Evaluation of the effectiveness of countermeasures to enhance pedestrian safety

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EVALUATION OF THE EFFECTIVENESS OF COUNTERMEASURES TO ENHANCE PEDESTRIAN SAFETY

by

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A dissertation submitted in partial fulfillment of the requirements for the

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EVALUATION OF THE EFFECTIVENESS OF COUNTERMEASURES TO ENHANCE PEDESTRIAN SAFETY

is approved in partial fulfillment of the requirements for the degree of

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Examination Committee Chair

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Examination Committee Member

Examination Committee Member

Graduate College Faculty Representative
ABSTRACT

Evaluation of the Effectiveness of Countermeasures to Enhance Pedestrian Safety

by

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Professor of Department of Civil and Environmental Engineering
University of Nevada, Las Vegas

Pedestrian safety is a major concern in the United States because over 4,700 pedestrians are killed and 70,000 are injured annually. Nevada has one of the highest pedestrian fatality rates in the United States. Thus, there is a need to enhance pedestrian safety using existing and new strategies and to evaluate the effectiveness of these strategies. The objective of this research is to evaluate the effectiveness of various countermeasures to improve pedestrian safety. The countermeasures evaluated in this research include: 1) an in-pavement flashing light system, 2) pedestrian countdown signals, 3) turning traffic must yield to pedestrians signs, 4) a portable speed trailer, 5) in-roadway knockdown signs, 6) a high visibility crosswalk, 7) warning signs for motorists, 8) regulatory signs, and 9) advance yield markings.

A before-and-after analysis was used to evaluate the selected strategies. Measures of effectiveness (MOEs) were used to evaluate the impacts of these countermeasures, including pedestrians’ and motorists’ behaviors. Data were collected immediately prior to the installation of each countermeasure and a few weeks after the installation of each countermeasure. Data were collected during both AM and PM peak periods. The data
obtained from the two study periods (before installation and after installation) for each MOE were evaluated using statistical tools.

Results from the analyses of the data show that the in-pavement flashing light system is an effective strategy to increase motorists’ yielding and to reduce average vehicle speeds at a location with low traffic and pedestrian volumes. The pedestrian countdown signal helps to improve pedestrians’ crossing behaviors. The observed mean vehicular speeds were higher when the pedestrian countdown timer was displayed on the pedestrian signal head than with the traditional pedestrian WALK phase. The installation of the sign “turning traffic must yield to pedestrians” increased motorists yielding behavior when they executed turning maneuvers on either red or green phases. The average vehicle speed was reduced upstream and downstream of the location of the portable speed trailer. The high visibility crosswalk, warning signs for motorists, regulatory signs for motorists, and advance yield markings at a mid-block location showed positive safety benefits in motorists’ and pedestrians’ behaviors.

The MOEs used to evaluate countermeasures indicate improvements in both motorists’ and pedestrians’ behaviors. In most cases, these changed behaviors are positive and statistically significant. Even though these deployed strategies and their influence on pedestrians’ and drivers’ were effective in prevailing weather conditions and the geographic location of the Las Vegas metropolitan area, these findings are of value to other regions with similar traffic and pedestrian characteristics.
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CHAPTER 1

INTRODUCTION

The objective of the proposed research is to evaluate the effectiveness of potential countermeasures to enhance safety, particularly pedestrian safety. Chapter 1 provides a brief discussion of the motivation for the study, a statement of the problem, and the objectives of the study.

1.1 Motivation

Traffic safety is a high priority not only in the United States, but also throughout the world. Worldwide, an estimated 1.2 million people are killed and as many as 50 million people are injured in road crashes annually. These figures will increase by about 65 percent between 2000 and 2020 unless there is a new commitment to prevention. By the year 2020, road traffic deaths will decline about 30 percent in high-income countries; however, they will increase substantially in low-income and middle-income countries. Road injuries were the ninth-leading contributor to the global burden of disease and injury in 1990, and it is predicted to be the third-leading contributor by 2020 (World Health Organization, 2004). According to the National Highway Traffic Safety Administration (NHTSA), more than 42,000 people were killed in 2003 and about 3 million were injured in traffic-related crashes on the roads of the United States
Pedestrians are more vulnerable than motor vehicle passengers in traffic crashes and suffer more serious injury in crashes. In the U.S., walking trips account for only 6 percent of all trips but pedestrians represent over 11 percent of all fatalities (Pedestrian and Bicycle Information Center, 2004). Based on trip share, a disproportionate number of pedestrians are involved and killed in crashes.

A demographic classification is identified as follows: children (aged less than 12 years), adolescents (aged from 12 to 17 years), adults (aged from 17 to 65 years), and seniors (aged more than 65 years). Individuals less than 20 years of age and more than 65 years in age accounted for more than 35 percent of total traffic fatalities (NHTSA, 2004). Even though people less than 20 years of age and more than 65 years of age comprised 41 percent (US Census Bureau) of the total population, people in these demographic groups are less likely to drive. A larger proportion of these demographic groups are involved in crashes as compared to other population groups. Young people and seniors are among the most vulnerable road users, drivers as well as pedestrians, based on the demographic groups. Most of the walking trip makers are younger and older aged people. Therefore, they are more exposed to traffic. Several cues are involved when crossing a road to interact with traffic.

The older population is growing rapidly. Advancements in the medical field, better medical facilities, health consciousness, and physical exercise help increase the average life expectancy of individuals. The population 65 years of age and older in the U.S. is expected to double between 2000 and 2030 (Austin and Faigin, 2003; Griffin, 2004). The older age group has become a larger proportion of drivers and will continue to rise as the baby boomers reach retirement. Crashes involving the elderly are also expected to rise.
along with the increase in this population. The older population accounted for 14 percent of total driver fatalities in 1999, and it is expected to be as much as 25 percent of total driver fatalities by 2030 (Lyman, Ferguson, Braver, and Williams, 2002). The population aged 85 years and older already comprises the fastest growing segment of the population (Safer Roads for America, 2004). As the proportion of such older road users increases, there is a need for increased focus on safety perspectives for senior drivers and pedestrians.

Senior citizens take a longer time to recognize and to take action for any cues. Several psychological processes are involved in a pedestrian’s maneuvering to cross a street. These processes include recognition, identification, detection, and decision. The elapsed time to complete these tasks is called perception and reaction (PR) time. Research shows that the younger population has a lower PR time than their older counterparts. The PR time increases with aging (American Association of State Highway and Transportation Officials, 2001). Despite younger people taking a shorter time to respond to events, they might not be able to take proper action in a potential threat. By the same token, fatigue and the influence of drug and alcohol cause increased PR times. Other factors affecting pedestrian behavior and safety include the following:

i. Environmental: road type, intersection, and lighting.

ii. Traffic: volume, moving and stationary vehicle, and communication with road users.

iii. Personal: physical abilities, motivation, experience, and psychological state.

iv. Social: presence of others and trip purpose.
The time required to make decisions when driving is not the same for all age groups (Lemer, 1993). Seniors take a longer time to make decisions in response to stimuli (Lemer, 1994). This is due in part to human factors such as vision, hearing, and motor skills. The PR time also varies with dexterity of the driving tasks (Consdort, 2004). Licensed teenage drivers do not have the same dexterity as an experienced driver for driving. Seniors are also vulnerable as pedestrians at intersections and midblocks. At controlled intersections, both drivers and pedestrians might have difficulties seeing signal heads at the other side of streets that are extremely wide (e.g., greater than 80 feet). At uncontrolled midblock locations, pedestrians might have difficulties judging an acceptable gap before crossing. On the other hand, drivers might expect that the impending crossing pedestrians might have enough time to yield to them. Consequently, pedestrians are trapped in the middle of the wide streets while crossing, and both drivers and pedestrians are likely to fail to yield the right of way. Standard pedestrian signal heads installed along wide streets cause reduced visibility in older / vision impaired pedestrians. Pedestrian countdown signals help pedestrians to better understand the time available to complete crossing maneuver. An in-pavement flashing light system might be beneficial to enhance awareness of the crossing location for both motorists and pedestrians. Other common problems, in general, are inconspicuous crosswalks, pedestrians trapped in the middle of the street while crossing, and motorists and pedestrians not yielding the right of way.
1.2 Problem Statement

The pedestrian fatality rate in the State of Nevada had been among the worst in the nation over the past decade. Based on pedestrian fatality rates, Nevada has been among the 10 worst states for pedestrian safety since the early 1990s (NHTSA, 2004). Pedestrian fatalities per 100,000 population in the State of Nevada and the U.S. from 1994 to 2003 are shown in Table 1. Nevada has been ranked first on two occasions during the last 10 years, in 1996 and 1999, as having the worst pedestrian safety in the United States. Clark County is the fastest-growing (in terms of population) county in Nevada and one of the fastest-growing counties in the United States. Clark County’s population had increased more than 85 percent in the past decade from 1990 to 2000 and more than doubled from 1990 to 2003. Nevada’s population grew by more than 66 percent and 86 percent from 1990 to 2000 and 1990 to 2003, respectively. These population growth trends are shown in Table 2.

