreover, motorists do not expect and are not usually looking for pedestrians crossing at midblock.

At midblock locations, where vehicle speeds are high, signalization (Figures 2-7 and 2-8) may be the only practical means of helping pedestrians to cross. The higher the vehicle speed, the greater the engineering challenge to help pedestrians cross safely. Fixed-time signal operation usually works best because it provides an automatic pedestrian phase. However, if pedestrians feel they are required to wait a long time to cross by the signal, many will simply choose to ignore the signal and cross during a gap in traffic.

Figure 2-7. Standard Pedestrian Button-Activated Traffic Signal (Turner et al., 2006)

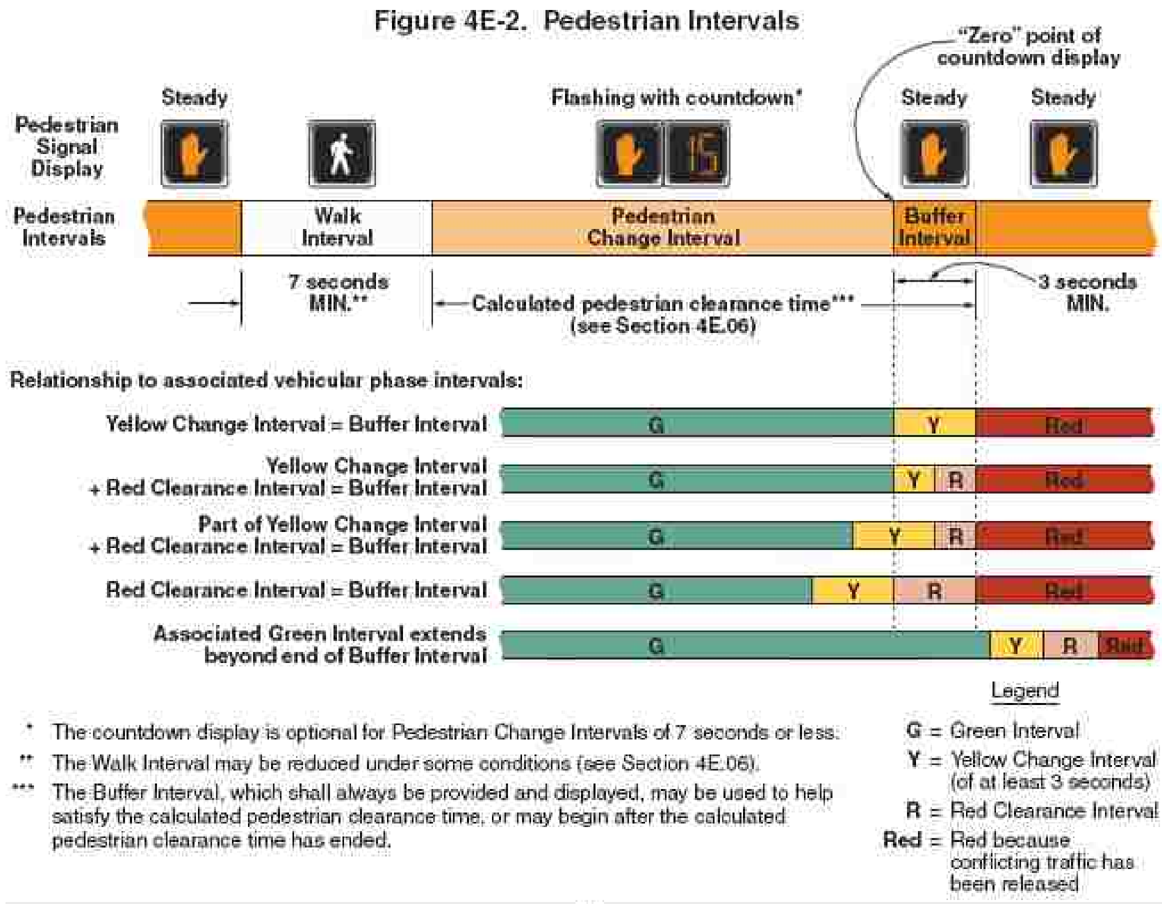


Figure 2-8. Pedestrian Signal Timing (MUTCD, 2012)

2.4 Evaluation of Engineering Traffic Control Countermeasures

Various engineered countermeasures and safety programs have been implemented with the objective being to reduce vehicle-pedestrian crashes. After reviewing numerous pedestrian safety initiatives, the Campbell et al., 2004 report indicated that "research on the effectiveness of pedestrian safety initiatives is inherently difficult because pedestrian crashes are generally quite rare at any given location; therefore, a study may not have enough data for numerical stability…. While the rarity of pedestrian collisions at a site is fortunate, it makes the study of countermeasures difficult" (p. 57).

To compensate for the problem of small numbers, researchers often aggregate data from multiple locations to reach conclusions.

Another major research problem involves selection bias and regression to the mean. Decision makers approve of countermeasures based on limited funding and a variety of other criteria. Often, remedies are employed where the problem is judged greatest. This may be prudent, but from a research perspective, problems can be created. In performing before and after intervention statistics, one problem is that, because before statistics are not available at the intervention site, a different site with statistics is used for comparison. In this case, "If the 'after' experience is different from the 'before' experience, one cannot know how much of the change was produced by the treatment and how much is a continuation of the pre-existing difference." The regression to the mean problem is a special type of selection bias. When "worst" sites are selected to install new engineered systems, then the "after" experience will inevitably be better due to "'regression to the mean.' When that particular flaw is embedded in a study design, one cannot know whether the favorable results are from the countermeasure, from the regression effects, or from a combination of the two." (p. 57)

Regarding the Campbell et al., 2004 report reviewing many U.S. studies of pedestrian safety countermeasure, some major findings were (pp. 122-125):

- There is evidence that substantially improved nighttime lighting can enhance pedestrian safety in some situations.
- At uncontrolled crosswalks (i.e., no stop sign or traffic signal on the approach roadway) on a two-lane road, the presence of a marked crosswalk is

associated with no difference in pedestrian crash rate, compared to an unmarked crosswalk.

- On multi-lane roads with traffic volumes above 12,000 vehicles per day, having a marked crosswalk alone, without other substantial improvements, is associated with a higher pedestrian crash rate (after controlling for other site factors) compared to an unmarked crosswalk.
- Providing raised medians on multi-lane roads can substantially reduce pedestrian crash risk and can help pedestrians cross the street.
- At intersections with traffic signals, adding a WALK/DON'T WALK signal with a standard timing scheme (i.e., motorists move parallel to pedestrians and may turn right or left on a green light across pedestrians' path) has no significant effect on pedestrian collisions.
- Various innovative pedestrian and motorist warning signs (Figure 2-9) have been found to reduce vehicle speeds or conflicts between pedestrians and motorists. These devices include the "strong yellow green" pedestrian warning sign, YIELD TO PEDESTRIANS WHEN TURNING sign, PEDESTRIANS WATCH FOR TURNING VEHICLES sign, three-section WALK WITH CARE signal head, and a DON'T START display to replace the flashing DON'T WALK display, and others.

Figure 2-9. Examples of Innovative Warning Signage (Campbell et al., 2004, p. 82)

- At many intersections, pedestrians must push buttons to activate the WALK phase. However, they often do not know whether pressing the button activates anything. If the WALK phase does not appear soon after the button has been pressed, some people lose patience and start crossing early, while the steady DON'T WALK is still being displayed. On the other hand, when a pedestrian presses an illuminated push button(Figure 2-10), a light near the button turns on, indicating that the WALK phase has been activated and will soon begin. Studies show that pedestrian compliance with signaling is improved with illuminated buttons.

Figure 2-10. An Illuminated Pedestrian Push Button (Campbell et al., 2004, p. 84)

- Automated pedestrian detection systems (Figure 2-11) can sense the arrival of pedestrians as they approach the curb before crossing the street, and then "call" the WALK signal (equivalent to pushing the button) without any action required on the part of the pedestrian. Studies show that these systems significantly improve pedestrian compliance if coupled with illumination indicators.

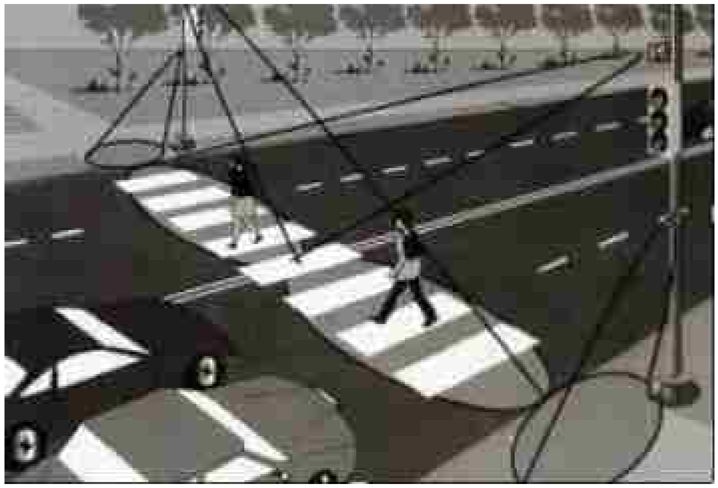


Figure 2-11. Automatic Pedestrian Detector System (Campbell et al., 2004, p. 84)

- Some midblock crossings are too wide for some pedestrians to cross safely within the time provided or given the traffic gaps. These can lead to being “trapped” in a crosswalk and running across intersections, which has been shown to be a cause of pedestrian crashes. Pedestrian refuge areas (Figure 2-12) between traffic lanes offer an effective solution to these problems.

Figure 2-12. Pedestrian on Left Cannot Safely Cross. Pedestrian Island, on Right. (Campbell et al., 2004, p. 85-86)

- Designated sidewalks and walkways enhance pedestrian safety. Rural roads should have shoulders for pedestrian travel.
- Overpasses and underpasses can substantially improve safety for pedestrians needing to cross freeways or busy arterial streets. However, such facilities must be carefully designed to encourage pedestrians to use the facilities and not continue to cross at street level.
- Enforcement of traffic laws and regulations for both pedestrians and drivers represents another important way to improve pedestrian safety. In particular, this includes enforcing the pedestrian regulations of jaywalking and crossing against the signal, and unsafe motorist behavior of speeding, not yielding to pedestrians when turning, and drunk driving.

2.5 Pedestrian Hybrid Beacon (PHB) System Studies

Multilane, high-speed arterial roads are both barriers and risks to pedestrian mobility. Standard button-activated traffic signals located midblock have several problems. They disrupt normal traffic flow unnecessarily, pedestrians often do not wait for the WALK signal, and it is costly. Considering these problems, in the late 1990s, Richard Nassi, who was transportation administrator for the City of Tucson, Arizona, developed the High-Intensity Activated Crosswalk, or HAWK, pedestrian beacon (Fitzpatrick and Park, 2010). Beginning in 2009, the Manual on Uniform Traffic Control Devices (MUTCD) gave the device a more generic name, the pedestrian hybrid beacon or PHB, which is now being widely used.

The PHB system stops vehicles so that pedestrians can safely cross the roadway, and then permits drivers to proceed as soon as the pedestrians have crossed. Pedestrian Hybrid Beach provides pedestrian with a “controlled crossing” which will allow them to communicate with motorists. Further, since the PHB will be synchronized with the designated traffic signal this will create less traffic congestion for both motorists and pedestrians to share the road (Public Works of Sacramento, 2014). The signaling sequence is shown in Figures 2-13 and 2-14.

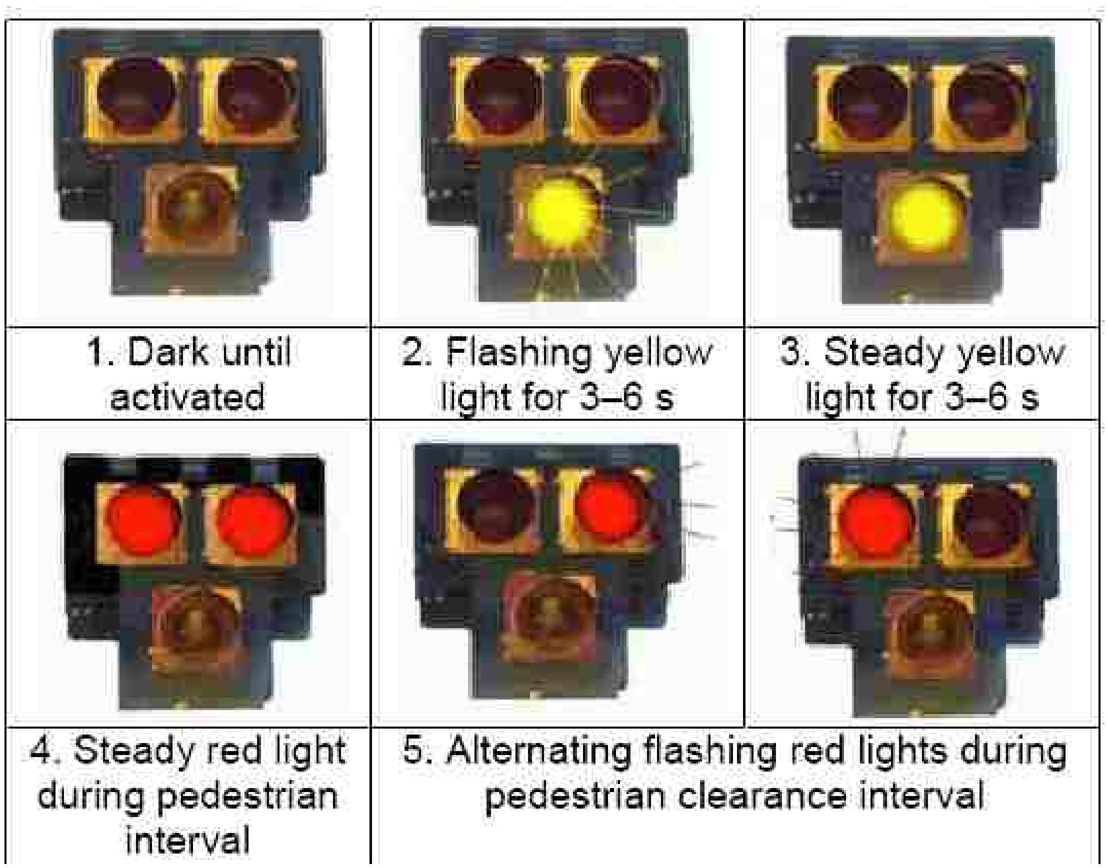


Figure 2-13. Signal Sequence for Pedestrian Hybrid Beacon (Fitzpatrick and Park, 2010)

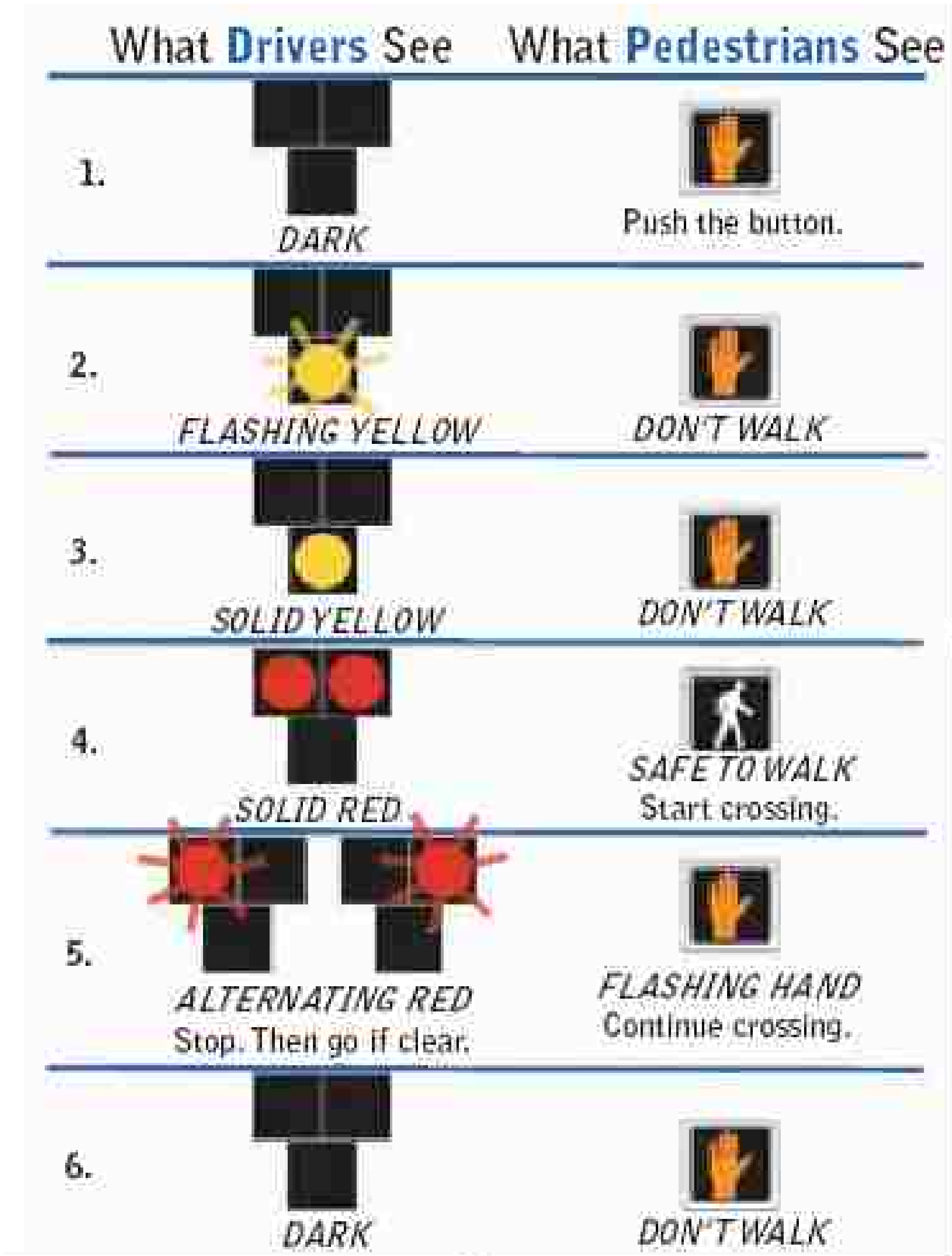


Figure 2-14. Pedestrian Hybrid Beacon System Operation (Fitzpatrick and Park, 2010)

The normal or resting mode for the PHB system is dark (no lights are illuminated). When a pedestrian arrives and presses the button, the vehicle traffic signal immediately starts flashing yellow, then changes to solid yellow, followed by a solid red phase for 7 s, requiring motorists to stop at the marked crosswalk stop line. At this time, pedestrians receive a WALK indication on the countdown timer. After seven s of solid red, a “wig-wag” flashing red signal (the left and right red beacon alternately flash) starts and pedestrians receive a flashing Don’t Walk signal. During the flashing wigwag red signal, vehicles may continue through the crosswalk once pedestrians have cleared. Arriving vehicles must come to a complete stop prior to proceeding. The PHB system will then go dark again.