Table 1 Pedestrian Fatalities in Nevada and US from 1994 to 2003

<table>
<thead>
<tr>
<th>Year</th>
<th>Pedestrian Fatality Rate Per (100,000 Population)</th>
<th>Nevada's Ranking</th>
<th>Pedestrian Fatalities in Nevada</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>US</td>
<td>Nevada</td>
<td></td>
</tr>
<tr>
<td>1994</td>
<td>2.11</td>
<td>3.71</td>
<td>4</td>
</tr>
<tr>
<td>1995</td>
<td>2.12</td>
<td>3.93</td>
<td>5</td>
</tr>
<tr>
<td>1996</td>
<td>2.05</td>
<td>4.26</td>
<td>1</td>
</tr>
<tr>
<td>1997</td>
<td>1.99</td>
<td>3.52</td>
<td>4</td>
</tr>
<tr>
<td>1998</td>
<td>1.93</td>
<td>2.64</td>
<td>6</td>
</tr>
<tr>
<td>1999</td>
<td>1.81</td>
<td>3.70</td>
<td>1</td>
</tr>
<tr>
<td>2000</td>
<td>1.69</td>
<td>2.13</td>
<td>10</td>
</tr>
<tr>
<td>2001</td>
<td>1.72</td>
<td>2.15</td>
<td>7</td>
</tr>
<tr>
<td>2002</td>
<td>1.68</td>
<td>2.40</td>
<td>6</td>
</tr>
<tr>
<td>2003</td>
<td>1.63</td>
<td>2.90</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 2 Population Growth of Nevada and Clark County from 1990 to 2000 and 2003

<table>
<thead>
<tr>
<th>Year</th>
<th>Population</th>
<th>% of Nevada's Population in Clark County</th>
<th>% Population Growth from 1990 to 2000</th>
<th>% Population Growth from 1990 to 2003</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nevada</td>
<td>Clark County</td>
<td>Nebraska</td>
<td>Clark County</td>
</tr>
<tr>
<td>1990</td>
<td>1,201,833</td>
<td>741,459</td>
<td>61.7</td>
<td>66.3</td>
</tr>
<tr>
<td>2000</td>
<td>1,998,257</td>
<td>1,375,765</td>
<td>68.8</td>
<td>85.5</td>
</tr>
</tbody>
</table>
| 2003 | 2,241,154  | 1,641,529\(^1\)                         | 73.2                                 | 86.5                                 | 121.4

Source: U.S. Census, *Southern Nevada Regional Planning Coalition, 2003*

Nearly 70 percent of Nevada's total population resides in Clark County (Nevada State Legislature Legislative Counsel Bureau, 2001). According to the Southern Nevada Regional Planning Coalition (SNRPC), Clark County's population as of July 2003 was 1,641,529, which reflects a 19.3 percent growth over the population in 2000. If the population growth rate remains the same as from 1990 to 2000, the estimated population of Clark County will be more than 6 million by 2025 (Federation for American Immigration Reform, 2004). The population in the Las Vegas metropolitan area includes the cities of Las Vegas, North Las Vegas, Henderson, and urban Clark County, and is about 1,612,000, which is more than 98 percent of the total Clark County population. Table 3 depicts the population distribution of the different jurisdictions within Clark County.

An analysis of crash data in the Las Vegas metropolitan area was used to identify locations with high pedestrian crash rates. Altogether, 19 sites were identified as pedestrian high crash locations (Transportation Research Center, 2004). Based on conditions and crash characteristics, various intelligent transportation systems (ITS) and other engineering pedestrian safety countermeasures were identified for deployment at

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these locations. The evaluation of nine of these countermeasures is the main focus of this research.

Table 3 Population of Clark County and Cities in Clark County (Year 2003)

<table>
<thead>
<tr>
<th>Jurisdictions</th>
<th>Population</th>
<th>% of Clark County Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>City of Las Vegas</td>
<td>535,395</td>
<td>32.6</td>
</tr>
<tr>
<td>City of Henderson</td>
<td>220,236</td>
<td>13.4</td>
</tr>
<tr>
<td>City of North Las Vegas</td>
<td>147,877</td>
<td>9.0</td>
</tr>
<tr>
<td>City of Boulder City</td>
<td>15,125</td>
<td>0.9</td>
</tr>
<tr>
<td>City of Mesquite</td>
<td>14,073</td>
<td>0.9</td>
</tr>
<tr>
<td>Unincorporated County</td>
<td>708,823</td>
<td>43.2</td>
</tr>
<tr>
<td>Metropolitan Las Vegas valley</td>
<td>1,612,331</td>
<td>98.2</td>
</tr>
<tr>
<td>Clark County</td>
<td>1,641,529</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Source: Southern Nevada Regional Planning Coalition Consensus Population Estimate - July 2003, Clark County Demographic Profile

1.3 Study Objectives

Various strategies to enhance pedestrian safety have been implemented and evaluated around the world. Such strategies have seen limited deployment and evaluation in the United States. Such countermeasures were deployed and evaluated at high crash locations identified within the Las Vegas valley. A before-and-after evaluation strategy was used to assess the effectiveness of these countermeasures. The successful countermeasures can be considered for similar kinds of traffic volume and site conditions throughout the United States. Some deployed novel strategies and their effects on pedestrians' and drivers' behavior can also be used in different parts of the world. In this research, nine countermeasures were installed and evaluated. Out of these nine, seven of the
countermeasures were installed at high-risk locations. The remaining two countermeasures, an in-pavement flashing light system and pedestrian countdown signals, are installed at other locations. The effectiveness of the implemented countermeasures was evaluated under prevailing weather conditions and in the geographic location of the Las Vegas valley.

1.4 Organization of the Dissertation

A review of literature pertaining to evaluation of deployed strategies is documented in Chapter 2. A brief description of the process used to enhance pedestrian safety is discussed in Chapter 3. It includes problem identification, potential countermeasures, measures of effectiveness (MOEs), data requirements for the study, and statistical tests used for analysis. A brief description of all sites with the deployed countermeasures, description of the proposed countermeasures, and the procedure for evaluation of each countermeasure are discussed in Chapter 4. The proposed countermeasures for each location and their deployment plan are also discussed in detail in Chapter 4. The analysis of existing conditions to support these proposed countermeasures is discussed in Chapter 5. Data analysis and results for evaluation of countermeasures are reported in Chapter 6. Results are presented for the evaluated countermeasures and corresponding MOEs. Based on the results, the effectiveness of the evaluated countermeasures is discussed in Chapter 7. Recommendations are made for future research, which are also presented in Chapter 7.
CHAPTER 2

LITERATURE REVIEW

A summary of the literature on pedestrian safety relevant to this research is presented in this chapter. It focuses on documentation related to the effectiveness of deployed countermeasures. Some of the countermeasures cited in the literature are “Yield Here to Pedestrians,” advance yield marking, restrictions on right turn on red, ITS light emitting-diode (LED) animated eyes, pedestrian countdown timers, and in-pavement flashing light systems. These countermeasures are categorized into three sections and will be discussed next. The three sections address ITS devices, advance yield marking, pedestrian countdown signals, high visibility crosswalk, traffic calming devices, etc.

2.1 ITS Signals Including LED Animated Eyes

Van Houten and Malenfant (2001) analyzed the effectiveness of an ITS LED at parking garage exit and midblock locations. The main purpose of the study was to assess the effectiveness of an ITS signal that included animated eyes and pedestrian symbols at a garage exit with limited visibility. The result of the study showed that the introduction of ITS signs increased the percentage of motorists yielding to pedestrians at the garage exit and midblock crosswalk location. The ITS eyes sign produced a significantly larger increase in driver’s yielding behavior than a flashing beacon at the midblock crossing.
Van Houten, Healy, Malenfant, and Retting (1998) evaluated two strategies for increasing the percentage of motorists yielding to pedestrians at crosswalks with pedestrian activated flashing beacons. These two strategies were: a) an illuminated sign with the standard pedestrian symbol next to the beacons, and b) signs 50 meters upstream of the crosswalk that displayed the pedestrian symbol and directed motorists to yield when the beacons were flashing. The main purpose of the study was to evaluate the effect of the two strategies when employed individually and combined on yielding behavior of motorists, and vehicle and pedestrian conflicts. A combination of the two interventions increased the yielding behavior of motorists and reduced vehicle pedestrian conflicts. It may be possible to produce similar results by installing an advance stop line with a sign directing that motorists stop at the line.

Van Houten, Retting, Van Houten, Farmer, and Malenfant (1999) evaluated a LED pedestrian signal head with animated eyes that scan from side to side at the start of the WALK indication. The study was conducted at two signalized intersections in downtown Clearwater, Florida, U.S.A. The results demonstrated that the experimental signal decreased the percentage of pedestrians not looking for turning vehicles and vehicle-pedestrian conflicts; similar results were obtained during a follow up study after six months.

Van Houten, Van Houten, Malenfant, and Andrus (1999) conducted a study to evaluate the effectiveness of animated eyes on drivers’ behavior. Observers scored data on whether motorist looked right and left before crossing the sidewalk and vehicle-pedestrian conflict. They found a significant reduction in vehicle-pedestrian conflict and an increase in percentage of pedestrians and motorists cautionary for particular threats.
Carsten, Sherborne, and Rothengatter (1998) evaluated innovative pedestrian signalized crossings as a part of DRIVE II project VRU-TOO (Vulnerable Road User Traffic Observation and Optimization). Signals were designed to make timings more responsive to pedestrian needs, i.e., to affect signal timings. As a part of innovative signalized pedestrian crossings, microwave detectors were mounted on traffic signals to register the approach of pedestrians. Microwave detection can be applied to: replace the normal push-button on signalized pedestrian crossings; provide an earlier activation of the pedestrian phase; provide an extension of the pedestrian phase for late arrivals; and provide longer pedestrian phases when there are large numbers of pedestrians. These signals were installed in three European countries. The first site was in Leeds, England; flows were up to 6,000 pedestrians an hour. The other two sites, one in Portugal and the other in Greece, had comparatively lower pedestrian flows. Some of the criteria used for evaluation were as follows: pedestrian-to-vehicle conflicts, percentage of pedestrians arriving on red who violated the red light (especially the percentage violating red when motorists had green), pedestrian comfort, and the number of encounters between pedestrians and vehicles (an encounter was defined as an interaction between a pedestrian and a vehicle where one needs to change course or speed due to behavior of others.) They found that pedestrian-to-vehicle conflicts were reduced in the after studies in most of the sites. However, the reduction in conflict in all of the sites was not statistically significant. At site 2 in Leeds, conflicts were also analyzed in relation to pedestrian flow, the conflict to flow ratio decreased from 1:2,034 in the before study to 1:2,300 in the after study. There was a reduction of the proportion of pedestrians who experienced long waiting
times (>30 seconds). Mean queue length decreased at all three sites in Leeds; however, maximum queue lengths went up at two sites.