Turner, Fitzpatrick, Brewer, & Park, 2006, found 93% yielding compliance with the hybrid beacon. Because beacon operation commences with the pedestrian button press, pedestrian compliance is quite high at hybrid beacon locations. Fitzpatrick and Park (2010) used a before-and-after empirical, Bayes approach to evaluate whether the hybrid beacon reduced pedestrian crashes on multilane roads. The empirical Bayes method is a statistical approach that determines the effectiveness of a treatment from external factors—such as increases in traffic volumes—and from the randomness of crashes. Data were collected on crashes and traffic volume at 102 unsignalized intersections that served as the control sites and at 21 PHB sites, typically 3 years before and 3 years after the installation. The number of observed crashes that occurred after the installation of a PHB system was then compared with the predicted number of crashes if the treatment had not been installed. The researchers found the following changes in crashes after installation of the PHB system:

- A 69 percent reduction in crashes involving pedestrians, statistically significant at a 95 percent confidence level;

- A 15 percent reduction in severe crashes that result in injury; this was not statistically significant at a 95 percent confidence level, probably because of the low number of these types of crashes; and
- A 29 percent reduction in total crashes, statistically significant at a 95 percent confidence level.

Research has shown that sites with PHB in analyzing the pedestrian and motorists actions conducted over time have resulted in average traffic speed at certain locations compared to others. Further, a decrease in the number of motorists not yielding to pedestrians, pedestrians trapped in the middle of the street, and pedestrian vehicle conflicts were seen. Furthermore, improvements in the overall the pedestrian and motorists' actions were consistent as the study progressed and motorists became accustomed to the system. (Pulugurtha and Self, 2013)

Compared to other device implementation and overall maintenance the PHB's are considerably more expensive, however if we are to consider the cost of a full traffic signal the pedestrian hybrid beacons are less expensive. For example, the median price of a pedestrian hybrid beacon is $51,460 with the maximum amount nearing $128,660 (Bushell, Poole, Zegeer, & Rodriguez, 2013).

Looking at the totality of the installation, past analysis has shown that the installation of PHBs have reduced the overall delay for blind participants and significantly lowered their crossing risks, which are associated with major intersections in metropolitan areas. (Road Commission for Oakland County, 2011).

CHAPTER 3

PHB SITE DESCRIPTION AND PRELIMINARY ANALYSIS

3.1 Site Description

In 2010 the City of Las Vegas, together with the Regional Transportation Commission of Southern Nevada's (RTC)'s Freeway and Arterial System of Transportation (FAST) division, initiated a pedestrian safety program to install and evaluate 15 new engineering countermeasures installed at 14 sites across Las Vegas. This research is concerned with the PHB traffic and crossing system installed at the midblock T-intersection of E. Sahara Avenue and S. 15th Street. Figures 3-1 and 3-2 show the PHB location in plan view. The area near the new pedestrian crossing includes apartment buildings, residential houses, a food market, and other stores. Right near the crosswalk are two bus stops on both sides of Sahara Ave.

Sahara Ave. is a major street, connecting the eastern and western portions of the Las Vegas Valley. This midblock location was selected because Sahara Ave. is one of the busiest arterial roads in Las Vegas. The average daily traffic volume for Sahara Ave. was about 40,000 vehicles per day in 2010 and the hourly daily volume (from Aug. 2009 to Jun. 2010) was above 1500, peaking at around 2000 vehicles per day (Figures 3-3 and 3-4). Data was again collected in from May to Aug. of 2011 and the traffic volume along Sahara Ave. dropped by about 500 vehicles per day for no known reason (RTC, 2013). Figures 3-5 and 3-6 show the bus stop pedestrian traffic near the PHB location, which shows a high volume for both trip origins and destinations (RTC, 2013). The bus stop locations are shown in Figure 3-2.

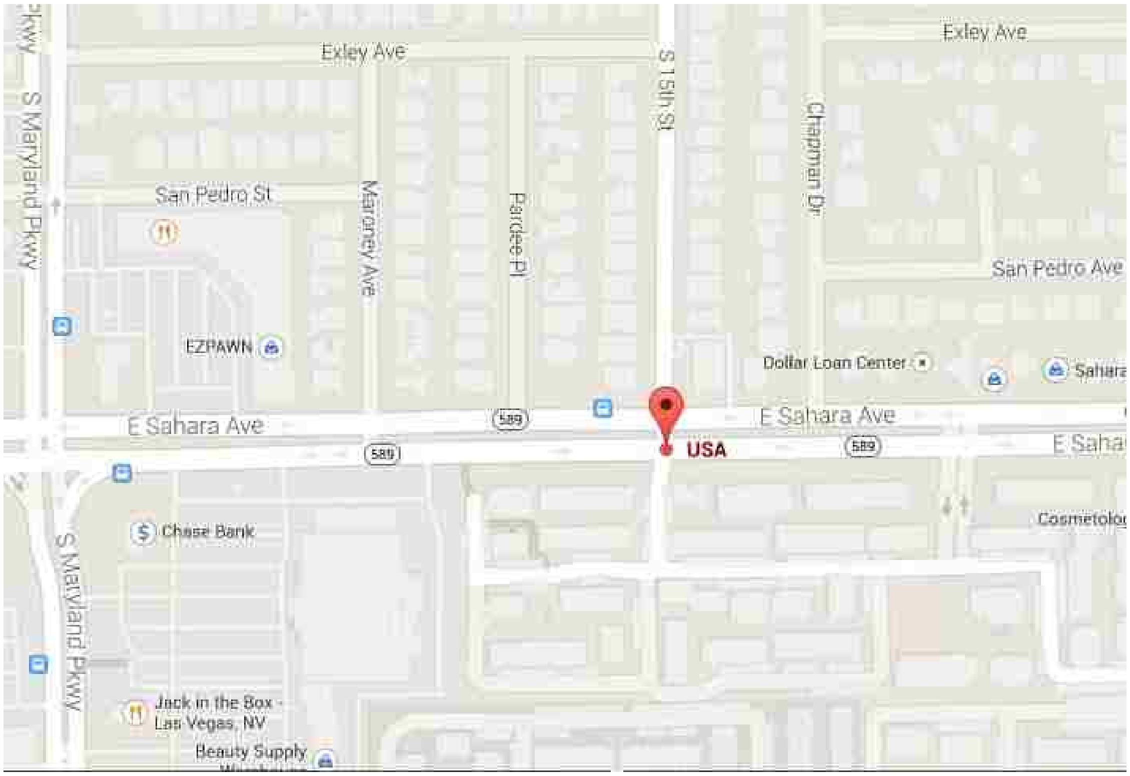


Figure 3-1. Plan Views of the PHB Location at Sahara Ave. and S. 15th St. (Google Map)

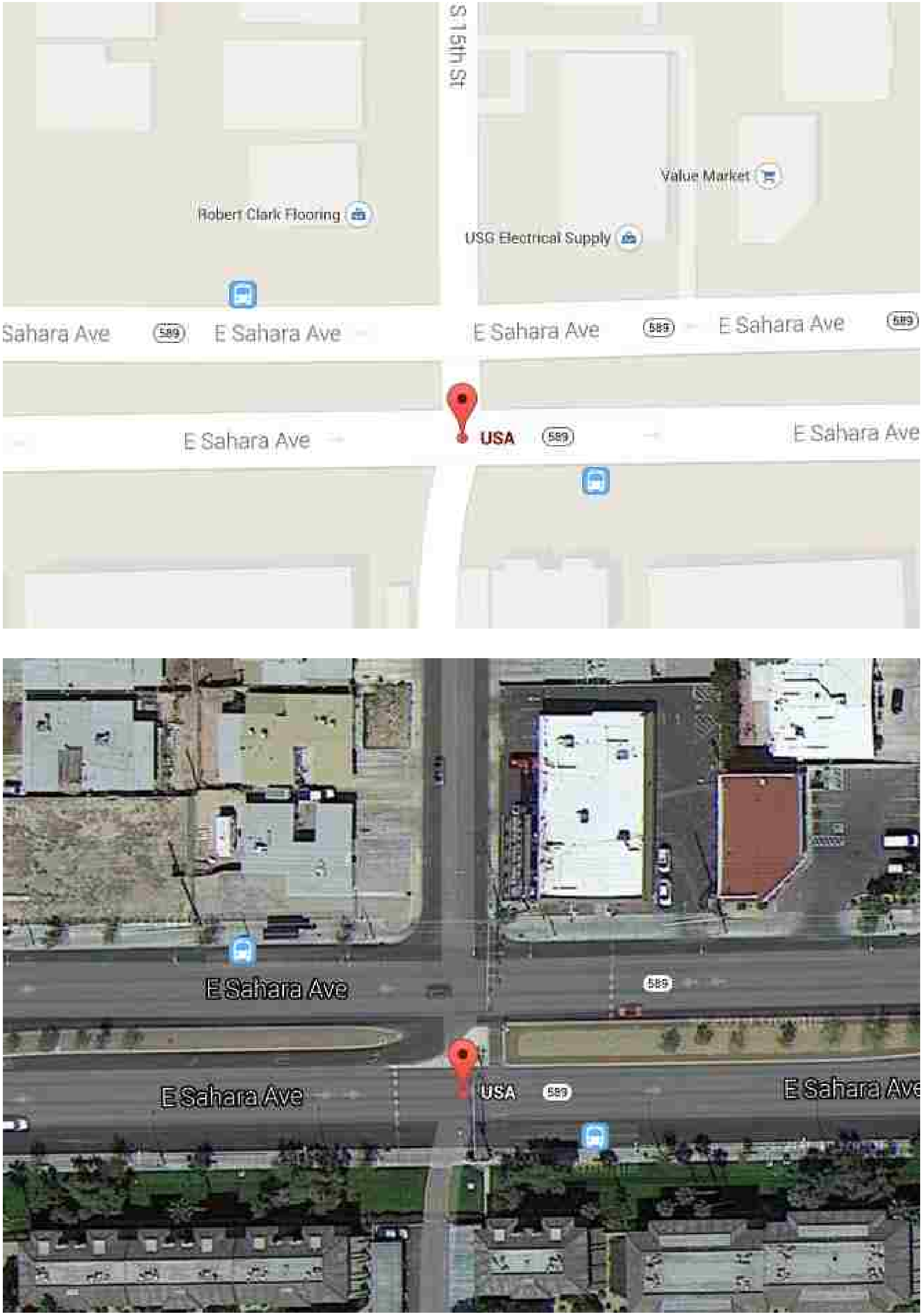
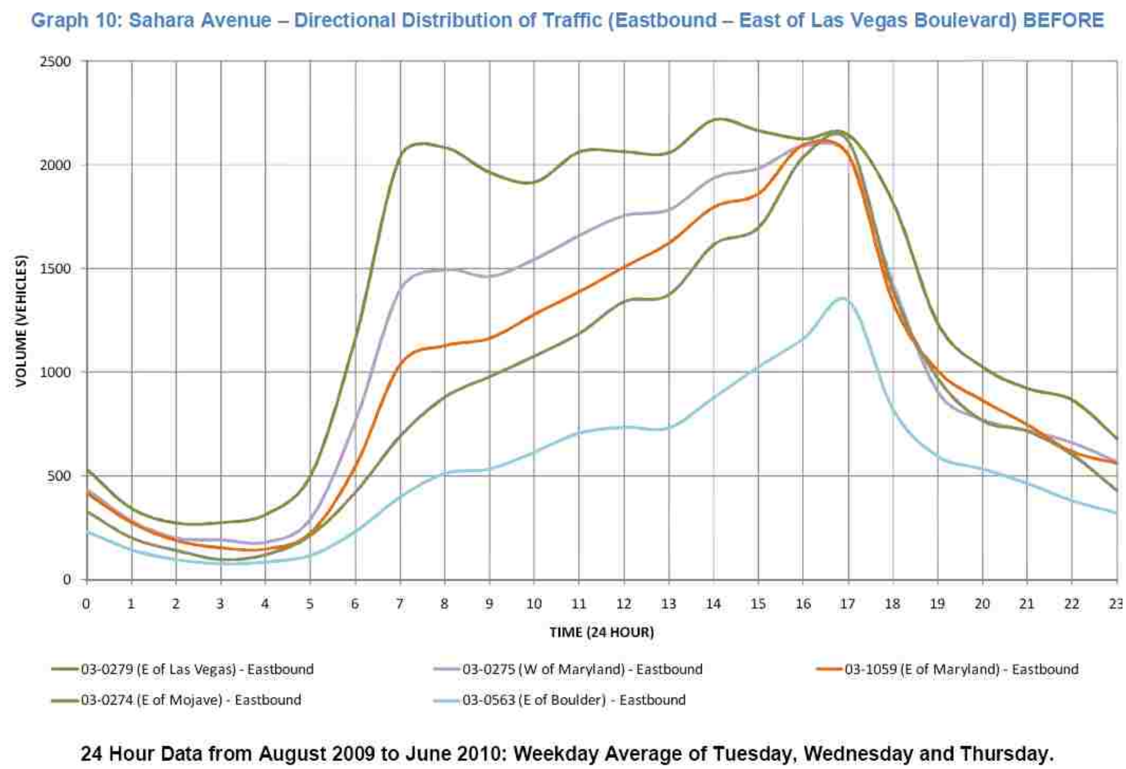


Figure 3-2. Close-up Plan Views Showing Types of Nearby Buildings (Google Map)



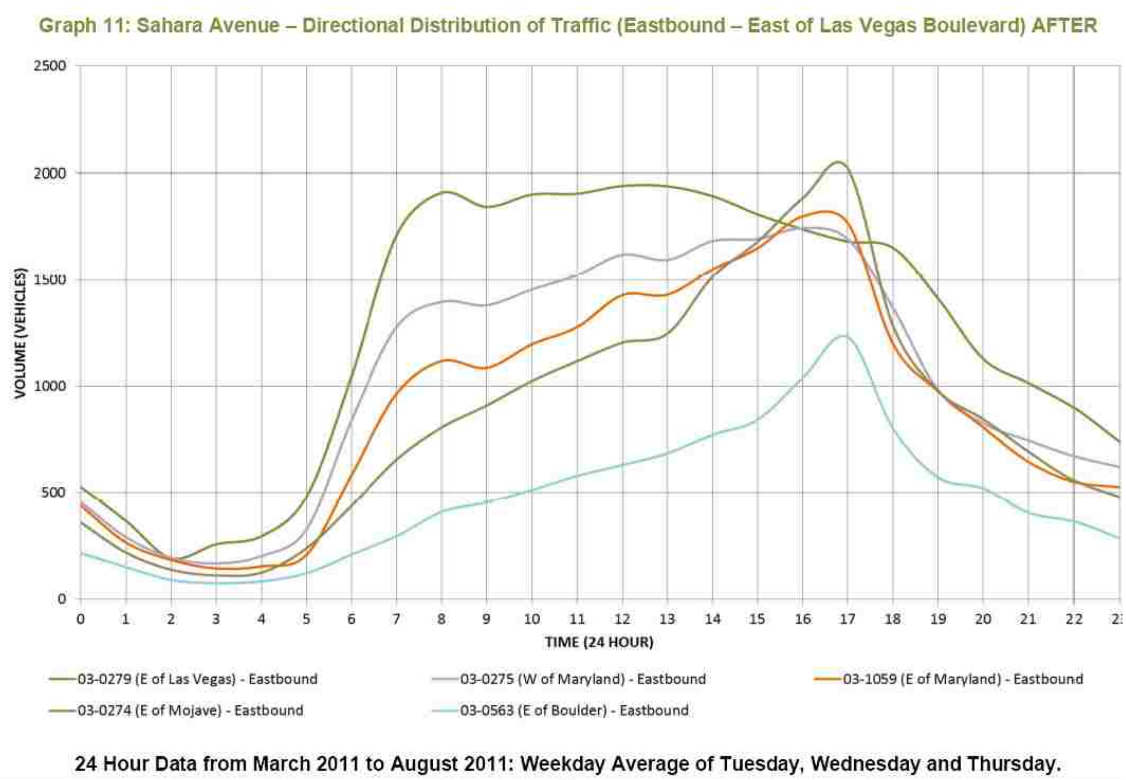
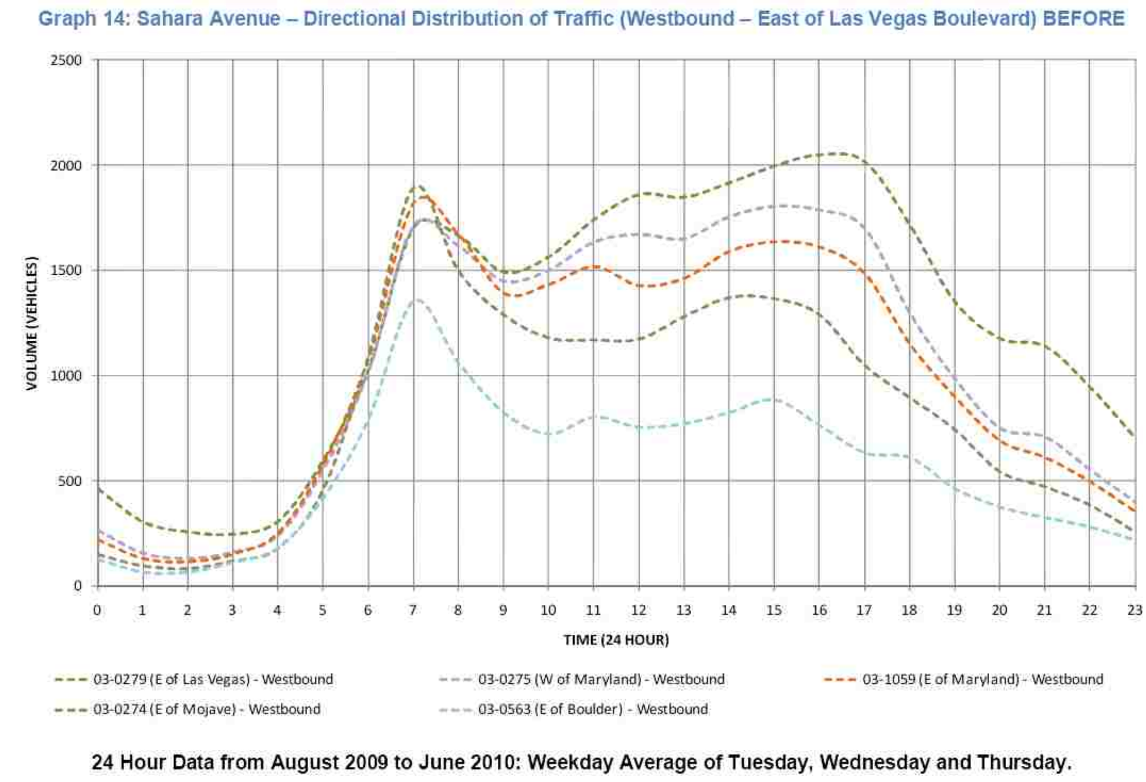