2.2 Advance Yield Markings, Stop Lines, Regulatory Signs, In-pavement Flashing Light System, Pedestrian Countdown Signals, and Yield Signs

Van Houten, McCusker, Huybers, Malenfant, and Rice-Smith (2002) conducted a study about the effectiveness of advance yield markings and fluorescent yellow-green RA 4 signs at crosswalks. The yield markings were placed along with the RA 4 crosswalk sign. A pedestrian-motor vehicle conflict was scored if the driver had to engage in abrupt braking or had to swerve to avoid striking a pedestrian, or if a pedestrian had to take sudden evasive action to avoid being struck. Results show a marked decline in conflicts for the two conditions that included advance yield markings and the “Yield Here to Pedestrians” sign. Conflicts decreased from 11.1 percent to 2.7 percent for the advance yield marking and “Yield Here to Pedestrians” and from 12.3 percent to 2.3 percent for the advance yield marking, “Yield Here to Pedestrians,” and fluorescent yellow-green sign groups.

Van Houten, Malenfant, Van Houten, and Retting (1997) evaluated auditory pedestrian signals and their effect in reducing vehicle and pedestrian conflicts. The percentage of pedestrians not looking for potential threats and conflicts were reduced after the implementation of an auditory signal.

Eccles, Tao, and Mangum (2004) evaluated the pedestrian countdown signals in Montgomery County, Maryland. A “before and after” study technique was used to
evaluate motorists' and pedestrians' behavior and vehicle speed. The results revealed a significant positive effect on pedestrian behavior and did not have any negative effect on motorist behavior. No effect on vehicle approach speed was observed due to the presence of countdown signals while vehicles entered intersections during clearance intervals.

The presence of a pedestrian countdown signal caused more pedestrians to enter the crosswalk during the flashing DON'T WALK phase. A larger proportion of pedestrians completed crossing on the flashing DON'T WALK phase which in turn reduces the chance of more pedestrians complete crossing before the DON'T WALK phase (Botha et al., 2002). The pre- and post-installation research performed showed that an addition informational, a numerical descending countdown of the flashing DON'T WALK clearance interval, was intuitively understood and used successfully by pedestrians. Pedestrians of over the age of 16 well understood countdown pedestrian indication and used the information appropriately (Farraher).

Mantri (2005) evaluated the effectiveness of pedestrian countdown timers in Las Vegas metropolitan area and found that the presence of a countdown timer helped the pedestrians to better understand the meaning of the flashing DON'T WALK sign. The countdown timers helped reduce the number of pedestrians trapped in the middle of the street. Analysis of data pertaining to motorist behavior was inconclusive. Results from pedestrian interviews showed that a majority of pedestrians interpret the meaning of flashing DON'T WALK sign and time shown on countdown timer correctly, and preferred countdown timer which starts with the flashing DON'T WALK phase (Pulugurtha and Nambisan, 2004).
Huang and Zegeer (2000) evaluated pedestrian countdown signals based on three measures of effectiveness: pedestrian compliance with the WALK signal, pedestrians who ran out of time, and pedestrians who started running when the flashing DON'T WALK appeared. They found significance decrease in pedestrian signal compliance, significant decrease in pedestrians who began running when flashing DON'T WALK signal appeared, no significant change in pedestrians who ran out of time.

Retting and Van Houten (2000) evaluated the effects of advanced stop lines by conducting a before and after study wherein the stop lines (bars) were relocated from 4 feet upstream of the crosswalk to 20 feet upstream of the crosswalk. Overall, the mean elapsed time between the start of the green signal phase and the lead vehicle entering the intersection increased from 3.3 to 4.0 seconds after the intervention. All of those observations were statistically significant (p-value < 0.0001). This study found that relocating stop lines at signalized intersections from the standard 4 feet to 20 feet from crosswalks can have significant effect on driver stopping behavior. The majority of drivers complied with the advance stop lines.

Retting, Nitzburg, Farmer, and Knoblauch (2002) reported finding from a field evaluation of two methods for restricting right turn on red (RTOR) to promote pedestrian safety. The implementation of signs prohibiting RTOR during specified hours yields better results than signs giving drivers discretion to determine whether pedestrians are present.

Huang, Zegeer, and Nassi (2000) conducted a study to evaluate the effectiveness of three pedestrian treatments at unsignalized locations. Three types of devices evaluated: an overhead crosswalk sign (in Seattle, Washington); pedestrian safety cones with
information “State Law: Yield to Pedestrians in Crosswalk in Your Half of Road” (in New York and in Portland, Oregon); and pedestrian-activated overhead signs with information “Stop for Pedestrians in Crosswalk” (in Tucson, Arizona). Pedestrian safety cones and overhead crosswalk signs appear to be effective for enhancing pedestrian safety at midblock crosswalks on low-speed, two-lane roads. The pedestrian activated sign in Tucson was not as effective in increasing compliance as were the other two devices, probably because they were installed on four- to six-lane, high speed arterials.

Derlofske, Boyce, and Gilson (2003) evaluated in-pavement flashing warning light systems. The first evaluation was made on the existing eroded crosswalk, then another evaluation was made after the crosswalk was striped. The behavior of drivers and pedestrians using the crosswalk, opinions of the pedestrians using the crosswalk, and the conspicuity of the crosswalk to unwarned drivers were recorded. A significant difference in the number of conflicts between eroded and new striping was observed. A conflict is defined as an occasion when a driver moves over a crosswalk while a pedestrian is in the crosswalk, the vehicle passing either in front or behind the pedestrian. There was a difference in the number of conflicts between striped crosswalks and in-pavement flashing warning lights; however, the differences were not statistically significant. Adding an in-pavement flashing warning light to a crosswalk that is already clearly striped makes the crosswalk more conspicuous, reduces the approach mean speed of vehicles, and reduces the mean number of vehicles that pass over the crosswalk while a pedestrian is waiting.

Hakkert, Gitelman, and Ben-Shabat (2002) conducted a study on crosswalk warning systems evaluation. Vehicle speeds about 30 m upstream of the crosswalk and near the
crosswalk were measured. Drivers' yielding behavior to pedestrians was considered in three situations: when a pedestrian is on the sidewalk; when a pedestrian is on the road at the beginning of crosswalk on crossing maneuver; and when a pedestrian is in the middle of crosswalk on a crossing maneuver. Pedestrians crossing within 5 to 30 m of crosswalk were counted. A vehicle-pedestrian conflict was defined as an abrupt change of course or speed by one of them, in order to avoid a collision. Conflict rates of vehicles and pedestrians were reduced significantly to less than 1 percent. A reduction to 10 percent in the proportion of pedestrians crossing outside the crosswalk was observed.

Under certain conditions, the flashing crosswalk can reduce average vehicle speeds up to 1.2 mph to 3.1 mph near the crosswalk zone. The observed speeds were reduced on an average by 1.9 mph and 0.8 mph after installation of the flashing crosswalk with and without the presence of pedestrians, respectively, but the differences were not statistically significant (Huang, Hughes, Zegeer, and Nitzburg, 1999).

Nasar (2003) conducted a study to evaluate the effectiveness of written signs with social assistance to increase the proportion of drivers stopping for pedestrians in crosswalks. The written signs with social assistance were “Thank you for stopping” and “Please stop next time.” If the driver stopped, the pedestrian crosser held up a green “Thank you for stopping” signs to drivers. If the driver did not stop, a confederate held up a pink “Please stop next time.” In weeks 1 and 3, baseline data on the proportion of drivers stopping for pedestrians at two sites were obtained. In week 2, the stopping behavior of motorists was observed with social assistance signs. An ABA reversal design was used to evaluate the effectiveness of strategies. The analysis showed a significant
increase in stopping behavior of drivers during the treatment condition (50.9 percent) from the baseline conditions (46 percent and 37.3 percent).

Lobb, Harre, and Suddendorf (2001) conducted a before and after study for a railway pedestrian crossing. Educational and environmental interventions were implemented to enhance pedestrian safety. The environmental interventions were designed to prevent illegal access at a train station by installing a new fence and repairing of existing holes. The educational intervention consisted of the following: talks given by safety officers to workers at factories nearby the train station and pupils at local schools about safe and unsafe crossing; distribution of leaflets bearing a safety message in the surrounding area; installation of new warning signs bearing a message “Walking across the tracks is a criminal offence” on the platforms and on fences near platforms; posters showing a young man apparently planning to walk across the tracks and the superimposed message “This train of thought could kill you” placed nearby factories and billboards in the vicinity of the train station; and planned media coverage about the safety program. Immediately after program interventions, a substantially high proportion of crossers used the over bridge than before, and 3 months later the increase compliance was even greater.

Van Houten, Malenfant, and McCusker (2001) conducted a study to evaluate “yield to pedestrian” sign along with advance yield marking at three multilane crosswalks in Nova Scotia, Canada. Each of these three sites was equipped with pedestrian activated flashing beacons. “Yield to pedestrian” signs were used to prompt motorists to yield for pedestrians at or behind the advance yield markings. Behavioral data on pedestrians and motorists were collected on weekdays between 8:30 a.m. and 4:30 p.m. Data were collected for 20 pedestrians crossing while vehicles were present. Vehicle-pedestrian
conflicts were reduced at all three sites. The percentage of motorists yielded within 3 m, between 6 and 9 m, and between 9 and 12 m from crosswalk also increased. The percentage of motorists yielding to pedestrians at all crosswalks also increased.

Lobb, Harre, and Terry (2003) conducted a before and after evaluation of interventions designed to reduce illegal and unsafe crossing of a rail corridor. Target subjects were boys, crossing on their way to and from a high school adjacent to a city station in Auckland, New Zealand. Four interventions, communications, education, continuous punishment, and intermittent punishment, were deployed. The after study showed that all of the deployed interventions significantly decreased the percentage of unsafe crossings.

2.3 High Visibility Crosswalk, Traffic Calming, and Other Devices

A study was conducted to improve pedestrian circulation and safety along the Queens Boulevard study corridor, while maintaining acceptable level of service (LOS). The study area, a 2.5-mile through route segment, is located between the Queensborough Bridge in Long Island City and the Van Wyck Expressway in Jamaica, New York, U.S.A. Existing condition data pertaining to pedestrian volume, traffic volume, crash records and travel speeds were collected. O’Mara (2000) observed the average peak hour pedestrian volume at the signalized intersections was 950 pedestrians. The observed highest hourly pedestrian volume was 3,000 pedestrians. Some safety improvement countermeasures are to be deployed. The measures of effectiveness to be analyzed for each of the improvements are accident rates, pedestrian walking behavior changes, and community feedback.

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Clark, Hummer, and Dutt (1996) evaluated the effectiveness of fluorescent strong yellow-green (SYG) pedestrian warning signs in improving safety in the mid-block crossing locations in several cities of North Carolina. The measures of effectiveness considered were vehicle-pedestrian conflicts and motorists slowing and stopping. A Z-test analysis was performed to determine the significance of the changes between the "before and after" intervention conditions. The observed results, indicate that the strong yellow green signs produced marginal safety improvements at midblock pedestrian crossings in daylight. Only a limited number of twilight observations were obtained and no observations were obtained at night or in adverse weather conditions. They did not suggest any effect of SYG under such conditions. Although most of the observed trends were expected, changes were small in magnitude and were statistically insignificant.

Nitzburg and Knoblauch (2001) conducted a study to evaluate high-visibility ladder style crosswalk with illuminated overhead crosswalk sign treatment in low volume and low speed nonsignalized intersections in Clearwater, Florida. Traffic volumes, traffic gaps, and drivers' and pedestrians' behavior at control sites and experimental sites were observed. The yielding behavior of drivers in daytime at first half, second half, and both halves of crossing were found to have improved statistically significantly at the experimental sites as compared to comparison sites.

King, Carnegie, and Ewing (2003) conducted a study on pedestrian safety after implementing certain strategies. Some of the changes along the road corridor were raised medians, redesigned and signalized intersections, etc. A before and after study strategy was applied for the evaluation. Both quantitative methods (speed and volume counts) and qualitative methods (pedestrian tracking, video, before-and-after photography) were used
for the comparison. The posted speed limit was 45 mph. In before the test condition, the 85th percentile westbound and eastbound speeds were 51 mph and 52 mph, respectively. The after condition speed was 49 mph for each direction. Results showed that the 85th percentile speed reduced by 2 to 3 mph and pedestrian exposure risk decreased by 28 percent. Along with the reduction in speed, conflicts were expected to be lowered, a projected savings in direct and indirect costs of $1.7 million over the next 3 years.

Dutt, Hummer, and Clark (1997) conducted an evaluation of conventional yellow signing materials and fluorescent strong yellow-green (SYG). A written questionnaire survey was conducted to assess driver perception of SYG warning signs at midblock pedestrian crossings. Data were collected at least a month after the installation of SYG signs to compensate for the novelty effect. Results of the study showed that the average conspicuity rating of the SYG sign was between 7.8 and 8.7 (on a scale of 10), and the average conspicuity rating of the standard yellow sign was between 4.4 and 4.8 (on a scale of 10). These responses were statistically significant (P<0.0001). This study also concluded that the respondents identified the SYG color more readily with caution than they did the standard yellow.

Huang and Cynecki (2000) evaluated the effects of traffic calming treatments on pedestrian and motorist behavior at both intersections and midblock locations. The strategies applied were bulbouts, raised intersections, and pedestrian refuge islands. A before-and-after strategy was used for comparison. Interventions were evaluated based on three measures of effectiveness: average pedestrian waiting time, pedestrians crossing in the crosswalk, and pedestrians for whom motorists yielded. None of the treatments had a significant effect on the percentage of pedestrians for whom motorists yielded or the
average pedestrian waiting time. However, the raised intersection in one location and refuge islands with zebra crosswalks at another location increased the percentage of pedestrians crossing in the crosswalk.

Abdulsattar, Tarawneh, McCoy, and Kachman (1996) evaluated the effectiveness of the “turning traffic must yield to pedestrians” sign. The sign was installed at 12 marked crosswalks and data were collected before and after the installation of the sign. The measure of effectiveness used was the vehicle-pedestrian conflict. The results showed that the sign was effective in reducing left-turn conflicts 20 to 65 percent and right-turn conflicts 15 to 30 percent; both reductions were statistically significant at the 0.05 level.

Abdulsattar and McCoy (1999) conducted drivers’ comprehension of a “turning traffic must yield to pedestrians” sign among different age groups during turning maneuvers. For the left-turn situation younger drivers (under 56 years) paid more attention to the sign than older drivers. During right-turn movements, drivers and pedestrians always were in interaction, unless an exclusive right-turn phase was provided.

2.4 Crossing Behavior

A review of the literature shows limited research on pedestrians’ crossing behavior. However, several references were found relating to the motorists’ perspective and their yielding behavior to pedestrians. Field observations revealed that pedestrians not using the crosswalk, motorists not yielding to pedestrians, and pedestrians not waiting for acceptable gaps leads to serious safety concerns (Nambisan, Pulugurtha, Vasudevan, and Karkee, 2004). Drivers blame pedestrians both for behaving erratically and for failing to
use designated crossing area (Redmon, 2003). Pedestrian safety improvements include, making pedestrians aware of safe behavior, making drivers aware of the presence of pedestrians, and getting engineers and planners to think of accommodating pedestrians and to consider safety aspects in highway and transportation facility design. Redmon (2003) found that all pedestrians in a survey indicated their concern about being hit by a car. Several respondents referred to the poor conditions of sidewalks. Some pedestrians complained of not having adequate time to cross the street before the WALK signal changes.

About 18% of all midblock pedestrian crashes occurred at about 150 feet away from an intersection. A significantly lower potential for conflict was observed if pedestrians cross at an intersection instead of crossing at midblock locations (Cui and Nambisan, 2003). An observational study of pedestrians’ behaviors at various urban crosswalks and a pedestrian user survey showed that the crosswalk location relative to the origin and destination of a pedestrian was the most influential decision factor for pedestrians choosing to cross at a designated location (Sisiopiku and Akin, 2003). Pedestrians’ not looking for vehicle turning movement and the resultant conflict could be reduced by implementing appropriate countermeasures aimed at reducing the conflict (Van Houten, Retting, Van Houten, Farmer, and Malenfant, 1999).

2.5 Summary

Various efforts have evaluated countermeasures to enhance pedestrian safety. The literature review did not identify any attempts to evaluate the effectiveness of a strategy a “Portable speed trailer.” Some articles were documented pertaining to countermeasures,
in-pavement flashing light system, pedestrian countdown signals, "Turning traffic must
yield to pedestrians" sign, in-roadway knockdown signs, high visibility crosswalk,
warning signs for motorists, regulatory signs for motorists, and advance yield markings.
However, the literature review did not identify any consistent and systematic evaluation
of the countermeasures. Identifying a broad range of MOEs for safety countermeasures
and evaluating the effectiveness of a set of countermeasures in a systematic way is the
main focus of this dissertation.
CHAPTER 3

METHODOLOGY TO EVALUATE PEDESTRIAN SAFETY

The main objective of this study is to evaluate the effectiveness of different countermeasures to enhance pedestrian safety. The countermeasures are intended to address safety problem characteristics. In this chapter, some problem characteristics and potential countermeasures to address these problem characteristics are discussed briefly. Measures of effectiveness to evaluate a countermeasure and an evaluation strategy are also discussed in Chapter 3.

3.1 Identify Problem Characteristics

Some of the problems road users encountered are discussed in this section. Identifications of these problems will be beneficial in selecting potential safety countermeasures. Some of these problems are related to safety of pedestrians and others are safety concerns for both pedestrians and motorists. These problems are as follows:

i. Pedestrians not using crosswalks,

ii. Inconspicuous crosswalks,

iii. Pedestrians trapped in the middle of the street while crossing,

iv. A high percentage of elderly pedestrians involved in crashes,

v. Inconspicuous pedestrian signals due to wide streets,
vi. Pedestrians and motorists not yielding the right of way,

vii. Pedestrians not waiting for signals or acceptable gaps before crossing,

viii. Conflicts between right turning vehicles and pedestrians,

ix. Speeding problems, and

x. A larger proportion of nighttime crashes.