Figure 3-3. Hourly Eastbound Traffic Volumes along Sahara Ave. to the East and West of Maryland Parkway (RTC, 2013)



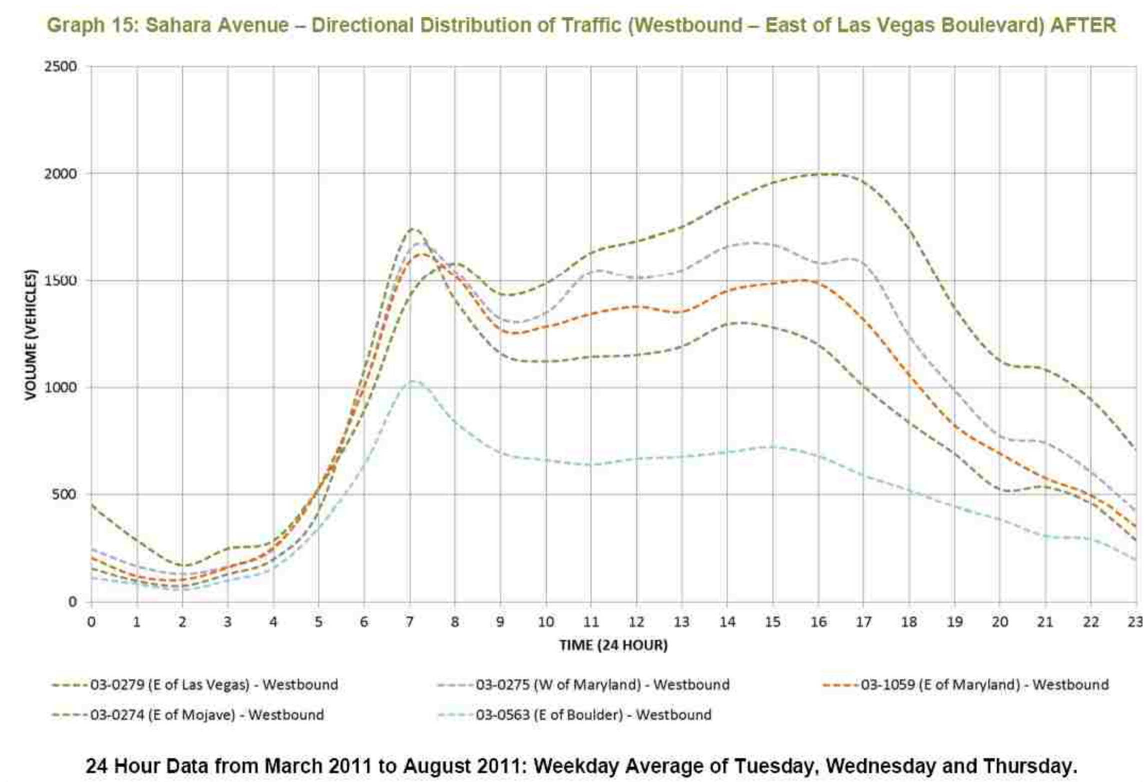


Figure 3-4. Hourly Westbound Traffic Volumes along Sahara Ave. to the East and West of Maryland Parkway (RTC, 2013)

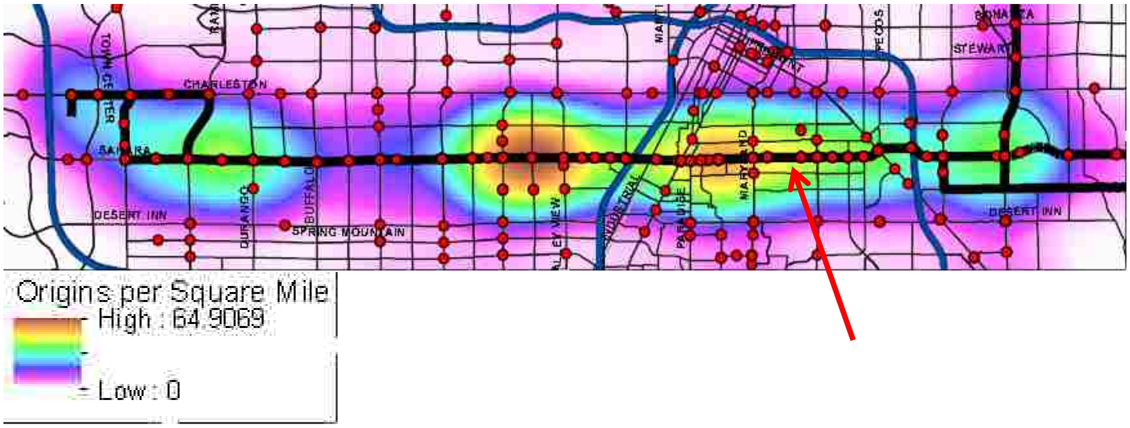


Figure 3-5. Bus Rider Origin Locations in 2012 (Origins per sq. mi.; RTC, 2013)

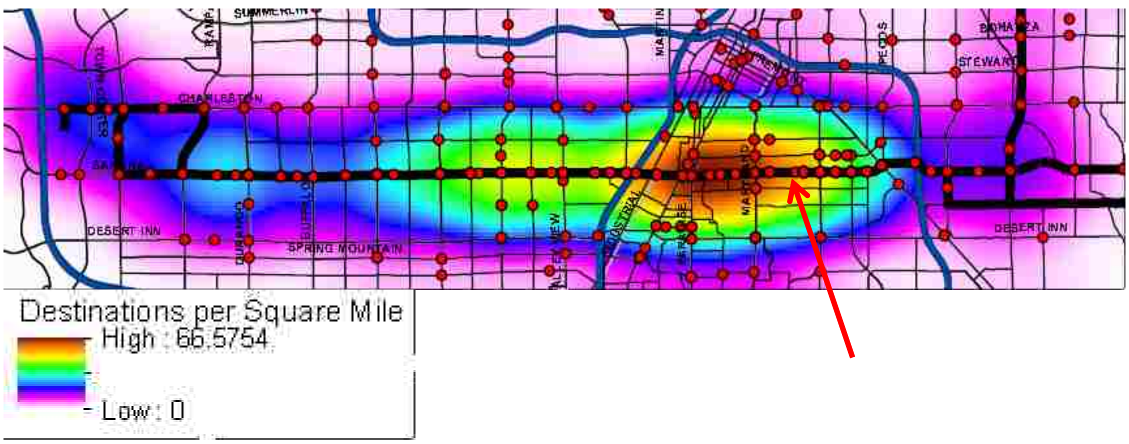


Figure 3-6. Bus Rider Destination Locations in 2012 (Destinations per sq. mi.; RTC, 2013)

Sahara Ave. at this PHB location is an eight-lane divided roadway with a posted speed limit of 45 mph; it has three vehicle lanes plus a bus lane in each direction. The curb-to-curb length of the crosswalk is 118 ft. and includes a refuge island in the middle of the street as shown in the Figures. The installed PHB system, including traffic signals, signage, crosswalk markings, pedestrian buttons and signals are shown in Figures 3-7 to 3-13.

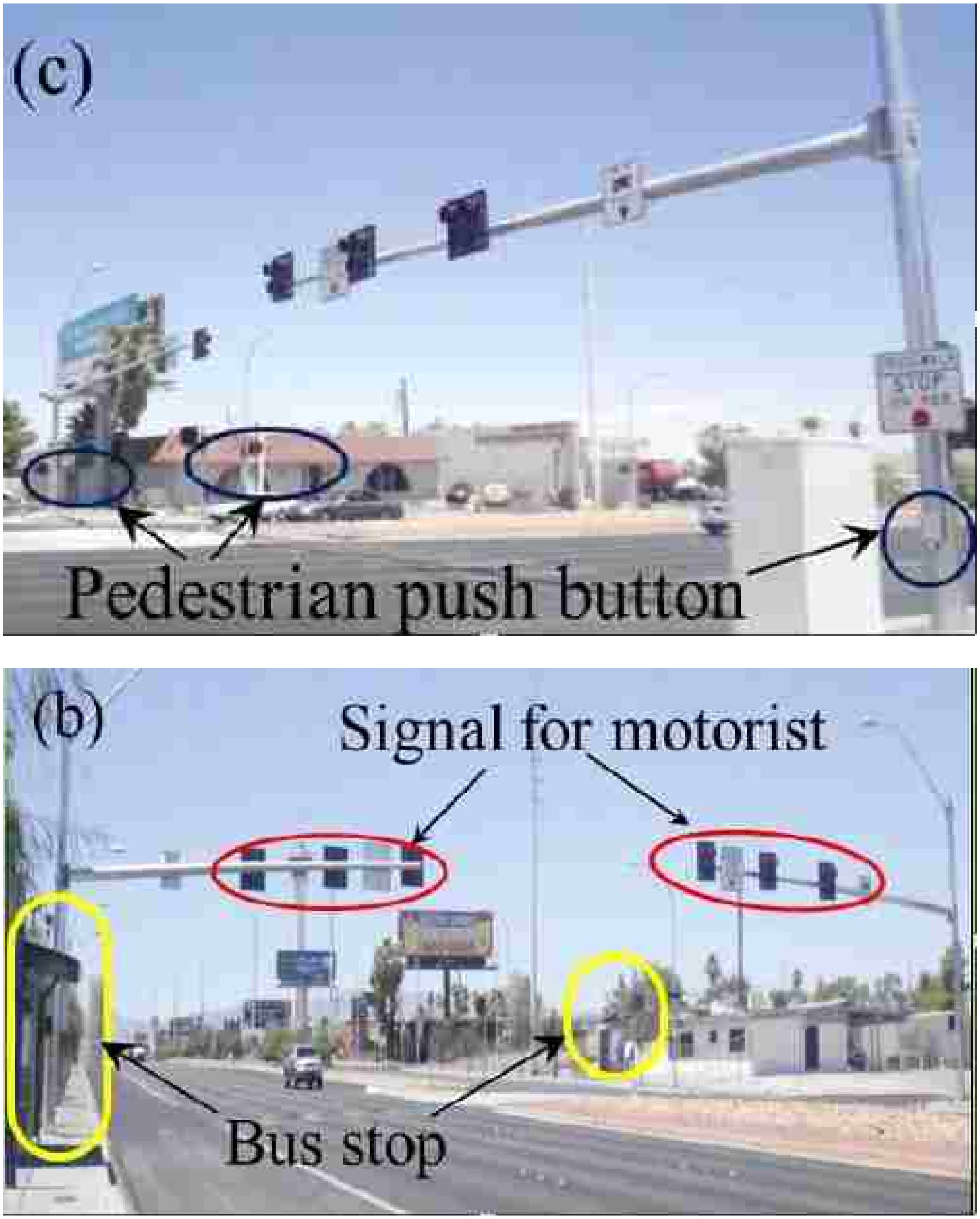


Figure 3-7. Location of PHB Pushbuttons and Traffic Signals (Khadka, Veeramisti, Paz, & Morris, 2013)

Figure 3-8. View of PHB System (Facing West on Sahara Ave., Google Map)

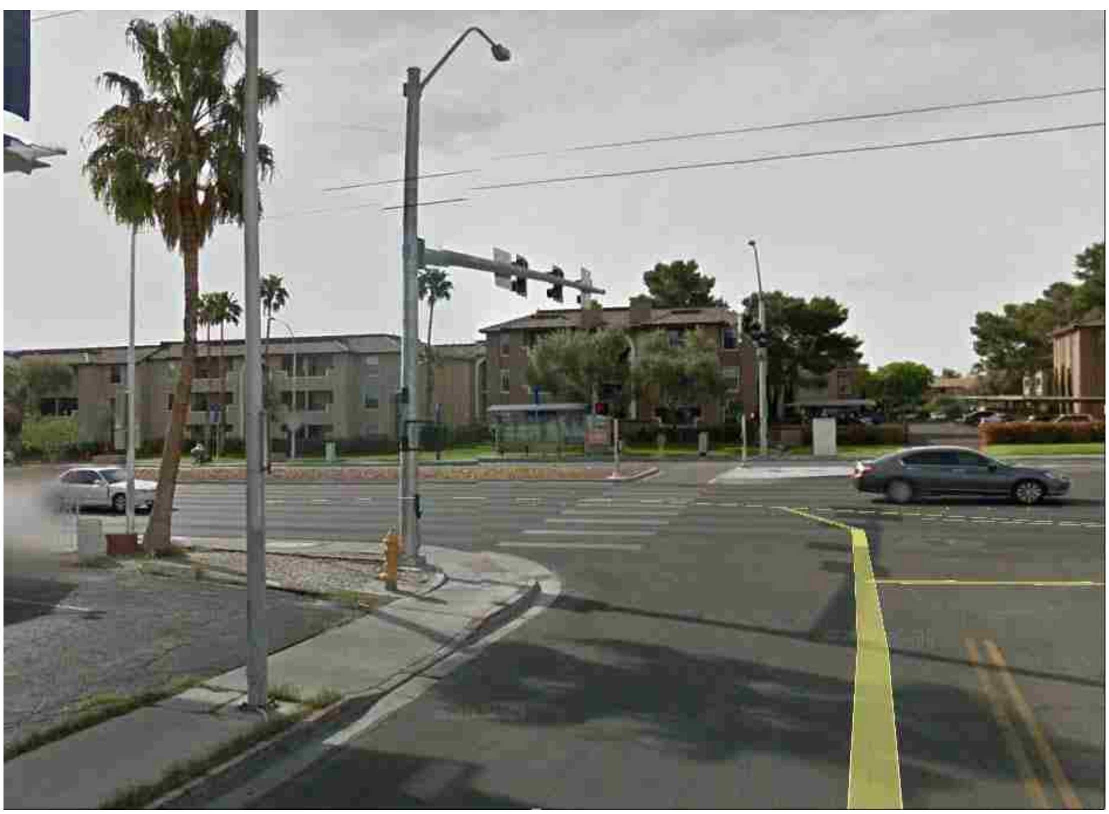


Figure 3-9. View of PHB System (Facing South on S. 15th St., Google Map)

Figure 3-10. View of PHB System (Facing North on S. 15th St., Google Map)

Figure 3-11. View of Activated PHB System (Facing East on Sahara Ave.)