3.2 Identify Potential Countermeasures

Countermeasures are intended to address the identified safety problems. Some of the potential countermeasures to address these problems are as follows (Transportation Research Center UNLV, 2004):

i. In-roadway knockdown signs: Problems to be addressed by installing “In-roadway knockdown sign” are pedestrian not using the crosswalk, pedestrian trapped in the middle of the street while crossing, and motorists failing to yield.

ii. Intelligent transportation systems (ITS) no right turn on red (RTOR): Some of the problems to be addressed by deploying ITS no RTOR signs are motorists’ failure to yield and a conflict between pedestrian / right turning vehicles.

iii. Warning sign for motorists: This sign is intended to address motorists’ failure to yield and conflicts between pedestrians and vehicles.

iv. Regulatory sign for motorists: Some of the problems to be addressed by installing “Regulatory signs for motorists” are motorists’ failure to yield and conflicts between pedestrians and vehicles.
v. Turning vehicles must yield to pedestrians: This sign is expected to address the following problems, motorists’ failure to yield and conflicts between pedestrians and right turning vehicles.

vi. Advance warning for motorists (roving eyes): The sign “Advance warning for motorists (roving eyes)” is expected to decrease motorists’ failure to yield and to decrease conflicts between pedestrians and vehicles.

vii. Pedestrian activated flashing yellow: Deployment of this signal is expected to decrease motorists’ failure to yield and to reduce vehicle speeds.

viii. Pedestrian countdown signals: Some of the problems to be addressed by deploying “Pedestrian countdown signals” are pedestrians trapped in the middle of the street while crossing and pedestrians who do not wait for signals. Animated eyes also can be installed on top of the “Pedestrian countdown signals” to alert pedestrians to look for turning vehicles. Therefore, the “Pedestrian countdown signals (animated eyes)” will be more beneficial for pedestrians to cross the road safely.

ix. Enlarged pedestrian signal heads: The deployment of the “Enlarged pedestrian signal head” is expected to decrease the high percent of elderly pedestrians involved in crashes, to make pedestrian signal heads more conspicuous, and to decrease pedestrians trapped in the middle of the street while crossing.

x. Advance yield markings: The installation of “Advance yield markings” is expected to increase motorists’ yielding.

xi. High visibility crosswalk: The installation of “High visibility crosswalk” is expected to increase pedestrian crosswalk usage, to increase crosswalk conspicuity, and to increase motorists’ yielding.
xii. Median refuge: The “Median refuge” is intended to address some of the existing problems: pedestrians trapped in the middle of the street, pedestrians who do not wait for acceptable gaps, and motorists’ failure to yield.

xiii. Danish offset: The “Danish offset” is expected to address the following problems: pedestrians trapped in the middle of the street while crossing, pedestrians’ failure to yield, and pedestrian who do not wait for acceptable.

xiv. Pedestrian channelization: The installation of “Pedestrian channelization” compels pedestrians to use crosswalks; therefore, more pedestrians are expected to use crosswalks.

xv. ITS automatic pedestrian detection devices: The “ITS automatic pedestrian detection devices” might result in reducing pedestrians who do not wait for signals, and also reduce pedestrians not crossing with acceptable gaps in traffic.

xvi. Portable speed trailer: Some of the targeted problems to be addressed by installing “Portable speed trailers” are motorists’ failure to yield and speeding.

xvii. Pedestrian call buttons that light up: The “Pedestrian call buttons that light up” reminds pedestrians to push the button while waiting before crossing.

xviii. Smart lighting: Some problems to be solved by the installation of “Smart lighting” are the high percentage of elderly pedestrians involved in crashes, motorists’ failure to yield, and the high percentage of nighttime crashes.

xix. In-pavement flashing light system: The “In-pavement flashing light system” is expected to increase motorists’ yielding, to decrease conflict between pedestrians and vehicles, and to reduce vehicle speed.
3.3 Measures of Effectiveness

Crashes are an appropriate MOEs for safety evaluation and effectiveness of any installed countermeasures to be evaluated. It is time-consuming and data need to be gathered for a long period to evaluate the impacts of countermeasures on crashes. Crashes are relatively rare events. However, there are other indicators of safety and the potential for crashes. Such indicators can be used to evaluate safety. Surrogate MOEs were identified to evaluate the effectiveness of countermeasures. Surrogate data were collected and analyzed to quantify the MOEs. Surrogate data used to derive MOEs are discussed in this section. Some of these MOEs are intended to quantify motorists’ behavior, others are for pedestrians’ behavior, and a few of them are intended for both motorists’ and pedestrians’ behavior. The list of MOEs used to quantify motorists’ and pedestrians’ behavior to evaluate the effectiveness of countermeasures is shown in Table 4.

3.4 Statistical Tests

The test for two proportions, the Welch-Satterthwaite t-test, and a paired t-test were used, based on the types MOEs evaluated. The evaluated MOEs based at a desired confidence level of 95 percent.

3.4.1 Test for Two Proportions

The test for two proportions, a statistical tool, was used to determine if the proportions obtained for the two populations are significantly different.
Let $P_1 =$ proportion of success of the population 1

$P_2 =$ proportion of success of the population 2

Then, the null hypothesis ($H_0$) is that the percentage of success in population 1 ($P_1$) and population 2 ($P_2$) are the same. The alternative hypothesis ($H_a$) is the percentage success in population 1 ($P_1$) is more than the percentage of success in population ($P_2$).

These hypotheses are expressed mathematically as follows:

$H_0: P_1 = P_2$, and

$H_a: P_1 < P_2$

The one-tailed test for proportions was used to test these hypotheses at the 95 percent confidence level.

Let $X_1 =$ number of success events of population 1 out of a total of $n_1$ observations

$X_2 =$ number of success events of population 2 out of a total of $n_2$ observations

The population proportions $P_1$ and $P_2$ are estimated by the sample proportions:

$\hat{P}_1 = \frac{X_1}{n_1}$ and $\hat{P}_2 = \frac{X_2}{n_2}$

For large sample sizes, the two sample proportions are approximately normally distributed (Navidi, 2004), and the Z-test for testing the equality of the two proportions vs. the 1-sided alternative can be used.

The test statistic used is $Z_0$, and it is defined as follows

$$Z_0 = \frac{\hat{P}_1 - \hat{P}_2}{\sqrt{\hat{P}(1 - \hat{P})\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

where

$$\hat{P} = \frac{X_1 + X_2}{n_1 + n_2}$$
$Z_0$ is distributed approximately $N(0, 1)$ when $H_0$ is true.

The significance probability or P-value for equality of proportions vs. the 1-sided alternative is calculated by:

$$P\text{-value} = P(Z < Z_0)$$

The null hypothesis is rejected if the P-value $< 0.05$ (for 95% confidence level).

Similarly, a two tailed test can also be performed. The two-tailed test for proportions was used to test these hypotheses at the 95 percent confidence level. The P-value is calculated from:

$$P\text{-value} = 2 P(Z > |Z_0|)$$

The null hypothesis of equal proportions is rejected if P-value $< 0.05$.

**Hypotheses test**

The null hypothesis, $H_0$, is the claim about the process and characteristics that is initially assumed to be true. The alternative hypothesis, $H_a$, is the claim that is different from $H_0$. The following is an illustration of the hypothesis testing procedure.

- $H_0$: $\mu_p = x$ (mean of sample proportion is the same for both the before and the after study)
- $H_a$: $\mu_p \neq x$ (mean of sample proportion is not the same for both before and after study)

Reject $H_0$ if, P-value $\leq \alpha$ or $z$-value $\geq z_\alpha$

Do not reject $H_0$ if, P-value $> \alpha$ or $z$-value $< z_\alpha$

The $z$-value is obtained from a statistical table. The value of $\alpha$ is taken as 5%. Either one-tailed or two-tailed test is conducted based on the countermeasures to be evaluated. The critical $z$-value corresponding to 95% confidence level is 1.645 (for two-tailed test).

In testing one-tailed test, null hypothesis claims that the mean of the before observation is less than or equal to the mean of the after observation. Then, an alternative hypothesis is
that the null hypothesis is not true, and thus the mean of the before observation is greater than the mean of the after observation. If the null hypothesis is set as the mean of the before observation is more than or equal to the mean of the after observation. The alternative hypothesis is then that the mean of the before observation is less than the mean of the after observation. The graphical illustration of the one-tail test is shown in Figure 1.

The two-tailed test is applicable when the compared values are not directionally sensitive. The null hypothesis claims that the two means, before study and after study, are same. If the means are different, in contrary to the assumption to set null hypothesis, then the hypothesis is referred as alternative hypothesis. The graphical illustration for the two-tail test is shown in Figure 2.

One of the limitations in using the Z-test for proportions is that the sample size in both of study periods should be the same.

3.4.2 The Welch-Satterthwaite t test

The Welch-Satterthwaite t test is used when the assumption that the two populations have equal variances seems unreasonable. It provides a t statistic that asymptotically approaches a t distribution as the sample sizes become large, allowing for an approximate t test to be calculated when the population variances are not equal. This test is different from the ordinary Student’s t distribution. The variances of the two groups are assumed equal in the Student’s t distribution (Samuels and Witmer, 1999).
Figure 1. One-tail hypothesis test.