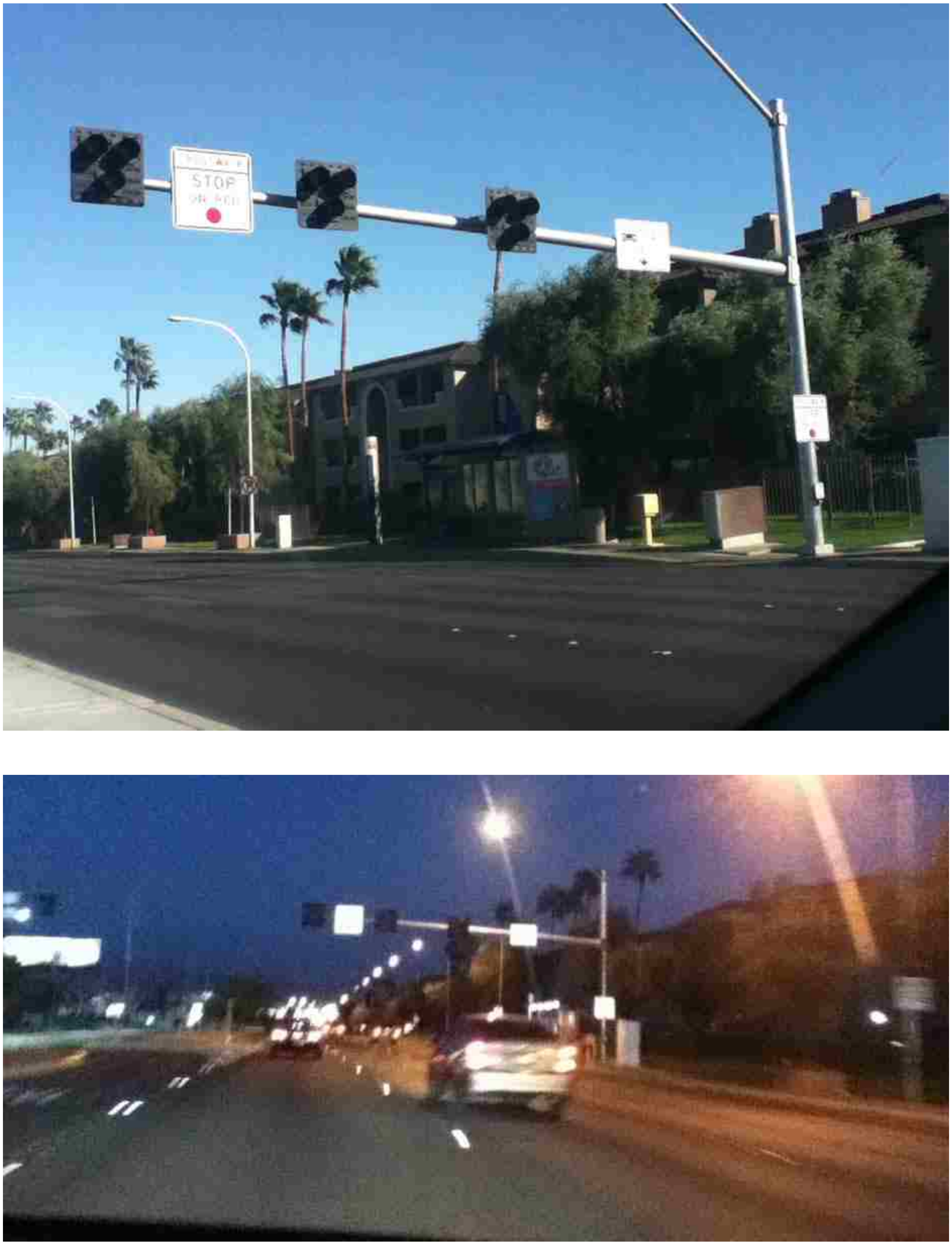


Figure 3-12. Views of PHB System in “Dark” Mode

Figure 3-13. View of Activated PHB System at Night

3.2 Preliminary Analysis of Khadka, Veeramisti, Paz, and Morris, 2013

This study evaluated the effectiveness of such a signal installed at E. Sahara Avenue, Las Vegas. Data was collected from videos captured by two cameras facing eastbound and westbound for two weeks; one week each for before and after operation of the signal. Statistical analyses (descriptive analysis and t-test) were performed considering different performance measures such as pedestrian waiting time at the curb. On average, jaywalking occurrences dropped significantly from 32.6% to 8.2% and the total crossing time decreased by 5.3 seconds. In addition, motorist compliance, yielding to pedestrians attempting to cross the street, improved with 6.9% fewer non-yielding vehicles. An outline of the study methodology is shown in Figure 3-14:

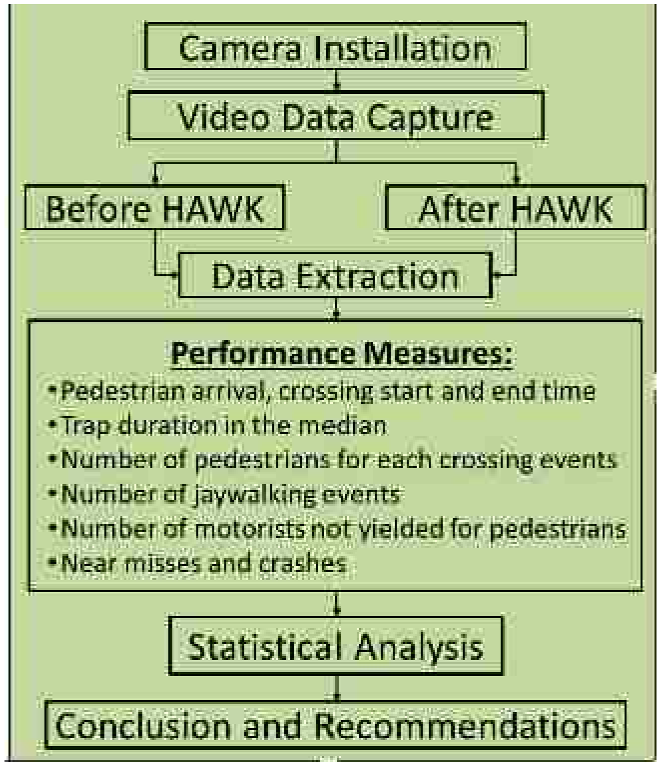
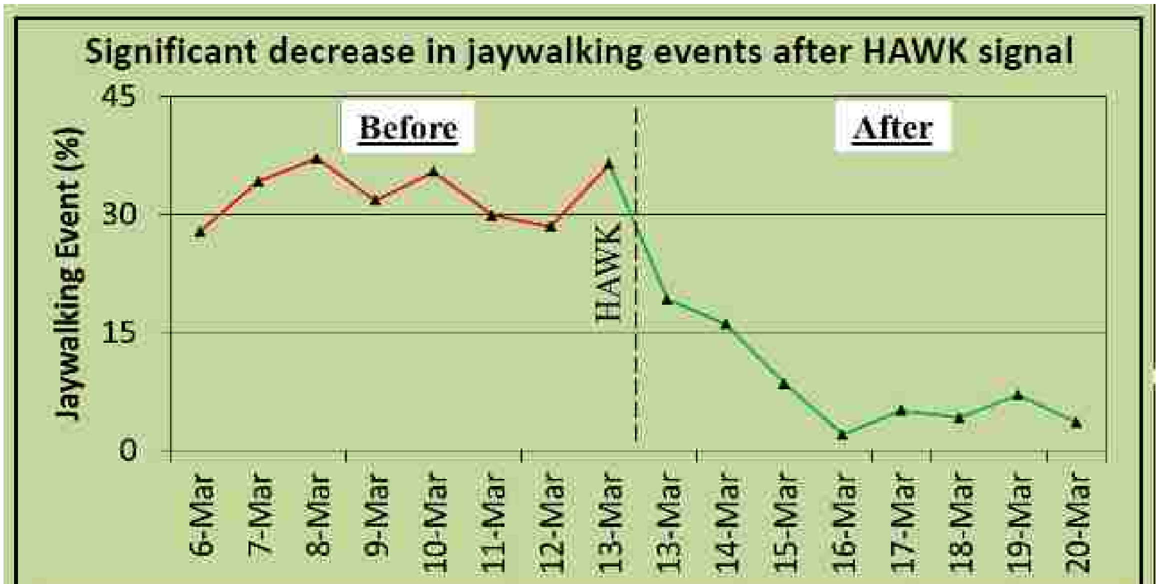


Figure 3-14. Effects on Compliance of a HAWK Signal in Las Vegas (Khadka et al., 2013)

Some of the Graphs from this preliminary study are shown in Figure 3-15; the pie chart shows that out of all near-miss/crash events, 92% occurred before HAWK installation, and 8% occurred before HAWK installation.

This study concluded that “jaywalking, near-misses/crash, total pedestrian crossing time, and average number of motorists not yielding to the pedestrians were significantly reduced after the HAWK signal installed at Sahara Avenue in Las Vegas, Nevada. Hence, the HAWK signal can be used effectively for safe and efficient pedestrian crossings.”



Description	Mean Before	Mean After	Decrease in %	t-value	p-value
Avg. % daily jaywalking events	32.6	8.2	24.4	9.6	<0.005

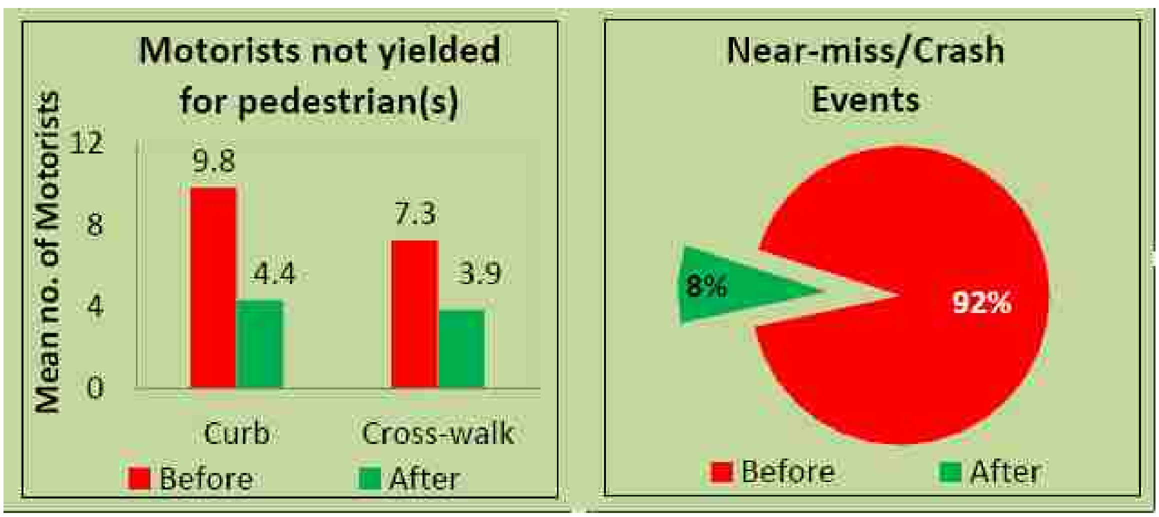


Figure 3-15. Graphs from Preliminary PHB Study (Khadka, et al., 2013)

CHAPTER 4

DATA COLLECTION AND METHODOLOGY

4.1 Outline of the Methodology Used in this Study

An outline of the methodology used in this study (adapted from Khadka et al., 2013) is shown in Figure 4-1.

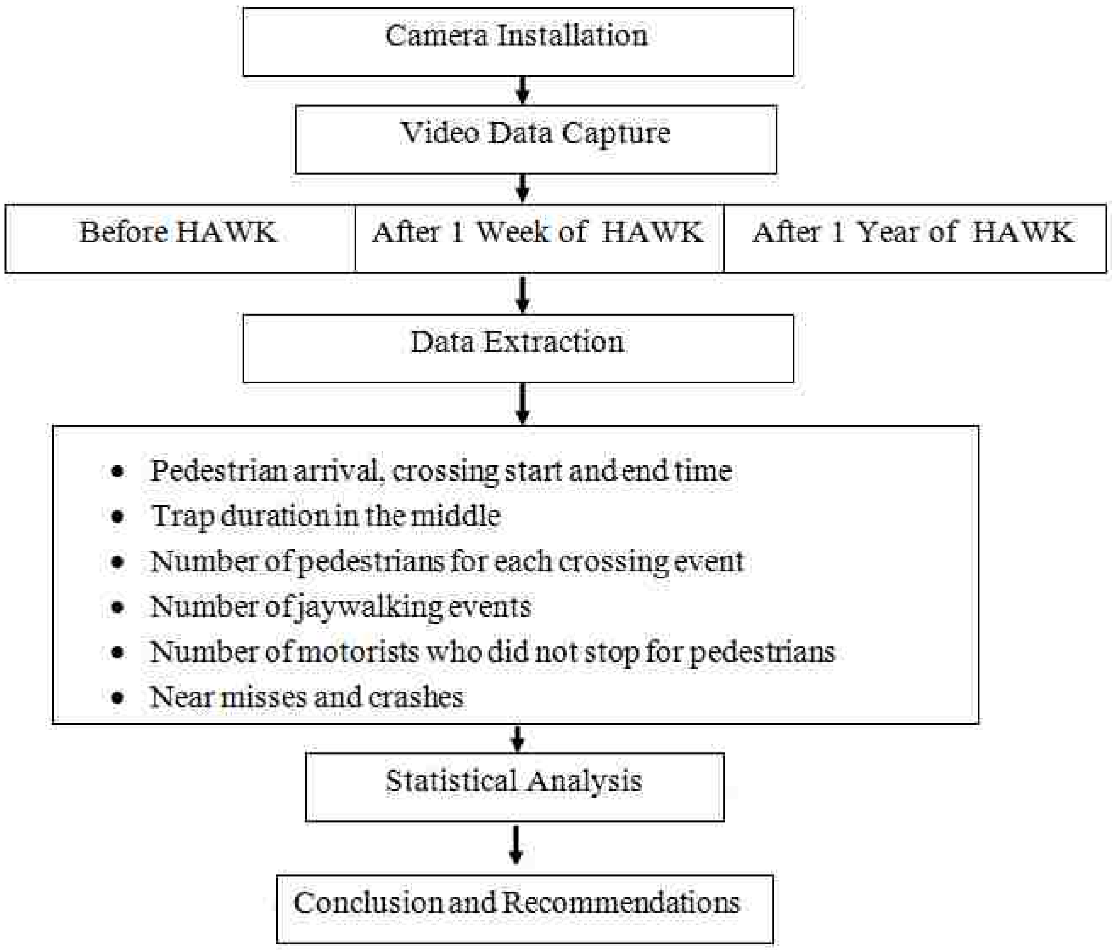


Figure 4-1. Outline of the Present Study of a HAWK Signal in Las Vegas (Adapted from Khadka et al, 2013)

4.2 Data Collection

The intersection data was collected using two cameras installed near the PHB. The traffic signal faces towards the eastbound and westbound sections of Sahara Avenue. These cameras were installed on Tuesday March 6, 2012 at 11 a.m. a week before the PHB signal was officially activated on Tuesday, March 13, 2012 at 10 a.m. The cameras operated continuously to observe pedestrian and motorist movements until 9:30 a.m. On March 20, 2012, with the exception of a few periods when memory cards were replaced. This enabled a full one week of before-and-after analysis of the PHB system. The video data was annotated to extract key pedestrian safety measures; the variables recorded along with their names used in the data files, are given below and in Table 4-1:

Date - date of observation

N_Ped - number of pedestrians in each observation event

Looking - event that a pedestrian looked for traffic

Pushed_button - event that a pedestrian pushed the button (after PHB installation)

Arrival_time - time of arrival of pedestrian(s) at the crosswalk

Start_time - the time at which the group of pedestrian begins to cross the street

Wait_time - the time a pedestrian has to wait for cars to stop

Veh_stop - the number of vehicles that stopped at the crosswalk

N_vehicles - total number of vehicles

Trapped_ped - the number of pedestrians trapped in the median for each event

End_time - the time at which pedestrian(s) reach the other side

Reqd_time - Time spent in crossing the street

Xing_time = Wait_time+ Reqd_time

Jaywalking - the number of jaywalking events for both directions (northbound and southbound); a jaywalking event occurs when a pedestrian walks on the street or crosses the street without following any traffic rules such as not walking on corners or footpaths, not crossing roads on cross walks or ignoring the traffic lights (ALM, 2014).

Table 4-1. Data Variable Names Used in Study

Before PHB	**After One Week of PHB**	**After One Year of PHB**
Date	Date	Date
N_Ped	N_Ped	N_Ped
Looking	Looking	Looking
----------	Pushed_button	Pushed_button
Arrival_time	Arrival_time	Arrival_time
Start_time	Start_time	Start_time
Wait_time	Wait_time	Wait_time
Veh_stop	Veh_stop	Veh_stop
N_vehicles	N_vehicles	N_vehicles
Trapped_ped	Trapped_ped	Trapped_ped
End_time	End_time	End_time
Reqd_time	Reqd_time	Reqd_time
Xing_time	Xing_time	Xing_time
Jaywalking	Jaywalking	Jaywalking
Comments	Comments	Comments

The variable 'Jaywalking' in the data files is the total distance covered in a Jaywalking event (measured in meters). This column was used to calculate the total number of jaywalking events, and all rows in the three data files corresponding to a jaywalking event were filtered out from further analyses. The 'Comments' column had information about whether the person was walking or cycling; all rows corresponding to cyclists were also removed.

The number of hours of video recording that we were able to transfer to data was not the same for each day in the three sampling events. There were a total of 8 partial days of data in each of 'Before Installation' and 'After One Week of Installation', and 4 partial days of data in 'After One Year of Installation'; the total number of hours for each sampling event are shown in Table 4-2.

Table 4-2. Number of Hours of Data for Each Day in the Three Sampling Events

Before PHB		After 1 Week of PHB		After 1 Week of PHB	
Date	N_Hours	Date	N_Hours	Date	N_Hours
3/6/2012	12.7	3/13/2012	14.31	4/27/2013	14
3/7/2012	22.98	3/14/2012	23.48	4/28/2013	15
3/8/2012	23.55	3/15/2012	23.3	4/29/2013	10
3/9/2012	23.69	3/16/2012	23.54	4/30/2013	3
3/10/2012	4.12	3/17/2012	23.47	Total	42
3/11/2012	23.72	3/18/2012	7.82		
3/12/2012	23.75	3/19/2012	13.9		
3/13/2012	9.29	3/20/2012	9.44		
Total	143.79	Total	139.27		

4.3 Data Analysis Methodology

Summarization of Waiting Times and Crossing Times

In order to assess the effectiveness of the PHB system, the distributions of two of the continuous variables in the collected data set will be compared across the three sampling periods:

Waiting Time = Wait_time = Start_time - Arrival_time

Crossing Time = Reqd_time = End_time - Start_time

In addition, the three sampling periods will also be compared in terms of the following five compliance variables:

Number of pedestrians using the crosswalk = N_Ped

Number of pedestrians at the crosswalk who look for traffic

Number of pedestrians at the crosswalk who pushed the button

The number of vehicles that stopped at the crosswalk = Veh_stop

Number of distractions during crossing

Box plots and histograms are used to summarize the continuous variables, and daily averages are calculated for the count variables using the following formula:

$$\bar{x} = 24 \times \frac{\text{Sum of the count variable}}{\text{Total number of hours}} \qquad \text{Eq. 1}$$

Comparison of Mean Waiting Times & Crossing Times for the Three Sampling Periods

The method of One-way of Variance (ANOVA) is used to compare the means of a continuous measurement (such as Waiting Time and Crossing Time) from more than two populations (see Appendix B, Walpole and Myers, 2011; Devore, 2011). The method of ANOVA has been used in many engineering applications (for example, Davim, Reis, & Antonio, 2004; Ross, 1998; Taguchi, 1993; Taguchi and Konishi, 1987). The means of Waiting Time and Crossing Time for data collected 'Before Installation', 'After One Week of Installation', and 'After One Year of Installation' are compared by one-way ANOVA, which tests the null hypothesis of equal means:

H_0: $\mu_{\text{Before}} = \mu_{\text{After 1 Week}} = \mu_{\text{After 1 Year}}$ vs. the alternative hypothesis

H_1: Not all the three means are equal, i.e., the null hypothesis is false

The method of one-way ANOVA (Walpole and Myers, 2011) is a model-based inference method, which requires that the response variable *Y* (Waiting Time or Crossing Time) can be expressed by the following linear model.

$$Y_{ij} = \mu + P_i + e_{ij} \qquad \text{Eq. 2}$$

where, i = 1 (before), 2 (after one week), and 3 (after one year)

j = 1, 2,… n_j (each individual observation),

μ are the population means of each group, and

e_{ij} are random errors (unexplained variation or residuals) that are assumed to be normally distributed with a common error variance σ^2 for each *i*.

The method of one-way ANOVA splits the total variability in the combined sample from the three sampling events as:

$$\sum_{i=1}^{3}\sum_{j=1}^{n_i}(x_{ij} - \bar{x}_{..})^2 = \sum_{i=1}^{3}\sum_{j=1}^{n_i}(x_{ij} - \bar{x}_{i.})^2 + \sum_{i=1}^{3} n_i(\bar{x}_{i.} - \bar{x}_{..})^2$$

where n_i is the number of observations in the sampling event i, $i = 1, \ldots, 3$,

$$\bar{x}_{..} = \frac{\sum_{i=1}^{3}\sum_{j=1}^{n_i} x_{ij}}{N} = \text{grand mean}, \; N = \sum_{j=1}^{n_i} n_i, \text{ and } \bar{x}_{i.} = \frac{\sum_{j=1}^{n_i} x_{ij}}{n_i} = \text{ mean for the sampling}$$

event i, i = 1, 2,… 3, …

The left-hand term of the above equation is called the Total Sum of Squares (TSS), the first term on the right-hand side is the Error Sum of Squares (SSE) and the second term on the right-hand side is called the Treatment Sum of Squares (SS Treatment). The null hypothesis of equal means is rejected for large values of the F-ratio calculated from:

$$F_{obs} = \frac{\text{SS Treatment}/(3\text{-}1)}{\text{SSE}/(\text{N-}3)}.$$

In case the null hypothesis of equal means is rejected, a multiple comparison method is used to test for pair-wise differences. If the probability distribution of the residuals turns out to be non-normal, the non-parametric ANOVA procedure of Kruskal-Wallis is used to compare the medians of the distributions, and the pair-wise Wilcoxon rank-sum test is used for post-hoc analyses (Devore, 2011). An alternative to comparing the means or the medians via ANOVA is the Kolmogorov-Smirnov test (Thas, 2011) which compares the probability distributions of the variables of test.

Comparison of Probability Distributions of Waiting Times and Crossing Times for the Three Sampling Periods

The probability distributions of waiting times and crossing times for data collected 'Before Installation', 'After One Week of Installation', and 'After One Year of Installation' are compared by the Kolmogorov-Smirnov test (Thas 2011). Here, the null hypothesis of identical distributions

$H_0 : F_1(y) = F_2(y)$ for all y values

is tested against the two-sided alternative hypothesis

$H_0 : F_1(y) \neq F_2(y)$.

The population distribution functions $F_i(x)$ are estimated by the sample distribution functions or empirical distribution functions (ecdf). The K-S test computes the maximum distance D_{Max} between the two empirical distribution functions to theoretical cut-off levels; the null hypothesis of equal distributions is rejected if the observed value of D_{Max} exceeds the theoretical cut-off value. Figure 4-2 shows the ecdf's of Waiting Times for 'Before' and 'After 1 Week' sampling events to illustrate the K-S Test.

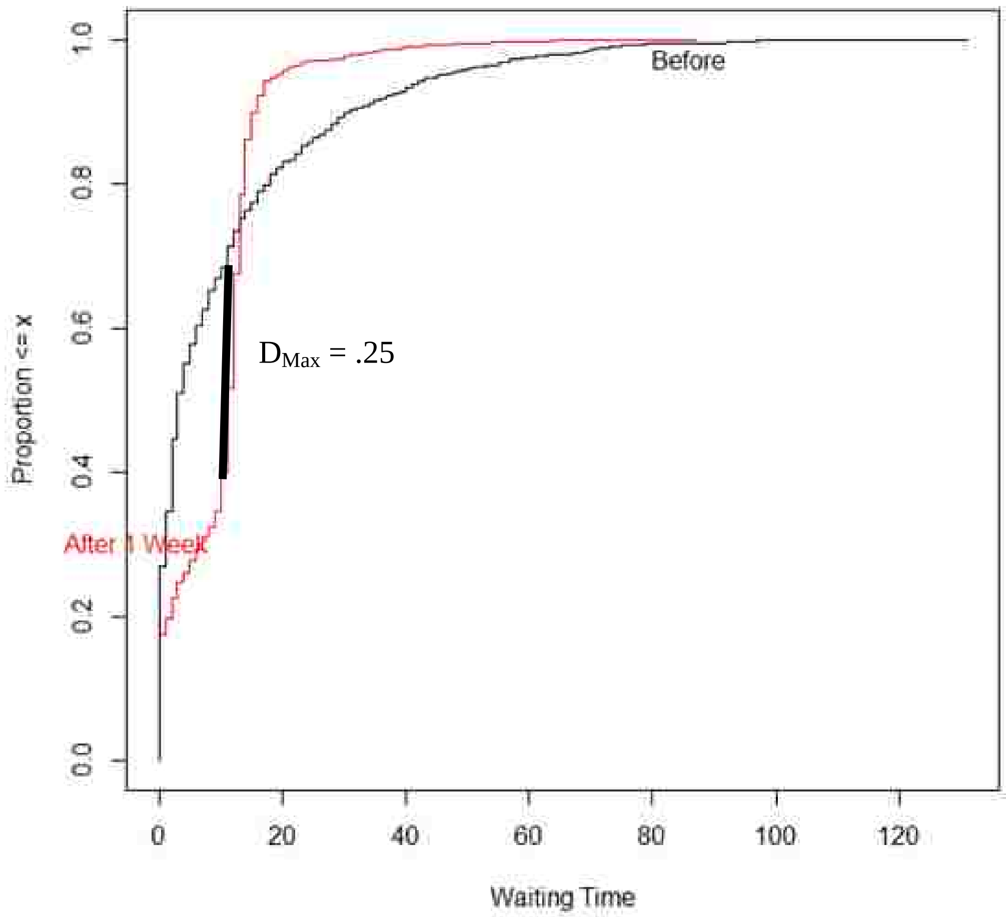


Figure 4-2. ecdf’s of Waiting Times for Before and After One Week (K-S Test)

CHAPTER 5

RESULTS OF DATA ANALYSIS

Summary of the Combined Data

The entire data set includes people using the crosswalk and jaywalkers, and both of these subsets consist of pedestrians and cyclists. Box plots (Figure 5-1). Histograms (Figures 5-2 and 5-3) of the entire data set along with descriptive statistics (Tables 5-1 and 5-2) are included to summarize the Waiting Time and Crossing Time in the combined data set.

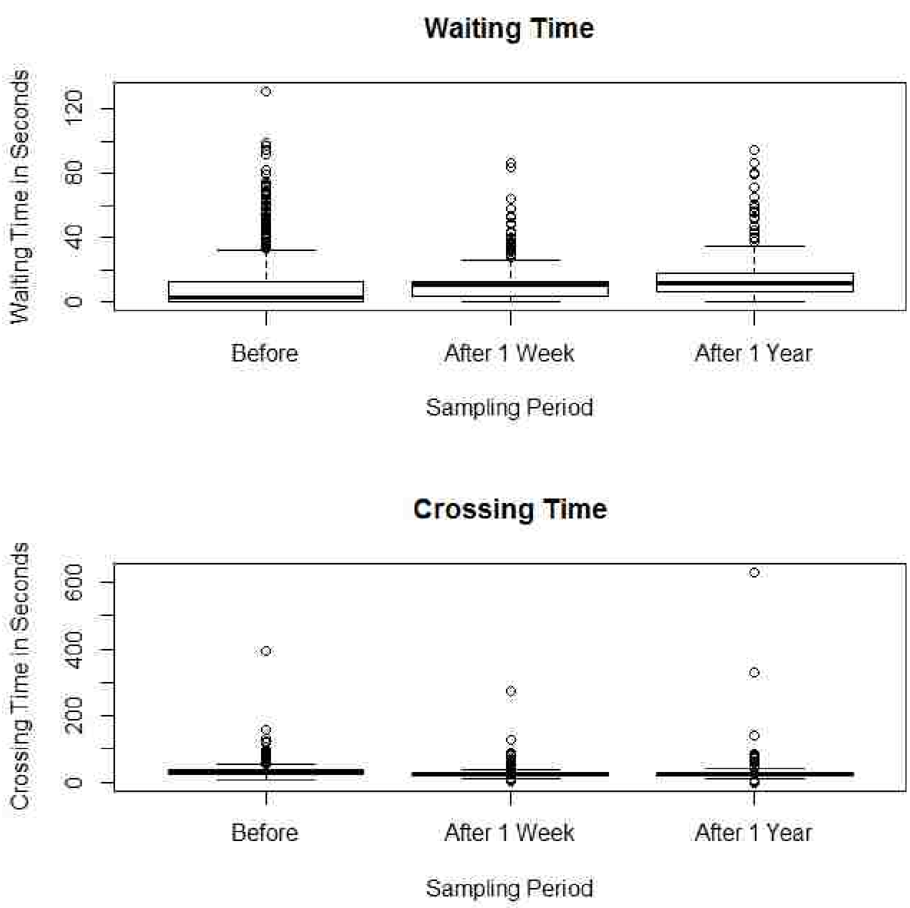


Figure 5-1. Box plots of Waiting Time and Crossing Time by Sampling Period for the Combined Data Set

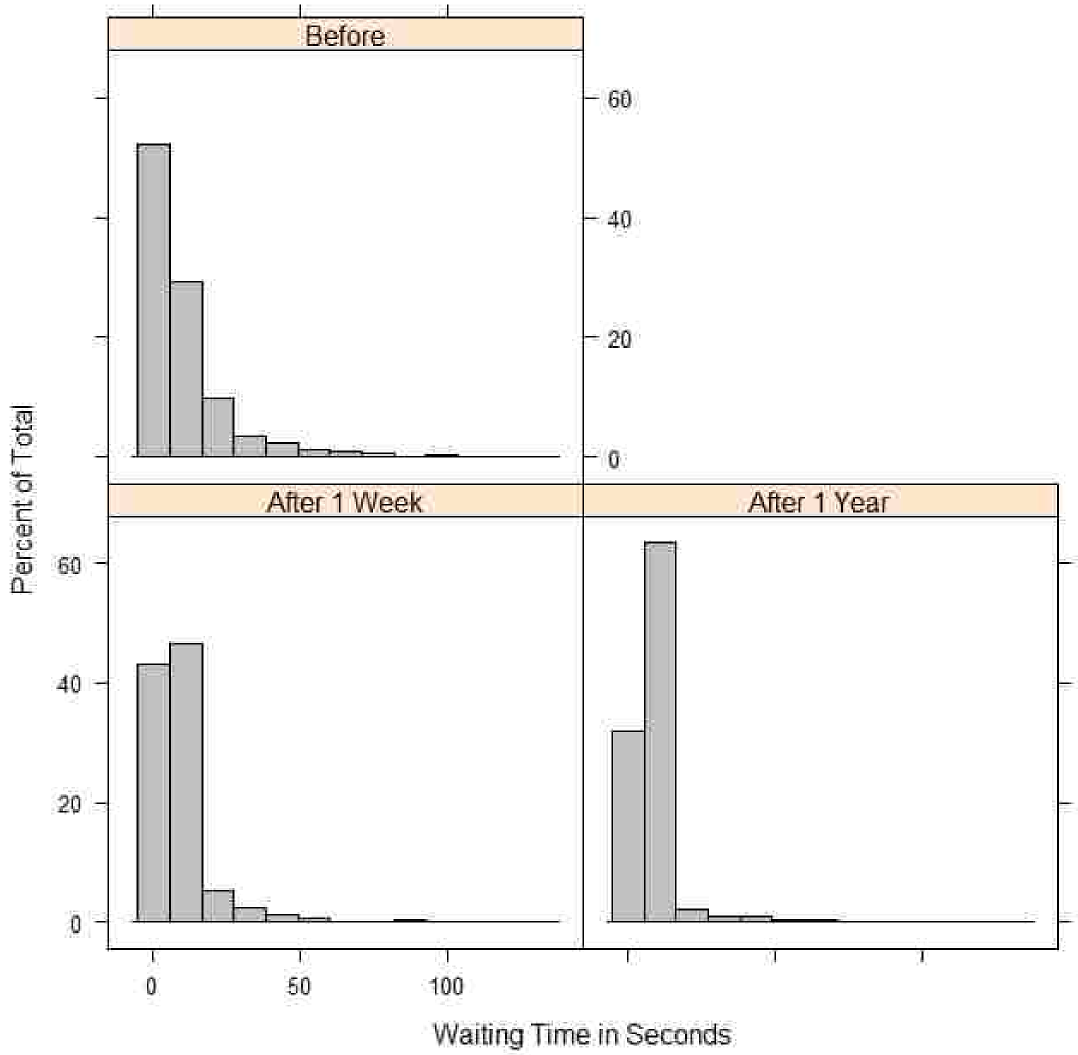


Figure 5-2. Histograms of Waiting Time by Sampling Period

Table 5-1. Descriptive Statistics of Waiting Times in Seconds for the Entire Data Set

	n	Mean	Median	sd	Min	Max
Before	1381	8.31	2	14.68	0	131
After 1 Week	1383	9.55	11	8.28	0	87
After 1 Year	321	15.3	12	15.15	0	95

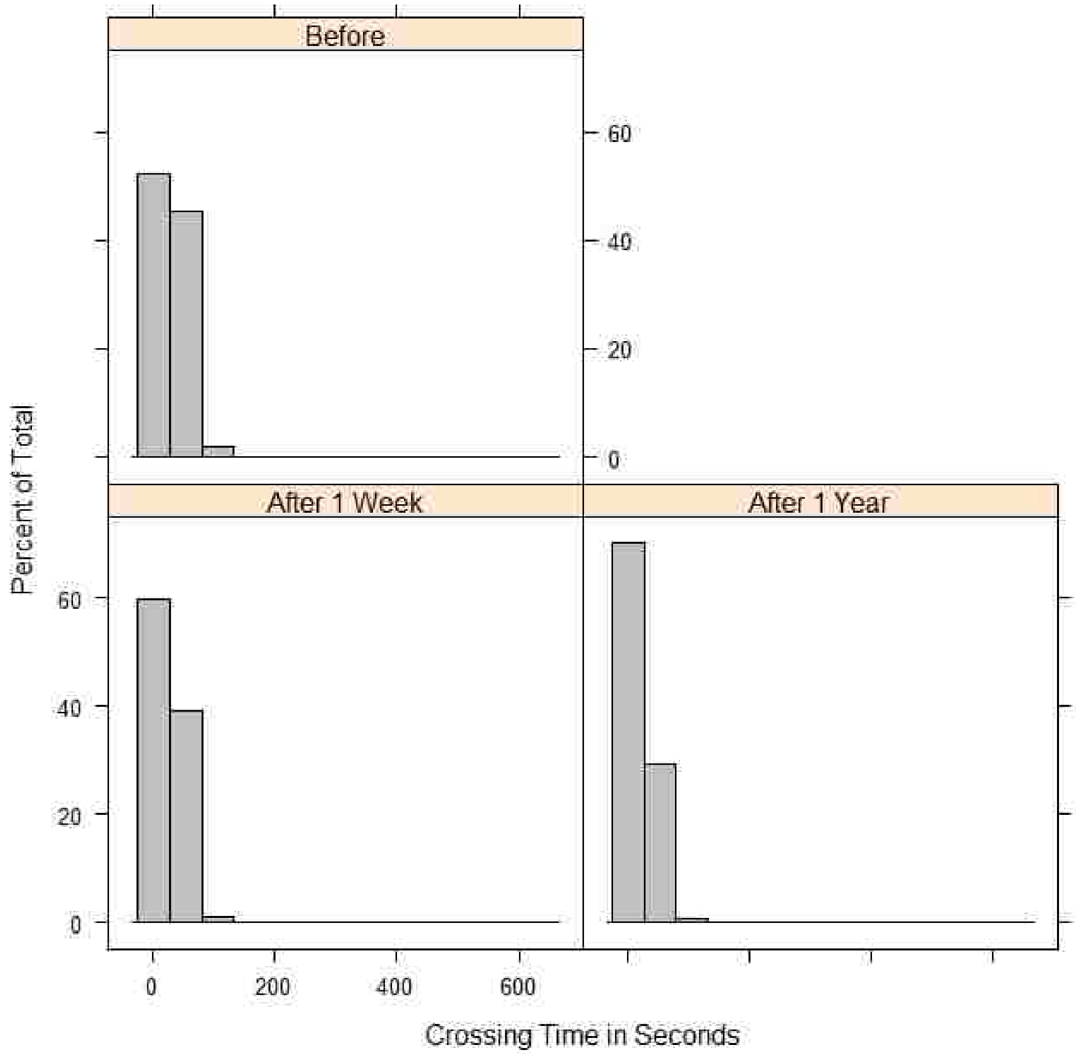


Figure 5-3. Histograms of Crossing Time by Sampling Period

Table 5-2. Descriptive Statistics of Crossing Times in Seconds

	n	Mean	Median	sd	Min	Max
Before	1381	33.65	29	21.01	0	395
After 1 Week	1383	26.42	25	11.98	5	273
After 1 Year	321	31.71	26	51.76	0	632

Total daily counts of the compliance measures tabulated in Tables 5-3 through 5-5 are plotted in line graphs in Figures 5-4 through 5-6, respectively. A decline in each of the compliance measure can be seen from these figures.