Figure 2. Two-tail hypothesis test.
The Welch’s t-test will be used to identify the difference between means of independent samples. Let
\[
\mu_1 = \text{mean of population 1, or true average of treatment 1},
\]
\[
\mu_2 = \text{mean of population 2, or true average of treatment 2},
\]
\[
n_1 = \text{number of observations in the first sample (sample 1)},
\]
\[
n_2 = \text{number of observations in the second sample (sample 2)},
\]
\[
\bar{x}_1 = \text{sample mean of } n_1 \text{ observations},
\]
\[
\bar{x}_2 = \text{sample mean of } n_2 \text{ observations},
\]
\[
\sigma_1^2 = \text{sample variance of sample set 1},
\]
\[
\sigma_2^2 = \text{sample variance of sample set 2}
\]

Test statistic, \( t = \frac{\bar{x}_1 - \bar{x}_2 - \Delta}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \) (2)

Null hypothesis: \( H_0: \mu_1 - \mu_2 = \Delta \)

Alternate hypothesis: \( H_a: \mu_1 - \mu_2 \neq \Delta \)

A t-distribution with degree of freedom, \( n = \frac{\left(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}\right)^2}{\frac{s_1^4}{n_1^2(n_1 - 1)} + \frac{s_2^4}{n_2^2(n_2 - 1)}} \) (3)

The t-value is obtained from a statistical table corresponding to calculated degree of freedom, which is referred as \( t_{n,r} \). A \( \Delta \) denotes the null value or the difference between means and appropriate situation under consideration. Two samples are selected independently and are assumed to be normally distributed. If the sample sizes are more

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than 30 ($n_1>30$ and $n_2>30$) as per Central Limit Theorem normality assumption is no longer necessary.

3.4.3 Paired t test

A paired t-test is used when the observations on the two populations of interest are collected in pairs under homogeneous conditions. A set of $n$ paired of observations is taken. Let $X_{11}, X_{12}, \ldots, X_{1n}$ and $X_{21}, X_{22}, \ldots, X_{2n}$ be represented as the first pair and the second pair observations, respectively. The mean and variance are represented by $\mu_1$ and $\sigma_1^2$, respectively, for the first pair. Similarly, the mean and variance for the second pair observations are denoted by $\mu_2$ and $\sigma_2^2$, respectively. A hypothesis test about the difference between $\mu_1$ and $\mu_2$ is accomplished by performing a one-sample t-test on $\mu_D$, where $\mu_D$ is the difference between paired means (Montgomery and Runger, 2003).

The null hypothesis of no difference in means of two pairs vs. the 1-sided alternative is expressed as follows:

- $H_0$: $\mu_D = 0$
- $H_a$: $\mu_D > 0$

The test statistic computed from the sample is:

$$t_0 = \frac{\bar{D}}{S_D \sqrt{n}}$$

where $\bar{D}$ and $S_D$ are the mean and standard deviation of difference of sample speed observations.

The significance probability or P-value is calculated by:

$$P\text{-value} = P(t_{(d)} > t_0)$$

35
The calculated $t_0$ is compared with the obtained $t_{df}$ from a statistical table. The value of $t_{df}$ is based on the sample size and confidence level in which hypothesis is tested. If the obtained P-value is more than the critical $\alpha$-value, i.e., 0.05 at the 95 percent confidence level, then $H_0$ is accepted. Similarly, if the P-value is less than the $\alpha$-value, then $H_0$ is rejected at the 95 percent confidence level.

3.5 Statistical Tests for MOEs Evaluation

The z-test was used to evaluate the MOEs if the sample size was big to assume the normality of the sample distribution. If the sample size was at least 30 then the sample distribution can be considered as normal. Hence the z-test was used. A sample size less than 30 was considered as small. The distribution of the sample still being considered as normal and the t-test was used for statistical evaluation. In general, the Welch’s t-test was used for small samples. The list of evaluated MOEs, units of MOEs, and the performed statistical tests are shown in Table 5. The null hypothesis and alternative hypothesis for each MOE are shown in Table 6. The null hypothesis was that the values of MOEs during the before study period and the after study period were the same. The alternative hypothesis was set in two ways. In the first type, the values of MOEs during the before study period were more than those of the after study periods. Likewise, another type of alternative hypothesis was that the values of MOEs during the before study period was less than those of the after study periods. These types of hypotheses are depicted in Table 6.
### Table 5 List of MOEs and Statistical Tests

<table>
<thead>
<tr>
<th>Measures of Effectiveness</th>
<th>Units</th>
<th>Statistical Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percent</td>
<td>Others</td>
</tr>
<tr>
<td>1. Percentage of pedestrians / vehicles taking evasive actions</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>2. Pedestrians not completing roadway crossings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.1. Percentage of pedestrians who were in the crosswalk during the flashing DON'T WALK phase</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>2.2. Percentage of pedestrians who were in the crosswalk at the end of all-red</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>2.3. Percentage of pedestrians who were trapped in the middle of crossing</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>2.4. Percentage of pedestrians who crossed the second half of the intersection during the WALK phase</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>3. Percentage of pedestrians who violated signal (crossing during the DON'T WALK phase)</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>4. Percentage of pedestrians who pushed the call button</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>5. Percentage of pedestrians who pushed the call button and waited for the WALK phase</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>6. Percentage of pedestrians who did not push the call button and waited for the WALK phase</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>7. Percentage of pedestrians who violated signal that involved pedestrian started to cross during the pedestrian clearance phase</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>8. Percentage of drivers who yielded to pedestrians</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>8.1. Yielding distance to pedestrians by motorists</td>
<td>ft</td>
<td></td>
</tr>
<tr>
<td>8.2. Percentage of vehicles that blocked the crosswalk</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>8.3. Percentage of drivers executing right turn on red coming to complete stop</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>9. Percentage of pedestrians who looked at start of the WALK phase for turning vehicles</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>10. Pedestrian delay</td>
<td>sec</td>
<td></td>
</tr>
<tr>
<td>11. Vehicle speed</td>
<td>mph</td>
<td></td>
</tr>
<tr>
<td>12. Vehicular delay at intersections / midblock crossing</td>
<td>sec</td>
<td></td>
</tr>
</tbody>
</table>
Table 6 Hypothesis Tests for MOEs Evaluation

<table>
<thead>
<tr>
<th>Measures of Effectiveness (MOEs)</th>
<th>Null hypothesis</th>
<th>Alternative hypothesis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Values of MOEs</td>
<td>Values of MOEs</td>
</tr>
<tr>
<td></td>
<td>during (before</td>
<td>during (before study &gt;</td>
</tr>
<tr>
<td></td>
<td>study = after</td>
<td>after study)</td>
</tr>
<tr>
<td>1. Percentage of pedestrians / vehicles taking evasive actions</td>
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<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

3.6 Experiment Design

The data collection procedures are discussed in this section. The “before” and “after” study data were compiled and analyzed. Each MOE was analyzed at the 95 percent confidence level.
3.6.1 Longitudinal Research

Longitudinal or time series research design refers to the study over time using repeated measurements. There are some elements that are unique because such projects can extend over long periods (Beins, 2004). The effect of implemented countermeasures can be studied either a short or a long time span. A few examples of a long time series research are crash frequency per year, crash severity and distribution of crashes per year, etc. These MOEs can be measured in long time span. In this research, only a short time span observation was done.

3.6.2 Cross-sectional Research

A study, in which, researchers group different characteristics at the same time. This strategy is contrast to a longitudinal approach that studies the same individuals over time. Snap shot data were collected and analyzed, for example pedestrians' and motorists' behaviors. The most of the obtained data in this research are based on the cross-sectional research.

3.6.3 Methods of Research Design

Basically, three research design techniques are in practice, and these are discussed next (Beins, 2004):

3.6.3.1 Withdrawal Designs

In this design method, a baseline study is conducted and intervention (i.e., deployment of one or more of countermeasures) follows. Data pertaining to the behavior of interest are collected during treatment phase. Then, a treatment is removed and the conditions are returned to baseline phase. It also refers to ABA design, the letter A refers
to the baseline period and the letter B refers to the treatment phase. The ABA design strategy helps to understand the cause and effect relationship due to the intervention.

3.6.3.2 ABAB Designs

This is a type of withdrawal design that uses a baseline period followed by an intervention, an intervention will be removed and reapplication of an intervention. If there are two different interventions, the design is designated as AB₁AB₂. B₁ and B₂ are two types of interventions.

3.6.3.3 Multiple Baseline Design

A design method which studies multiple behaviors of an intervention may change across baseline and withdrawal process. The same or a different behavior of interest will be noted in different settings of the multiple baseline design. Data will be collected during the baseline, and then a treatment will be applied. This design strategy will follow the same logic as the withdrawal and ABAB designs.

However, in this research, data were collected prior to installation (before condition) and data were collected after installation of a countermeasure (after condition). In most cases, the installed countermeasure was left at site except a portable speed trailer.

3.6.4 Revealed Preferences

Modeling based on information about observed choices and decisions is called revealed preferences (RP). RP information means data about actual or observed choices made by individuals (Ortuzar and Willumsen, 2001). These were deduced from observations and not through direct feedback. The observed pedestrians’ and motorists’ behaviors are examples of revealed preferences.
3.6.5 Stated Preferences

Information is sought about what a respondent would do in one or more hypothetical situations. A common problem with stated preference data is how much faith could be put on individuals actually doing what they stated they would do when the situation arises. Respondents' preferences for each option are ranked in order of attractiveness. The strength of preference or choosing best option among a group can be rated in a rating scale. The rating score can be divided from 1 to 5; 1 is poor and 5 is excellent. Alternatively, rating scale can be excellent to poor without having numbers. A user survey about the performance of the installed countermeasure is an example of stated preference.