Table 5-3. Descriptive Statistics of Compliance Measures from Combined Data - Before PHB

Date	N_Hours	N_Ped	Looking	Trapped	Jaywalking	Veh_stop	N_Veh.
3/6/12	12.7	147	76	891	33	12	23
3/7/12	22.98	260	161	2163	68	32	28
3/8/12	23.55	334	226	1750	88	47	478
3/9/12	23.69	317	210	2400	70	38	400
3/10/12	4.12	34	27	89	3	5	22
3/11/12	23.72	238	188	950	58	17	124
3/12/12	23.75	306	231	2030	69	48	386
3/13/12	9.29	77	58	792	23	13	42
TOTAL	143.8	1713	1177	11065	412	212	1503
Hourly	mean	11.91	8.18	76.95	2.87	1.47	10.45
Daily	mean	285.90	196.44	1846.73	68.76	35.38	250.85

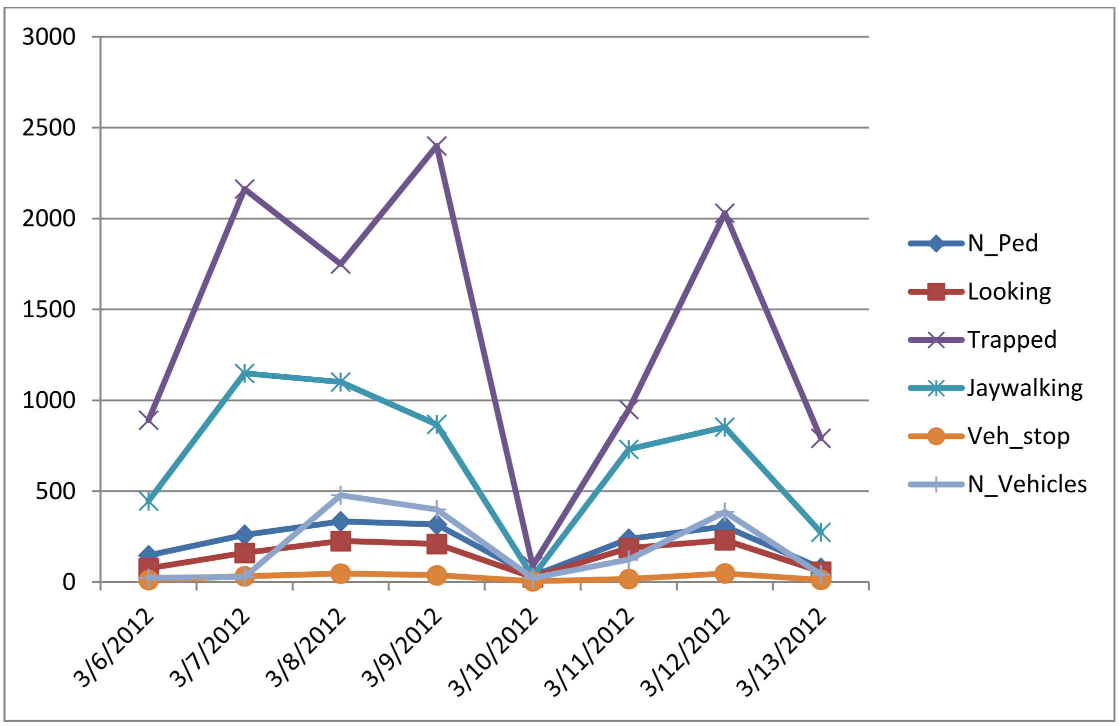


Figure 5-4. Line Graphs of Compliance Measures, Combined Data – Before

Table 5-4. Descriptive Statistics of Compliance Measures from Combined Data - After One Week of PHB

Date	N_Hours	N_Ped	Looking	Pushed	Trapped	Jaywalking	Veh_stop	N_Veh.
3/13/12	14.31	289	195	110	722	415	33	121
3/14/12	23.48	346	254	179	452	384	44	294
3/15/12	23.30	256	187	144	294	47	24	15
3/16/12	23.54	328	230	166	302	0	33	83
3/17/12	23.47	232	186	129	408	7	28	17
3/18/12	7.82	33	24	17	13	0	1	4
3/19/12	13.90	206	176	138	260	6	16	15
3/20/12	9.44	25	68	52	11	1	9	9
TOTAL	139.27	1715	1320	935	2462	860	188	558
Hourly mean		12.31	9.48	6.71	17.68	6.18	1.35	4.01
Daily mean		295.55	227.48	161.13	424.28	148.21	32.40	96.16

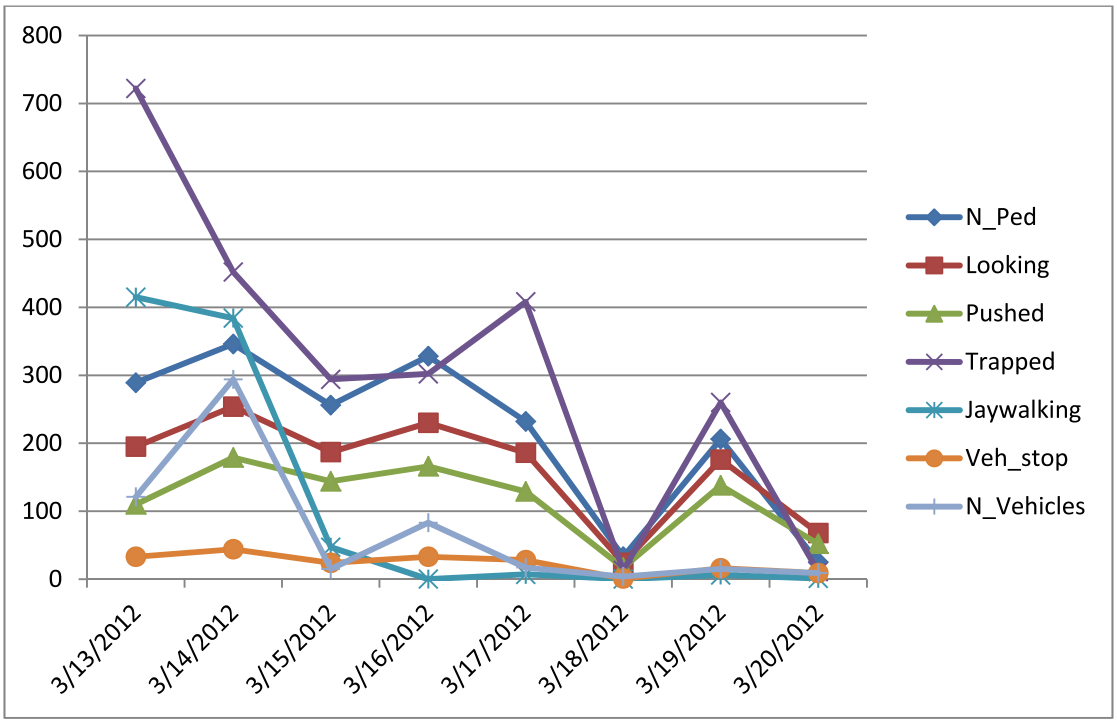


Figure 5-5. Line Graphs of Compliance Measures, Combined Data – After One Week

Table 5-5. Descriptive Statistics of Compliance Measures from Combined Data - After One Year of PHB

Date	N_Hours	N_Ped	Looking	Pushed	Trapped	Jaywalking	Veh_stop	N_Veh.
4/27/13	14	118	94	82	1	5	18	49
4/28/13	15	97	70	60	0	3	36	70
4/29/13	10	132	78	78	0	7	46	112
4/30/13	3	66	36	34	0	7	32	93
TOTAL	42	413	278	254	1	22	132	324
Hourly	mean	9.83	6.62	6.05	0.02	0.52	3.14	7.71
Daily	mean	236.00	158.86	145.14	0.57	12.57	75.43	185.14

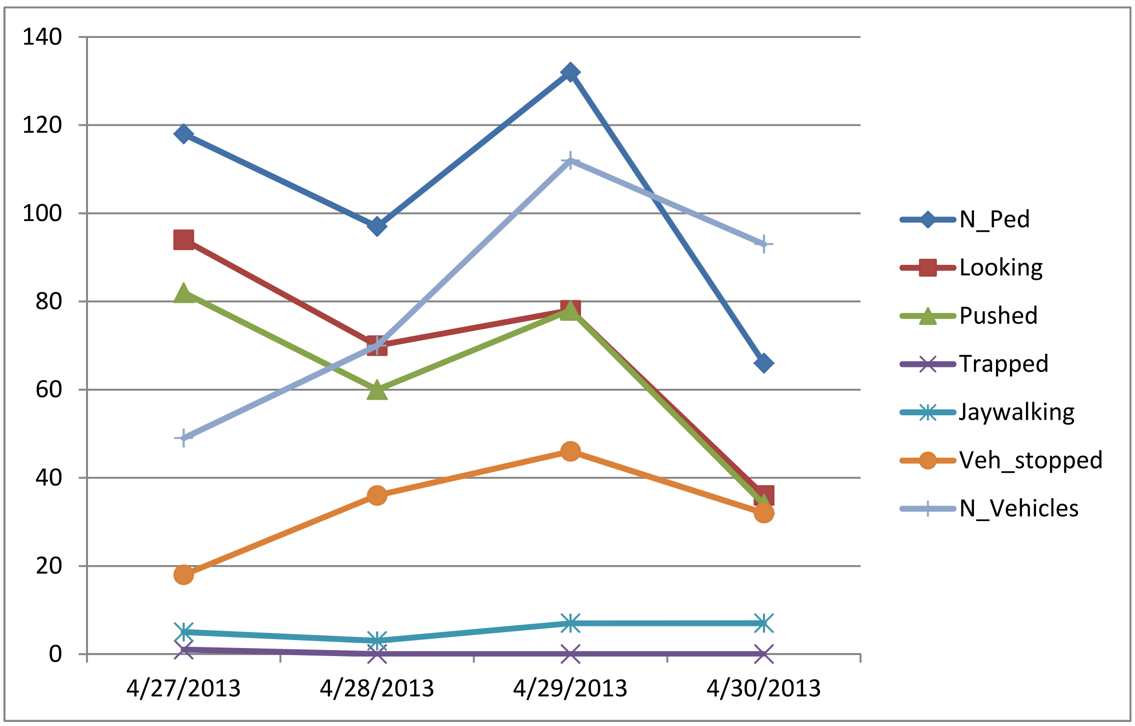


Figure 5-6. Line Graphs of Compliance Measures, Combined Data – After One Year

Analysis of Data for Pedestrians using the Crosswalk

We next present the results of statistical analysis for pedestrians using the crosswalk. The box-plots and histograms of Waiting Times and Crossing Times are shown in Figures 5-7 to 5-9, and the summary statistics are shown in Tables 5-6 and 5.7.

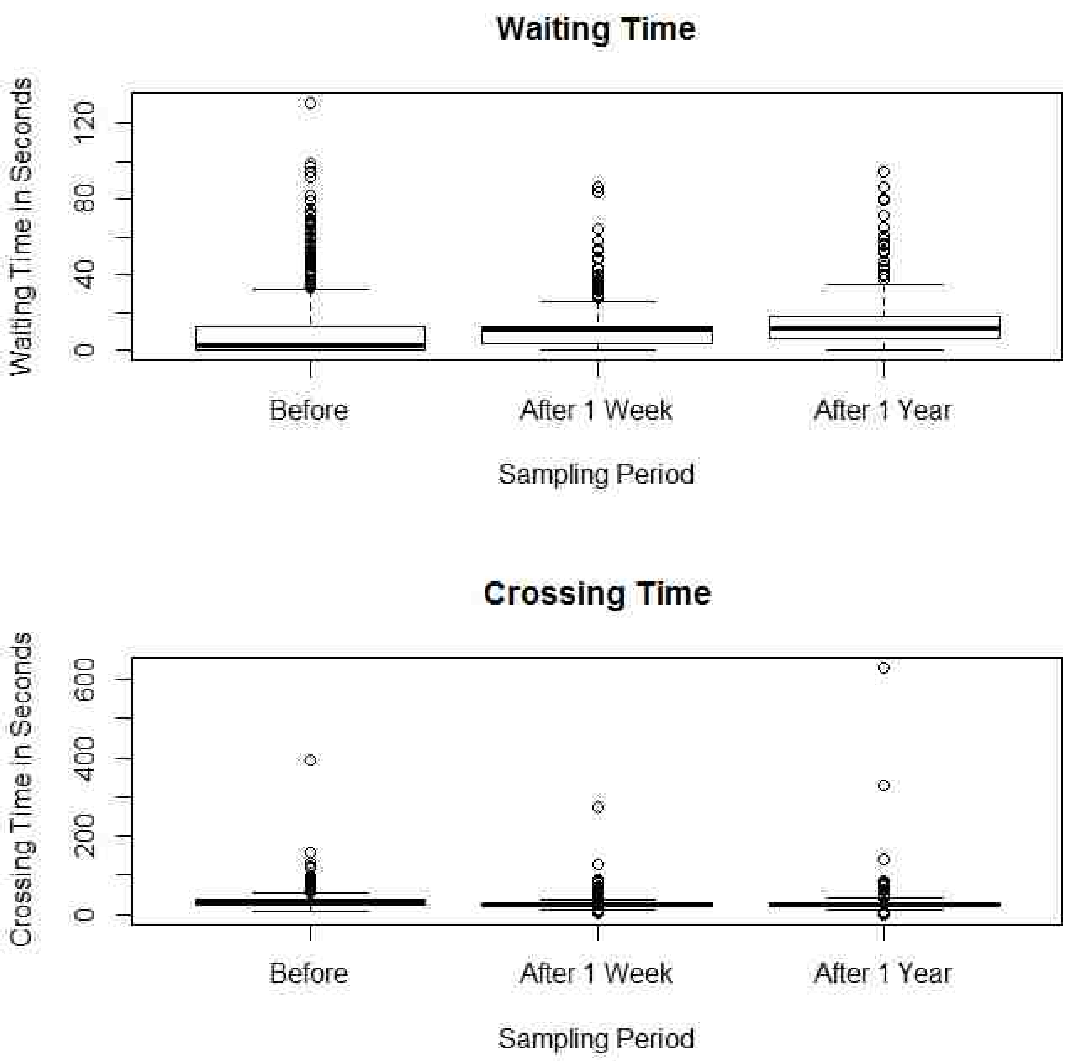


Figure 5-7. Boxplots of Waiting Time and Crossing Time by Sampling Period for Pedestrians Using the Crosswalk

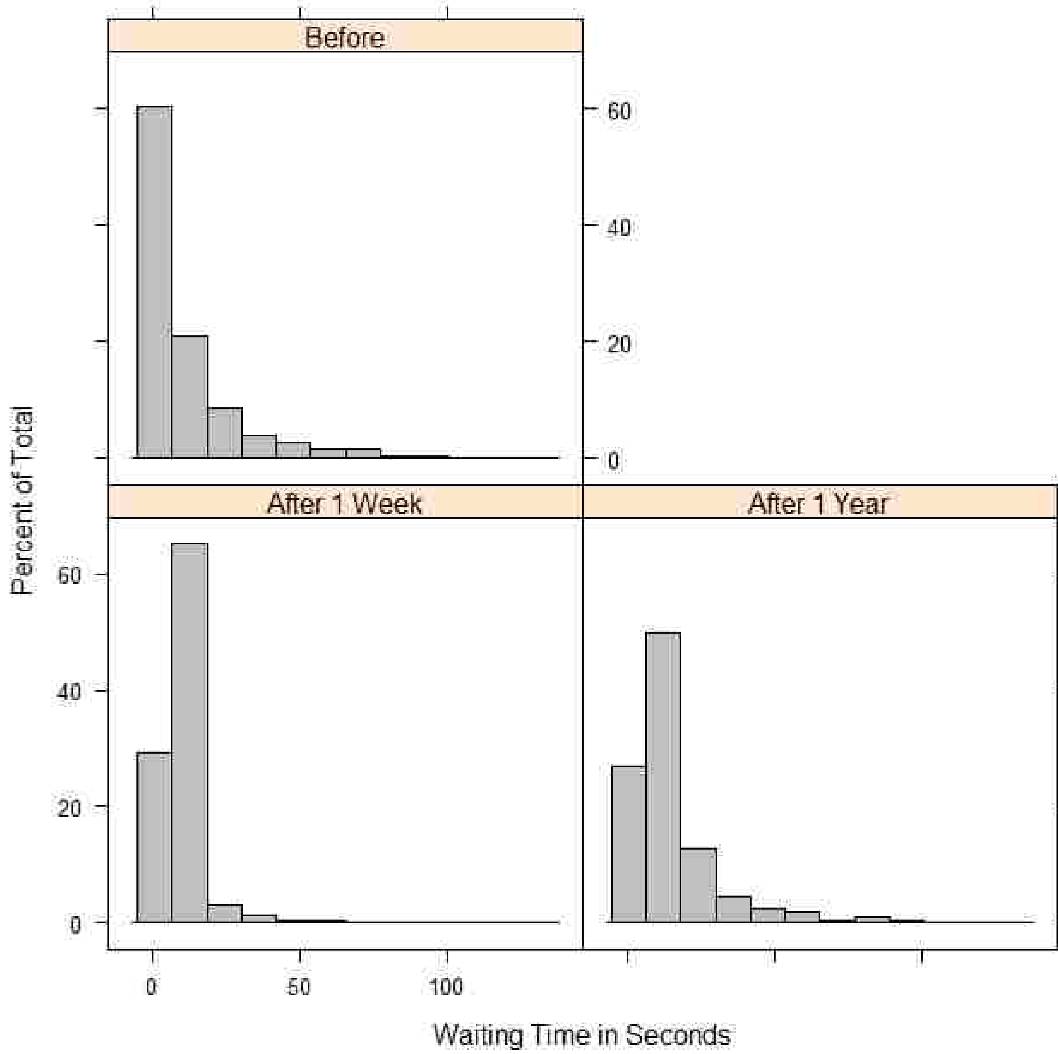


Figure 5-8. Histograms of Waiting Time by Sampling Period for Pedestrians Using the Crosswalk

Table 5-6. Descriptive Statistics of Waiting Times in Seconds for Pedestrians Using the Crosswalk

	n	Mean	Median	sd	Min	Max
Before	969	10.65	3	16.46	0	131
After 1 Week	1289	10.1	11	8.2	0	87
After 1 Year	301	15.01	12	14.66	0	95

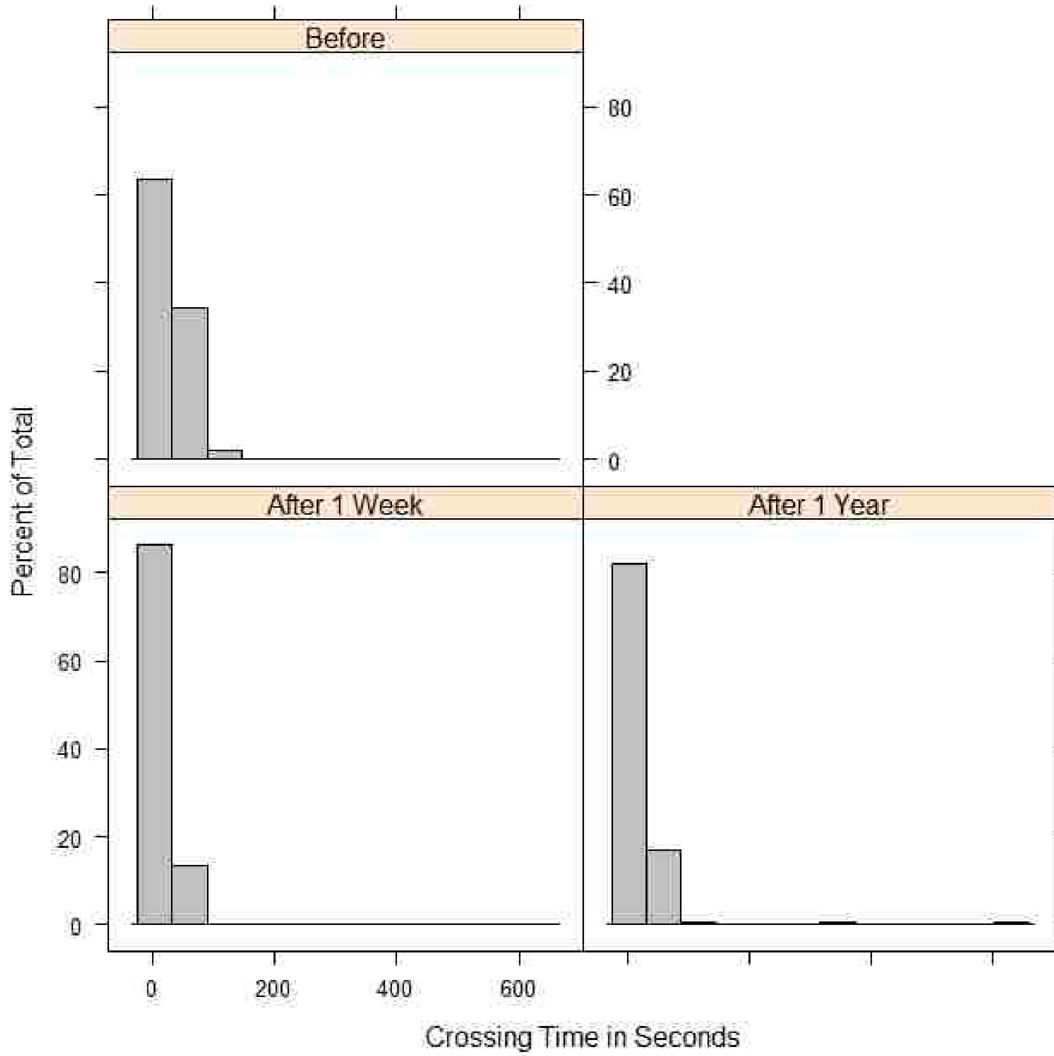


Figure 5-9. Histograms of Crossing Time by Sampling Period for Pedestrians Using the Crosswalk

Table 5-7. Descriptive Statistics of Crossing Times in Seconds for Pedestrians Using the Crosswalk

	Crossing Times in Seconds					
	n	**Mean**	**Median**	**sd**	**Min**	**Max**
Before	969	33.34	28	20.35	7	395
After 1 Week	1289	26.09	25	11.63	5	273
After 1 Year	301	29.99	26	40.85	0	632

Results of One-Way ANOVA for Waiting Times

The results of One-Way ANOVA for Waiting Times (Table 5-8) and Crossing Times (Table 5-9) are shown below. Since the P-values of the F-test are much smaller than 0.05, the null hypothesis of equal means is rejected for both of these variables.

Table 5-8. ANOVA Table for Waiting Times for Pedestrians Using the Crosswalk

	Df	Sum of Squares	Mean Squares	F	P-value
Sampling Period	2	5974	2986.8	18.46	0.00
Error	2556	413441	161.8		

Table 5-9. ANOVA Table for Crossing Times for Pedestrians Using the Crosswalk

	Df	Sum of Squares	Mean Squares	F	P-value
Sampling Period	2	29221	14610	34.71	0.00
Error	2556	1075819	421		

Tables 5-10 and 5-11 show the results of Tukey's HSD for post-hoc comparisons of mean Waiting Times and mean Crossing Times. The Bonferroni-adjusted P-value for Waiting Times show that the mean Waiting Times of 'Before' and 'After 1 Week' sampling events are equal, and that mean Waiting Times have significantly increased 'After 1 Week' and also 'After 1 Year' (Table 5-10). This is to be expected, since after the installation of PHB system, pedestrians have to wait for the lights to come on and traffic to stop.

The results for Crossing Times, however, are different - Crossing Time decreased by 7.25 seconds right after PHB system was installed, but this average gain in Crossing Time reduced to 3.34 seconds after one year (Table 5-11).

Table 5-10. Results of Tukey's HSD Post-hoc Tests for Waiting Times for Pedestrians Using the Crosswalk

	Difference	L95%	U95%	Adj P-value
After 1 Week - Before	-0.56	-1.83	0.71	0.56
After 1 Year - Before	4.36	2.39	6.32	0.00
After 1 Year - After 1 Week	4.91	3.00	6.82	0.00

Table 5-11. Results of Tukey's HSD Post-hoc Tests for Crossing Times for Pedestrians Using the Crosswalk

	Difference	L95%	U95%	Adj P-value
After 1 Week - Before	-7.25	-9.29	-5.20	0.00
After 1 Year - Before	-3.34	-6.52	-0.17	0.04
After 1 Year - After 1 Week	3.90	0.82	6.98	0.01

As mentioned earlier, one of the required assumptions for ANOVA is the normality of residuals or estimated error terms. Figure 5-10 shows a histogram and normal Q-Q plot for residuals for the Waiting Times, and Figure 5-11 shows the same for Crossing Times; non-normality of residuals can be seen from these two figures. The Shapiro-Wilk test of normality was used to confirm this result of non-normality of residuals for both of these variables. Since the P-values for Shapiro-Wilk Normality Test are much smaller than 0.05, normality of residuals is rejected for both of the ANOVA models.

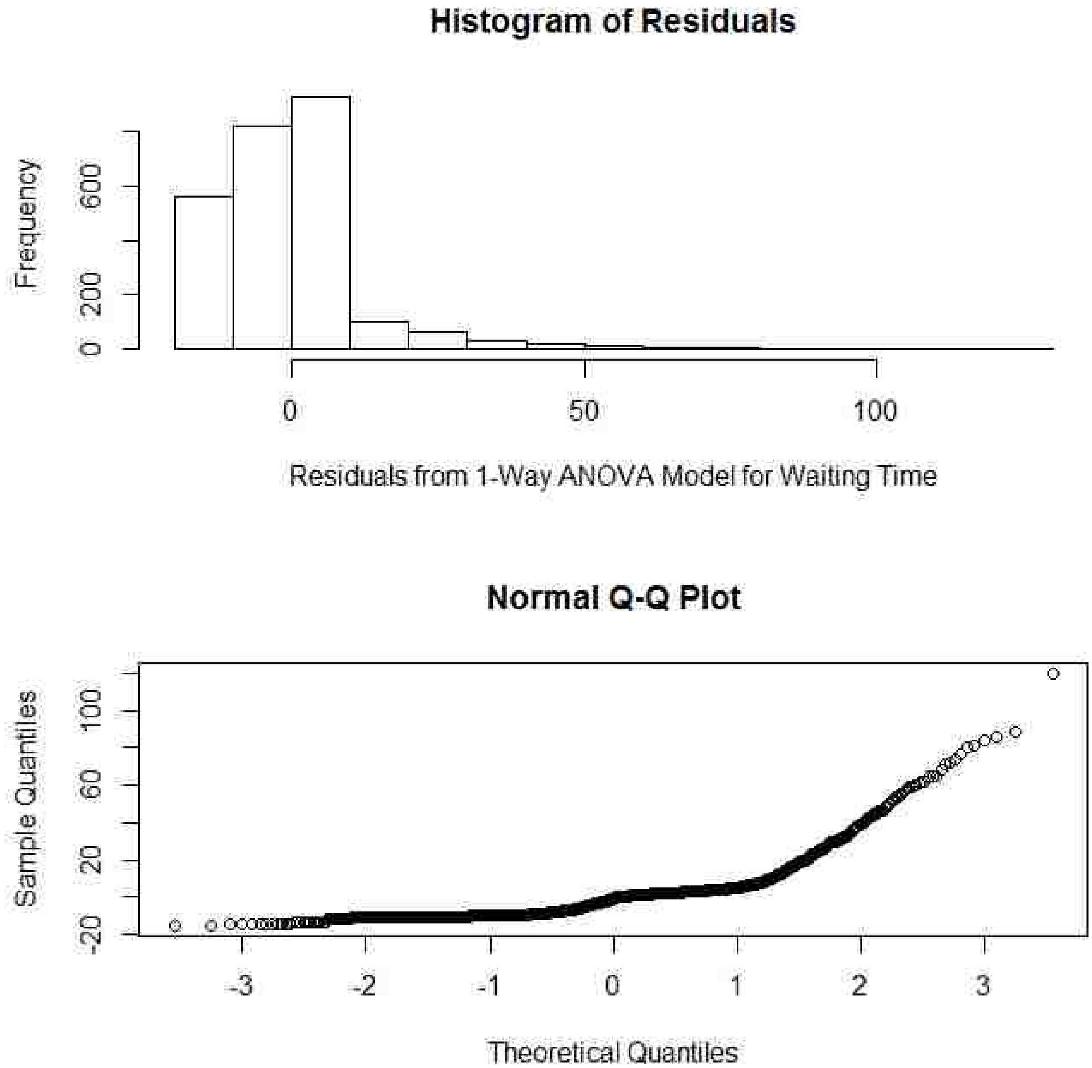
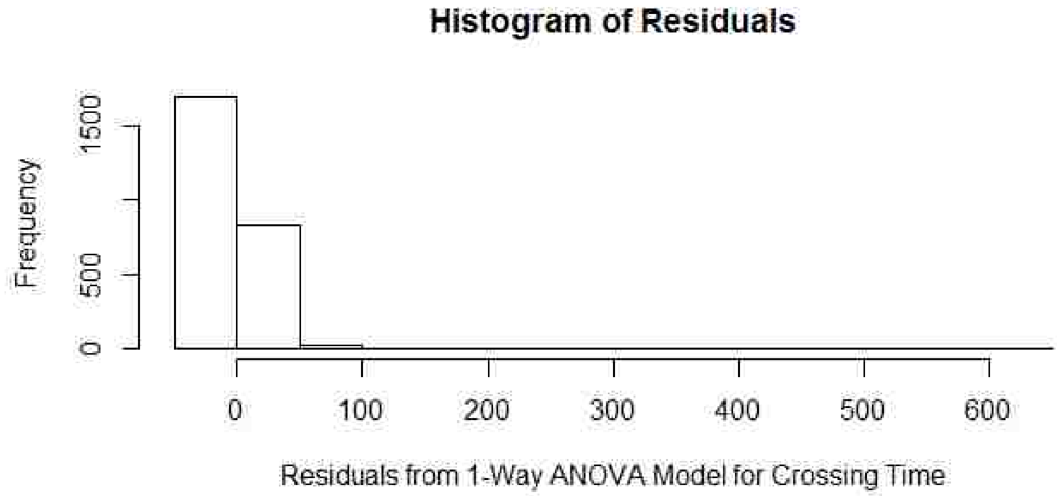


Figure 5-10. Histogram and Normal Quantile-Quantile Plot for Residuals from ANOVA Model for Waiting Time (Shapiro-Wilk Normality Test Statistic W = 0.73, P-value = 0.00)



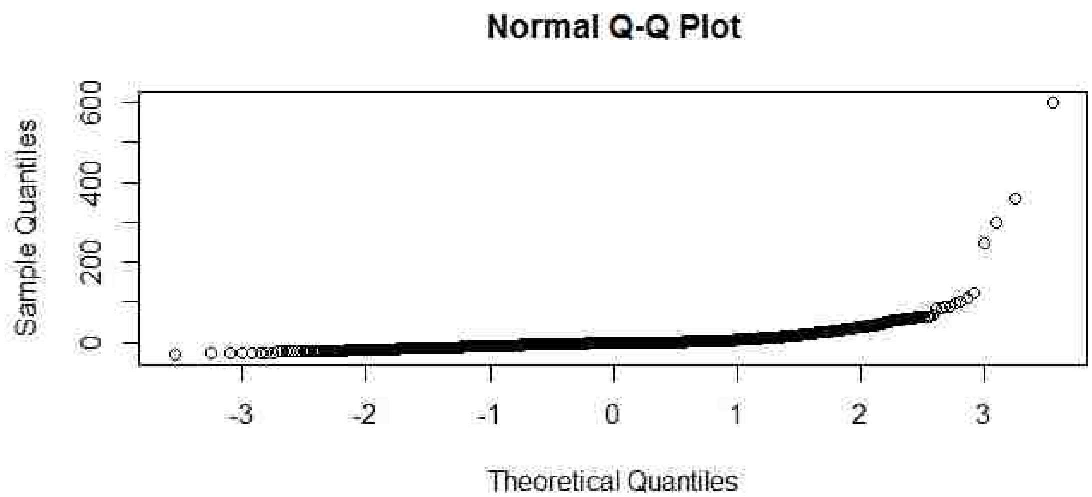


Figure 5-11. Histogram and Normal Quantile-Quantile Plot for Residuals from ANOVA Model for Crossing Time (Shapiro-Wilk Normality Test Statistic W = 0.42, P-value = 0.00)

Since the residuals from ANOVA models turned out to be non-normal, Kruskal-Wallis (KW) non-parametric ANOVA was used to compare the medians of Waiting Time and Crossing Time distributions for the three sampling periods. These results are shown in Table 5-12. Since the P-values are again much smaller than 0.05, the K-W test rejects the null hypothesis of equal medians.

Table 5-12. Results of KW ANOVA for Waiting Time and Crossing Time

Variable	df	Kruskal-Wallis chi-square	P-value
Waiting Times	2	121.50	0.00
Crossing Times	2	152.36	0.00

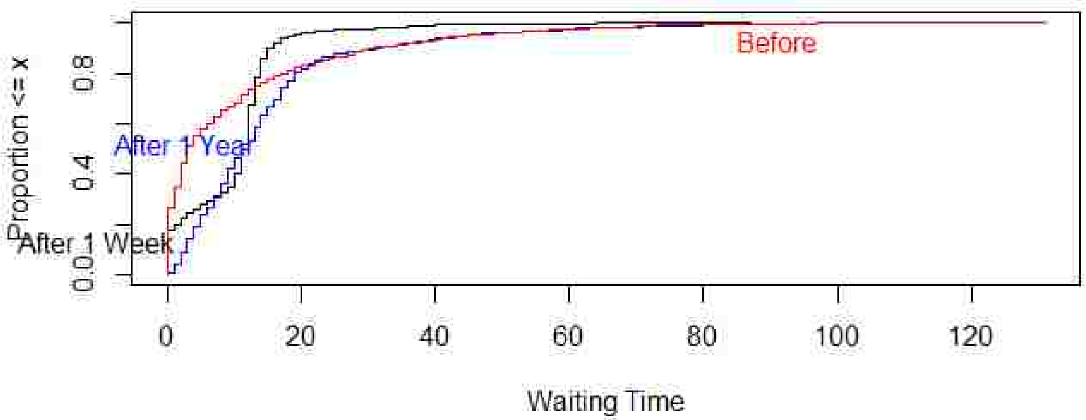
Since the K-W Test rejected the null hypothesis of equal medians, post-hoc analysis was done using Bonferroni adjusted Wilcoxon Rank-Sum Test. Table 5-13 shows the P-values.

Table 5-13. Bonferroni-Adjusted P-values of the Wilcoxon Rank-Sum Test

		After 1 Week	After 1 Year
Waiting Time	Before	0.00	0.00
	After 1 Year	0.00	
Crossing Time	Before	0.00	0.00
	After 1 Year	0.43	

The results from non-parametric ANOVA are consistent with the results from the classical One-Way ANOVA with one exception: Wilcoxon Rank-Sum Test did not detect a difference between the medians of Crossing Times for 'After 1 Week' and 'After 1 Year'.

The results of Kolmogorov-Smirnov test are next given. Figure 5-12 shows the empirical distribution functions (ecdf) of Waiting Times and Crossing Times for pedestrians using the crosswalk. Table 5-13 summarizes the results of the K-S test for pair-wise comparisons. It can be seen from Table 5-13 that, except for the distributions of Waiting Time for 'After 1 Week' and 'After 1 Year', all other distributions are statistically different.