In this research, the revealed preference strategy was used to obtain data of the identified MOEs.

3.6.6 Sampling Strategy

At least 30 samples are taken from each site and the corresponding information is recorded. In practice, if the sample size is at least 30, then the distribution of a sample can be approximated as a normal distribution.

Data were collected under various traffic conditions. Attempts were made to obtain statistically significant sample sizes for all identified MOEs. Data were obtained at various stages of implementation plan based on the identified MOEs.
3.7 Deploy Countermeasures

Different countermeasures were deployed at various sites. The existing condition data were collected before implementing any of the proposed countermeasures. Data were collected after the implementation of each countermeasure. Some of the countermeasures were evaluated independently and the others were evaluated in a group. However, sufficient time was allowed after implementing countermeasures prior to post study data collection. A minimum gap of approximately three to four weeks was provided between implementation of countermeasures and the after-condition data collection. This strategy is to reduce the novelty effects on road users who might have been influenced by the implemented countermeasures. A qualitative analysis and a quantitative analysis were used to evaluate the effectiveness of each strategy.

Several statistical tools were used to evaluate the deployed countermeasures. The types of statistical tools were based on the considered MOEs for evaluation. In some cases, several statistical tools were also used to evaluate a countermeasure. The statistical tools that were used for MOEs are shown in Table 5.

3.8 Data Collection

Field observations were conducted before and after deployment of countermeasures at site to obtain required data to derive the MOEs. Data were collected to identify and support the selected countermeasures at each site. Example of data collected include traffic volume, pedestrian volume, pedestrian information, and pedestrian crossing behavior. Pedestrian information included gender, age, and ethnicity. Different data collection strategies were used for intersections and midblock locations. The observed
pedestrian crossing behaviors at intersections were crossing direction, crosswalk usage, pedestrians trapped in the middle of the street while crossing, crossing distance from the crosswalk (if not using crosswalk), waiting time before crossing, purpose of the trip, and yielding behavior. Similarly, the observed pedestrian crossing behaviors at midblock locations were as follows: crossing direction, trapped in the middle of the street while crossing, distance of crossing from the nearest intersection, waiting time for an acceptable gap, and yielding behavior. In general, the pedestrians' activities approximately 200 feet on either side of the intersections were observed. At midblock locations, pedestrians' activities between intersections were observed.

Data pertaining to pedestrians, motorists, and traffic conditions were collected to evaluate the effectiveness of each countermeasure. Different types of required data for evaluation are listed as follows:

3.8.1 Crash Frequency (Pedestrian Crashes / Year)

Pedestrian crash data were obtained for the period from 1996 to 2000 within the Las Vegas metropolitan area. Based on this primary data, high crash locations in the Las Vegas metropolitan area were identified. Countermeasures were also selected based on the high crash locations as well as the type of crashes. The GIS crash database includes pedestrian and vehicle crashes, excluding crashes in parking lots.

3.8.2 Crash Severity (Distribution of Crashes by Injury Type / Year)

The severity of crash data and their distribution within the Las Vegas metropolitan area were collected. In general, pedestrian crashes are divided into two categories: fatal and injury. Likewise, vehicle crashes are categorized as follows: fatal, injury, and
property damage only (PDO). Specifically, crash severities are categorized on a 1 to 5 scale, where 1 is a crash with no injury and 5 is a fatal crash. Alternatively, the severity of crashes is divided into five categories as follows: fatal injury (K), incapacitating injury (A), non-incapacitating injury (B), no visible injury but complaint of pain (C), and no injury, property damage only (O), which is also referred as the KABCO injury scale (Zajac and Ivan, 2003).

3.8.3 Pedestrian and Vehicle Conflicts

A conflict is defined to occur when a motorist or a pedestrian has to change a course or speed to avoid a collision. Conflicts were observed only in the presence of a motorist and a pedestrian, or when an interaction occurred between a motorist and a pedestrian while a pedestrian is crossing. Only one event is noted when both a motorist and a pedestrian have taken actions to avoid collision. Evasive actions include a motorist stopping or swerving to avoid striking a pedestrian, or a pedestrian jumping back, suddenly stepping back, lunging backward or running forward to avoid being struck by a vehicle. Conflicts were scored from real-time field observations. Conflicts are expressed in terms of the total number of interactions between a motorist and a pedestrian while a pedestrian is crossing. The percentage of conflict is obtained by dividing the total observed conflicts by the total interaction events between a motorist and a pedestrian during the study period. Let X is the number of conflict events during the study period and Y is the total number of non-conflict events. The percentage of conflict is expressed as \([X/(X+Y)]*100\%\).
3.8.4 Pedestrian Not Completing Roadway Crossings

The data pertaining to pedestrians on the roadway or crosswalk can be divided into the following categories:

3.8.4.1 Pedestrians in the Crosswalk during the Flashing DON'T WALK Phase

The number of pedestrians in or near the crosswalk was counted when the flashing DON'T WALK appeared on the pedestrian signal. The corresponding percentage of total pedestrians crossing during the observation period was calculated. Data were collected from real time field observations. It was reported in terms of the percentage of total observed pedestrians.

3.8.4.2 Percentage of Pedestrians in the Crosswalk at the End of All-Red

The number of pedestrians in or near the crosswalk who initiated crossing before the solid DON'T WALK pedestrian signal that were still in a traffic lane after the cross street traffic received the green signal was counted. These pedestrians were reported in terms of the percentage of total observed pedestrians.

3.8.4.3 Frequency of Pedestrians Trapped in the Middle of Crossing

The number of pedestrians who were trapped in the middle of uncontrolled locations for at least 5 seconds was counted. Pedestrians were scored as trapped in the middle at the centerline or between lanes if they waited 5 seconds or more for a gap in traffic or the next WALK phase to finish crossing. These observations were converted into the percentage of total observed pedestrians.
3.8.4.4 Percentage of Pedestrians Who Crossed the Second Half of the Intersection During WALK Phase

Pedestrians were scored when they finished the second half of the crosswalk during the WALK pedestrian signal. The corresponding percentage of the total pedestrians who completed crossing the second half of the crosswalk during the WALK signal was also calculated.

3.8.5 Pedestrian Signal Violations (Crossing During the DON’T WALK Phase)

A pedestrian is considered to be a signal violator if the pedestrian steps in or near the crosswalk from the curb when the solid DON’T WALK sign is displayed on the pedestrian signal head. Such violators were reported as a percentage of the total pedestrians observed during the study period.

3.8.6 Percentage of Pedestrians Who Pushed the Call Button

Pedestrians were scored if they pushed the call button when the solid DON’T WALK signal or the flashing DON’T WALK signal was displayed. These data were converted to the percent of the total pedestrians that cross at a signalized intersection or a signalized midblock crosswalk.

3.8.7 Percentage of Pedestrians Who Pushed the Call Button and Waited for the WALK Phase

Pedestrians who crossed at a signalized intersection or a signalized midblock crosswalk pushed a call button and waited for the WALK signal before crossing were counted. These data were converted into the percentage of the total counted pedestrians during the study period.
3.8.8 Percentage of Pedestrians Who Did Not Push the Call Button and Waited for the WALK Phase

The percentage of pedestrians who crossed at a signalized intersection or a signalized midblock crosswalk and did not push a call button but waited for the WALK signal before crossing were recorded.

3.8.9 Percentage of Drivers Who Yielded to Pedestrians

Drivers' yielding behavior to pedestrians was recorded. In particular, the yielding behavior of a motorist at the crosswalk, right-turning on red, and yielding distance from the crosswalk was recorded. At signalized intersections, drivers who stop or slow to allow pedestrians to cross in front of them before proceeding were observed. Motorists yielding behavior was only scored when pedestrians had the right of way (i.e., during the WALK phase or during the flashing DON'T WALK phase if pedestrian started crossing when the WALK signal was displayed). Drivers' yielding behavior was presented in terms of the percentage of the total observations. The collected data pertaining to motorists yielding behavior will be discussed next.

3.8.9.1 Distance Vehicle Yields Upstream of the Crosswalk

Marks were placed on the curb at 10 feet intervals upstream of the crosswalk. Observers recorded the distance from the furthest mark whether the motorists stopped or slowed. The yielding distance of motorists was scored only at the moment the pedestrian crossed in front of the target vehicle because this was the critical point for visual screening.
3.8.9.2 Percentage of Vehicles That Blocked the Crosswalk

The frequency of vehicles blocking the crosswalk at locations with traffic signals observed. The number of vehicles that blocked the crosswalk during the study period was recorded. A vehicle was scored as blocking the crosswalk when the vehicle blocked at least half of the crosswalk. These data were converted into the percentage of total observed vehicles during the study period.

3.8.9.3 Percentage of Drivers Who Turn Right on Red Coming to Complete Stop

Drivers were scored as coming to a complete stop if their wheels stopped turning before they entered the crosswalk. Drivers were scored as right turn on red (RTOR) coming to rolling stop if the vehicle slowed considerably, but the wheels did not stop turning before entering the crosswalk. If drivers turned without appreciably slowing, they were scored as RTOR without slowing. This MOE was reported in terms of the percentage of total observed vehicles during the study period.