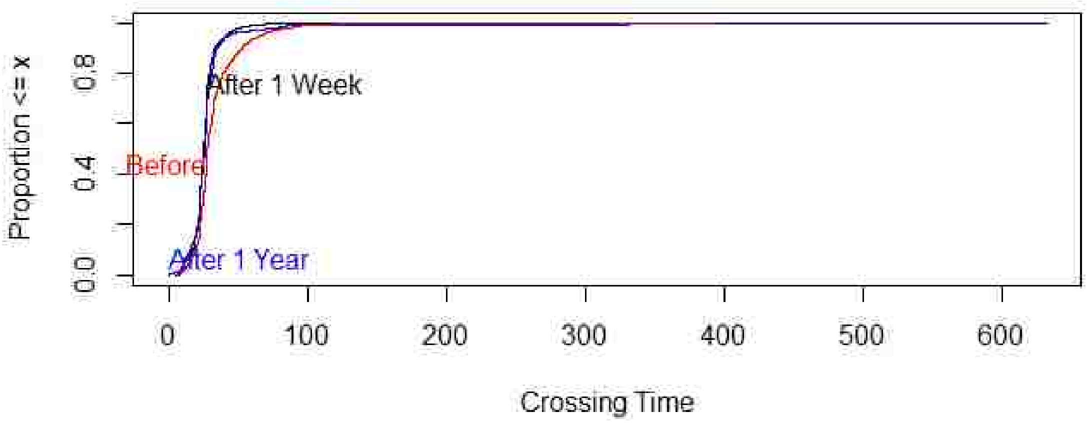


Figure 5-12. Ecdf's of Waiting Time and Walking Time for the Three Sampling Periods

Table 5-14. Results of the K-S Test for Pair-wise Comparisons

	Waiting Time		**Crossing Time**	
	D	**P-value**	**D**	**P-value**
Before Install	0.33	0.00	0.25	0.00
After 1 week	0.37	0.00	0.19	0.00
After 1 Year	0.23	0.00	0.08	0.12

Analysis of Count Data

In this section, the results for all compliance variables are reported. Table 5-15 shows daily averages of the compliance variables for pedestrians using the crosswalk, and Figure 5-13 shows these daily averages in a bar chart. Figure 5-13 shows that after PHB installation (i) the average number of pedestrians using the crosswalk has slightly increased, (ii) the number of pedestrians looking for traffic has decreased, (iii) the number of vehicles that stop has gone up, (iv) the number of distractions has continued to decrease, and (v) daily average number of jaywalking events has gone down.

Table 5-15. Daily Averages of the Compliance Variables for Pedestrians Using the Crosswalk

	N_Ped	Looking	Pushed	Vehicles stopped	Distractions	Jaywalking
Before	200.46	149.89	0.00	34.05	10.01	68.77
A1Wk	277.28	8.62	159.41	31.54	5.34	16.20
A1Yr	224.00	10.29	134.86	72.00	0.57	11.43

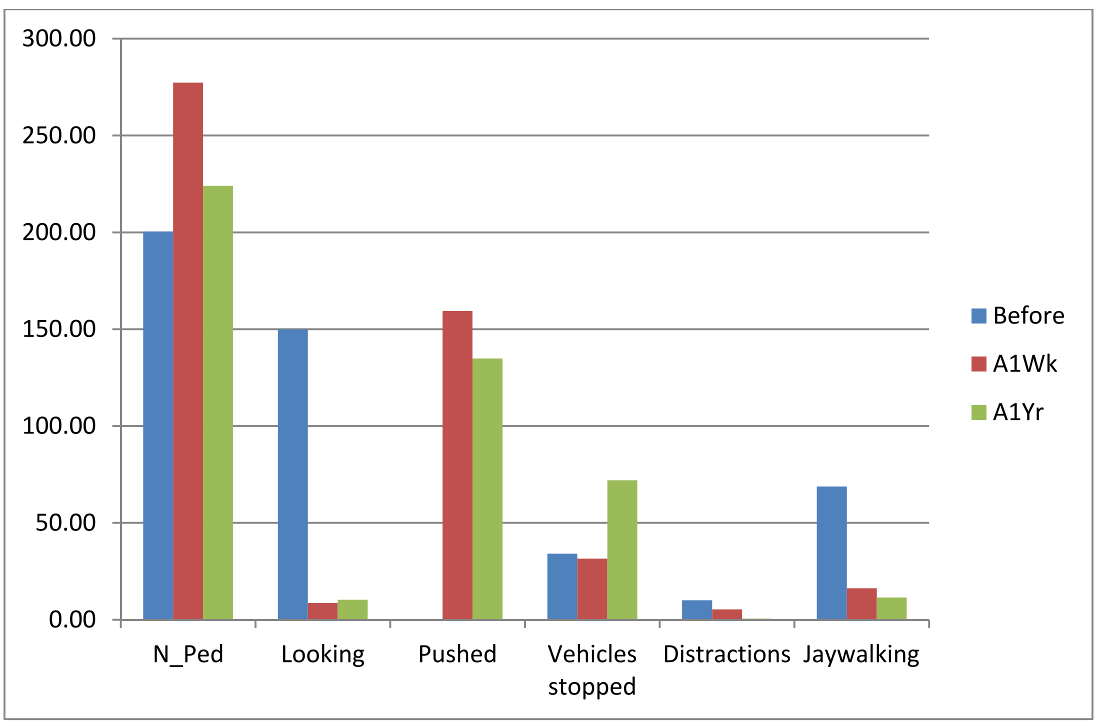


Figure 5-13. Summary of Pedestrian Count Results

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The installation of a PHB at the midblock of a major Las Vegas arterial street was found to improve pedestrian safety. Based on the statistical analysis, the pedestrian mean waiting time increased one week after PHB installation (by about 1 s), and significantly after one year (7 s). This is to be expected since with the PHB, complying pedestrians have to wait for the traffic light sequence to initiate and traffic to stop before crossing.

After installation of the PHB, pedestrian crossing time improved, with the average time reduced by 7.25 seconds one week after installation, and reduced by 3.34 seconds after one year. Since drivers are free to proceed once pedestrians cross, this implies the average driver delay was also reduced (over the original signalized crossing).

From the analysis of the count data, the average number of pedestrians using the crosswalk slightly increased, the number of distractions has continued to decrease, the number of vehicles stopping for pedestrians has increased, the number of pedestrians looking for traffic has decreased (due to increasing trust in the PHB traffic signal), and the daily number of jaywalking incidents reduced considerably.

From the pedestrian's point of view, the PHB helps pedestrians feel safer when they cross and, from the motorist's standpoint, the PHB system helps reduce driver travel delay and increases driver awareness of pedestrians crossing the street.

Section 3.2 of this report summarized the preliminary analysis of data one week before and after the PHB installation (Khadka, et al., 2013). This study confirms the general conclusions of that analysis.

6.2 Recommendations

A few random interviews were conducted with some pedestrians and drivers, one year after the PHB installation. Both pedestrians and drivers expressed some confusion with the PHB system. Pedestrians pushed the button, but there was no indication that the PHB system was activated or how long the pedestrian needed to wait. One recommendation is that the PHB system be modified to include both an activation indicator and small countdown screen for pedestrians.

The confusion for drivers was that the whole system is dark until it suddenly activates. Some drivers were not sure what all the flashing and red lights meant. Driving up on the crosswalk at 45 mph made it hard to see that it was a pedestrian crossing location, plus in the daytime, the traffic lights are harder to see. It is recommended that bright yellow signage be added as shown in Figure 6-1, which will help educate drivers that the mid-street light system is a pedestrian crossing point.

Some drivers are observed to blast through the activated PHB signals, seeming to recognize what it was after it is too late. Luckily, no pedestrians were crossing at these times. To help both this problem and promote pedestrian compliance, it may be worthwhile to create a Las Vegas educational program to improve pedestrian and driver understanding of the system – especially if the city intends to install more PHB systems.

Figure 6-1. A PHB Installed in Phoenix, AZ; note bright yellow signs (FHWA 2014)

Additional recommendations are related to future research. It is expected that the PHB system will result in overall reduced delay time for drivers, but this needs to be demonstrated. Driver delay time for standard signalized crosswalks can be compared to that of the PHB system. The pedestrian crossing volume should also be studied as a factor affecting driver delay time.

Pedestrian and driver compliance could also be studied by performing a survey, questioning instances of jaywalking and signal noncompliance, and additional statistics being noted, for example, pedestrian age and whether the subject appears intoxicated. The Las Vegas police department could be asked to help in questioning driver noncompliance.

APPENDIX A

ELECTRONIC COMPUTER FILES SUPPORTING REPORT

Appendix A will describe the files included on CD and DVD that are available or will be submitted with this dissertation to the Graduate College.

The raw video files representing the one week BEFORE and one week AFTER installation of the PHB system, as described in this report, are available at the Transportation Engineering Laboratory, Science and Engineering Building, UNLV, 4505 S. Maryland Parkway, Las Vegas, NV 89154.

I personally was responsible for viewing and collecting data from video recordings taken from the same cameras one YEAR after the PHB system installation. Four DVDs archive this raw data and the contents of these files are listed for each DVD here.

DVD 1:

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Volume in drive E is May 08 2013
Volume Serial Number is 6D62-6F95

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04/26/2013  08:00 AM       203,511,296 00000006.ASF
04/26/2013  09:00 AM       205,444,608 00000007.ASF
04/26/2013  10:00 AM       200,168,960 00000008.ASF
04/26/2013  11:00 AM       200,300,032 00000009.ASF
04/26/2013  12:00 PM       196,498,944 00000010.ASF
04/26/2013  01:00 PM       192,632,320 00000011.ASF
04/26/2013  02:00 PM       195,024,384 00000012.ASF
04/26/2013  03:00 PM       184,112,640 00000013.ASF
04/26/2013  04:00 PM       164,976,128 00000014.ASF
04/26/2013  05:00 PM       104,158,720 00000015.ASF
04/26/2013  06:00 PM       131,814,912 00000016.ASF
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04/26/2013  08:00 PM       215,012,864 00000018.ASF
04/26/2013  09:00 PM       200,562,176 00000019.ASF
              16 File(s)  2,916,900,864 bytes
               0 Dir(s)               0 bytes free
```

DVD 2:

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Volume Serial Number is 4864-EBE4

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04/27/2013  07:00 AM       185,259,520 00000021.ASF
04/27/2013  08:00 AM       192,697,856 00000022.ASF
04/27/2013  09:00 AM       194,991,616 00000023.ASF
04/27/2013  10:00 AM       193,058,304 00000024.ASF
04/27/2013  11:00 AM       190,207,488 00000025.ASF
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04/28/2013  05:00 PM        99,079,680 00000047.ASF
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04/29/2013  01:00 PM       187,913,728 00000059.ASF
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Volume Serial Number is 4C65-5CF7

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APPENDIX B

BACKROUND FOR STATISTICAL METHODOLOGY

Sample size

A sample represents a small number of members taken from a larger population. The larger the sample, the better it reflects the population. The term “sample size” refers specifically to the number of measurements in the sample.

Relations between Variables (StatSoft, 2014)

Regardless of their type, two or more variables are related if, in a sample of observations, the values of those variables are distributed in a consistent manner. In other words, variables are related if their values systematically correspond to each other for these observations. The two most elementary formal properties of every relation between variables are the relation's magnitude (or "size") and its reliability (or "truthfulness").

x bar or mean value (StatSoft, 2014)

The mean is a measure of the central tendency of the variable if it is reported along with its confidence intervals. The mean is the sum of a set of numbers divided by the number of members of the set. We are interested in statistics (such as the mean) from our sample only to the extent to which they can infer information about the population. The confidence intervals for the mean give us a range of values around the mean where we expect the "true" (population) mean is located (with a given level of certainty).

Hypothesis testing (Edanz Group, 2014b)

A hypothesis test is a test to ask how well observed data compare with a hypothesis about the observed data. In the classical tests, we test how well the data compare with the null hypothesis that there is no effect or association (i.e., any variation in the data is due to chance). We use a test statistic to assess the null-hypothesis.

p-value (Edanz Group, 2014b)

The p-value is the probability of getting the test statistic assuming the null hypothesis is true and so has a value that is always between 0 and 1. The p-value can be regarded as the probability that the results or data (such as a difference or a relationship) are due to chance or sampling error. Therefore, small p-values indicate that the results are probably not due to chance, meaning that there may be an underlying relationship in the data. The p-value should be lower than a chosen significance level (say, 0.05 or 5%) before we can reject our null hypothesis. This means that we accept we will make the wrong interpretation 1 in 20 times. A p-value of 0.001 is much more convincing.

- A non-significant effect is not evidence of no effect. The failure to detect an effect might just mean that the effect is small, that there is a lot of variability in the data and/or your sample size is too small. It does not necessarily mean that there is no actual effect.

- Statistical significance does not equal practical significance. With a large sample size, even small effect will be significant. Consider the magnitude of the effect and think about the context. Even if you find a significant effect, how important will that effect be in the specific context of interest?

- A significant p-value does not mean your experiment has worked. A p-value does not reflect the rigor of study design. A flawed study can give a highly significant effect while a well-designed study might lead to a non-significant effect if no effect exists.

t-Test for Independent and Dependent Samples (StatSoft, 2014)

The t-test is the most commonly used method to evaluate the differences in means between two groups. The groups can be independent (e.g., blood pressure of patients who were given a drug vs. a control group who received a placebo) or dependent (e.g., blood pressure of patients "before" vs. "after" they received a drug). Theoretically, the t-test can be used even if the sample sizes are very small (e.g., as small as 10; some researchers claim that even smaller n's are possible), as long as the variables are approximately normally distributed and the variation of scores in the two groups is not reliably different.

The t-test assumes normality which means the distribution of variable can be approximated by the normal distribution. In the t-test analysis, comparisons of means and measures of variation in the two groups can be visualized using box and whisker plots. The p-level reported with a t-test represents the probability of error involved in accepting our research hypothesis about the existence of a difference. Technically speaking, this is the probability of error associated with rejecting the hypothesis of no difference between the two categories of observations (corresponding to the groups) in the population when, in fact, the hypothesis is true.

Analysis of Variance (ANOVA) (Edanz Group, 2014a)

The Analysis of Variance or ANOVA is used to compare differences of means between two or more groups. ANOVA does this by examining the variation in the data and where that variation is found. Specifically, ANOVA compares the amount of variability between two conditions (groups) and variability within each condition (group). The problem we have is that we are determining statistics from a sample of and not the entire population. ANOVA assumes the data is normally distributed and variance is similar with different groups.

> When we take samples from a population, we expect each sample mean to differ simply because we are taking a sample rather than measuring the whole population; this is called sampling error but is often referred to more informally as the effects of "chance". Thus, we always expect there to be some differences in means among different groups. The question is: is the difference among groups greater than that expected to be caused by chance? In other words, is there likely to be a true (real) difference in the population mean? (Edanz Group, 2014a)

Let us say we install a new pedestrian traffic system that we believe will improve pedestrian safety and we compare it with the pedestrian behavior with the original traffic-signal system. For example, we could measure the time it takes pedestrians to cross the street with the old and new traffic systems. A t-test would compare the likelihood of observing the difference in the mean crossing-time for each group (each traffic signaling system). An ANOVA test, on the other hand, would compare the variability that we observe between the two conditions to the variability observed within each condition. In our case the crossing-time variability observed between the two traffic systems and variability observed with each signal system.

We measure variability as the sum of the difference of each score from the mean. So ANOVA is a measure of the difference of in between group variability and within group variability. In particular, ANOVA calculates a F-ratio test statistic to obtain the probability of obtaining the data assuming the null hypothesis. The null hypothesis is that all population means are equal. A significant probability (usually taken as $P < 0.05$) suggests that at least one group mean is significantly different from the rest, the alternative hypothesis. When comparing only two groups, the ANOVA P-value calculated is the same as the t-test.

It is a common misconception that the size of the F-ratio you compute directly indicates how strongly the relationship is between the independent and dependent variable. However, a separate computation is needed to get a true idea of the strength of the relationship.

Kruskal-Wallis test (StatSoft, 2014)

The Kruskal-Wallis test is a non-parametric alternative to one-way (between-groups) ANOVA. It is used to compare three or more samples, and it tests the null hypothesis that the different samples in the comparison were drawn from the same distribution or from distributions with the same median. Thus, the interpretation of the Kruskal-Wallis test is similar to that of the parametric one-way ANOVA, except that it is based on ranks rather than means. For more information see Devore, 2011.

Kolmogorov-Smirnov test (StatSoft, 2014)

The Kolmogorov-Smirnov one-sample test for normality is based on the maximum difference between the sample cumulative distribution and the hypothesized cumulative distribution. If the D statistic is significant, then the hypothesis that the respective distribution is normal should be rejected. For many software programs, the probability values that are reported are based on those tabulated by Massey; those probability values are valid when the mean and standard deviation of the normal distribution are known a-priori and not estimated from the data. However, usually those parameters are computed from the actual data. In that case, the test for normality involves a complex conditional hypothesis ("how likely is it to obtain a D statistic of this magnitude or greater, contingent upon the mean and standard deviation computed from the data"). For more information see Thas, 2011.

Post hoc comparisons (StatSoft, 2014)

Usually, after obtaining a statistically significant F-ratio test from the ANOVA, we want to know which means contributed to the effect; that is, which groups are particularly different from each other. We could of course perform a series of simple t-tests to compare all possible pairs of means. However, such a procedure would capitalize on chance. The reported probability levels would actually overestimate the statistical significance of mean differences. For example, suppose you took 20 samples of 10 random numbers each, and computed 20 means. Then, take the group (sample) with the highest mean and compare it with that of the lowest mean. The t-test for independent samples will test whether or not those two means are significantly different from each other, provided that they were the only two samples taken. Post-hoc comparison techniques on the other hand, specifically take into account the fact that more than two samples were taken. They are used as either hypothesis testing or exploratory methods.

Tuckey's HSD Post-hoc test (StatSoft, 2014)

This post hoc test (or multiple comparison test) can be used to determine the significant differences between group means in an analysis of variance setting. One does not conduct a post-hoc test unless you found an effect (rejected the null) in the ANOVA problem. If you fail to reject the null, then there are no differences to find.

For the Tukey's post-hoc test one first finds the differences between the means of all of our groups. We will compare this difference score to a critical value to see if the difference is significant. The critical value in this case is the HSD (honestly significant difference) and it must be computed. It is the point when a mean difference becomes honestly significantly different.

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