3.8.9.4 Percentage of Drivers Yielding to Pedestrians in the Crosswalk

At controlled locations where pedestrian and vehicular movements were controlled by a traffic signal, motorists' yielding behavior was only scored when the pedestrian had the right of way (i.e., pedestrian was in the crosswalk when the WALK sign or the flashing DON'T WALK sign was illuminated). Drivers were scored as yielding when they stopped or slowed to allow the pedestrian to cross in front of them before proceeding. Drivers were scored as not yielding if they turned within a lane of pedestrian's intended path.
At uncontrolled locations, a motorist is scored as yielding if he or she stops or slows, allowing the pedestrian to cross. A motorist is scored as unyielding if he or she passes in front of the pedestrian but would have been able to stop when the pedestrian arrived at the crosswalk. The problem is essentially the same as in calculating the distance that a motorist driving the speed limit can stop for a traffic signal that changes to red using the signal-timing formula (Pline, 1992). This takes into account driver reaction time, safe deceleration rate, posted speed limit, and the grade of the road. The required distance for motorists to stop their vehicle safely within perception and break reaction time is called stopping sight distance (SSD). The SSD is the sum of the distance traveled during the brake reaction time and the distance to break the vehicle to stop. According to AASHTO (2001) the stopping sight distance is given as follows:

\[
d = 1.47Vt + 1.075 \frac{V^2}{a}
\]  

(5)

where,

\[
d = \text{SSD, feet;}
\]

\[
t = \text{brake reaction time, s;}
\]

\[
V = \text{design speed, mph;}
\]

\[
a = \text{deceleration rate, 11.2 feet/s}^2
\]

Equation 5 can be used to determine the distance beyond which a driver can safely stop for a pedestrian, and a mark can then be placed on the sidewalk at this distance upstream on each approach to the crosswalk. Motorists downstream of this marking after the pedestrian has entered the roadway can be scored as yielding to pedestrians, but not for failing to yield. Motorists upstream of the landmark when the pedestrian entered the
crosswalk can be scored as yielding or not yielding because they have sufficient distance to safely stop. When the pedestrian first starts to cross, only drivers in the first half of the roadway should be scored for yielding. Once the pedestrian approaches within half a lane of the painted median, the yielding behaviors of motorists in the remaining lanes can be scored.

3.8.9.5 Percentage of Turning Drivers Yielding to Pedestrians

Yielding behavior of right-turning as well as left-turning motorists is scored. Yielding behavior of right turning motorists was observed, especially where right turn on red was permitted.

3.8.10 Percentage of Pedestrians Who Looked at Start of the WALK Phase for Turning Vehicles

Pedestrians were scored as looking for vehicles when they looked in the direction of a potential threat before entering the conflict path. Pedestrians must be observed to look in all potential threat directions to count as a successful activity (i.e., partial activity can be looking only for through traffic and not right turners). Pedestrians must look back over their shoulder to look for turning vehicles when the turning left or right initiates the turn from a position behind the pedestrian. Looking for a vehicle initiating a right turn or a left turn from a position ahead of them, the pedestrian must look ahead and not down or away from the threat. Pedestrians must look to the side for RTOR vehicle. These data were reported in terms of the total observed pedestrians during the study period.
3.8.11 Pedestrian Delay

Pedestrian delay is the time a pedestrian has to wait before crossing the street at a marked or unmarked crosswalk. The duration starts when the pedestrian is first oriented to make the crossing and ends when they begin to cross. Pedestrian delays were measured using a stopwatch. The stopwatch was started at the beginning of the flashing DON'T WALK. Each time a pedestrian came to a crossing area and prepared to cross the street, the time on the stopwatch was recorded for that pedestrian. When the WALK signal was displayed, the time on the stopwatch was recorded. The difference in time the WALK signal was displayed and the time that each pedestrian prepared to cross the street was the individual pedestrian delay. The delay was averaged and reported based on the total observation. Pedestrian signal violators were not scored (i.e., pedestrians crossing during the flashing DON'T WALK phase or during the solid DON'T WALK phase).

3.8.12 Vehicle Speed

Average vehicle speeds were measured using the space mean speed technique. A length of segment on the upstream and the downstream of an intersection was measured and the corresponding time taken by a vehicle to travel this segment was recorded. The same strategy was used at midblock locations. Vehicle speed was measured upstream and downstream of the crossing location.

3.8.13 Vehicle Delay at Intersections / Midblock Crossing

Vehicle delay is defined as the average amount of time a vehicle is stopped waiting at a traffic signal and/or yielding to a crossing pedestrian. The average vehicle stopped delay was measured using a delay study. Standard methodologies for conducting stopped
delay studies at signalized intersections were used (Roess, McShane, and Prassas, 1998). The average vehicle stopped delay for an approach was reported.
CHAPTER 4

PROBLEM IDENTIFICATION AND EVALUATION PLAN

A brief description of some of the high-risk locations and deployed countermeasures at these locations are discussed in Chapter 4. Likewise, site description and evaluation plan of countermeasures are discussed in this chapter. This research is a part of a project funded by the Federal Highway Administration (FHWA) in cooperation with local agencies. Local agencies include the Nevada Department of Transportation (NDOT), Clark County, the City of Las Vegas, and the City of North Las Vegas. The data collection strategy is designed and implemented by coordinating with local agencies within the Las Vegas metropolitan area. Correspondence was made with the local agencies to deploy countermeasures on sites. The list of different deployed countermeasures at various sites within the Las Vegas metropolitan area will also be described in Chapter 4.

4.1 Problem Locations and Potential Countermeasures

High crash zones were identified by using the geo-coded pedestrian crash data (Pulugurtha and Nambisan, 2002). A zoning methodology recommended by the National Highway Traffic Safety Administration (NHTSA) was used to identify high crash locations. The geo-coded pedestrian crash data were overlaid on the GIS coverage with
zip codes in the Las Vegas metropolitan area. The pedestrian crash rate per capita of each zip code was calculated by using the population within the zip code area. Two crash indices were used to identify and rank pedestrian high crash zones. The crash indices were calculated based on pedestrian crashes in the vicinity of a zone, severity of crashes, and length of the zone (corridor). The crash indices, Crash Index 1 and Crash Index 2, were obtained by multiplying the pedestrian crashes per mile in a zone by a weighted factor and divided by 100. However, the weighted factors for both indices were calculated differently. The weighted factor for Crash Index 1 was simply obtained by dividing the total number of fatal and severe injury crashes by the length of the zone. The weighted factor for Crash Index 2 was obtained by dividing the total number of fatal crashes times 5, and severe injury crashes times 3, by the length of the zone. They formulated these crash indices mathematically as follows (Pulugurtha and Nambisan, 2002):

\[
\text{Crash Index } 1_{\text{zone}} = \frac{\# \text{ Ped Crashes}_{\text{zone}} \times \# \text{ Fatal Ped Crashes}_{\text{zone}} + \# \text{ Severity Injury Ped Crashes}_{\text{zone}}}{\text{Length}_{\text{zone}} \times 100}
\]

\[
\text{Crash Index } 2_{\text{zone}} = \frac{\# \text{ Ped Crashes}_{\text{zone}} \times 5 \times \# \text{ Fatal Ped Crashes}_{\text{zone}} + 3 \times \# \text{ Severity Injury Ped Crashes}_{\text{zone}}}{\text{Length}_{\text{zone}} \times 100}
\]

The crash zones were ranked based on either Crash Index 1 or Crash Index 2. The ranking of each zone and corresponding crash indices are presented in Table 7.
Table 7 Crash Indices and Ranking of Various Zones in Las Vegas valley

<table>
<thead>
<tr>
<th>Zone #</th>
<th>Zones</th>
<th>Crash Indices</th>
<th>Ranking Based on Crash Indices</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Maryland Parkway (Flamingo Wash - Sierra Vista Drive)</td>
<td>8.96 31.37</td>
<td>1 1</td>
</tr>
<tr>
<td>2</td>
<td>Harmon Avenue (Paradise Road - Las Vegas Boulevard)</td>
<td>8.13 28.46</td>
<td>2 2</td>
</tr>
<tr>
<td>3</td>
<td>Flamingo Road (Paradise Road - Las Vegas Boulevard)</td>
<td>7.62 26.68</td>
<td>3 3</td>
</tr>
<tr>
<td>4</td>
<td>Bonanza Road (D Street - H Street)</td>
<td>6.84 26.60</td>
<td>4 4</td>
</tr>
<tr>
<td>5</td>
<td>Twain Avenue (Cambridge Street - Palos Verdes Street)</td>
<td>5.00 22.50</td>
<td>7 5</td>
</tr>
<tr>
<td>6</td>
<td>Lake Mead Boulevard (Pecos Road - Las Vegas Boulevard)</td>
<td>5.13 15.81</td>
<td>6 6</td>
</tr>
<tr>
<td>7</td>
<td>Fremont Street (15th Street - 6th Street)</td>
<td>5.14 15.43</td>
<td>5 7</td>
</tr>
<tr>
<td>8</td>
<td>Desert Inn Road / Boulder Highway</td>
<td>3.26 11.23</td>
<td>8 8</td>
</tr>
<tr>
<td>9</td>
<td>Charleston Boulevard (Eastern Avenue - Las Vegas Boulevard)</td>
<td>2.68 9.12</td>
<td>9 9</td>
</tr>
<tr>
<td>10</td>
<td>Maryland Parkway (Desert Inn Road - Sahara Avenue)</td>
<td>1.94 6.46</td>
<td>10 10</td>
</tr>
<tr>
<td>11</td>
<td>Bonanza Road (Eastern Avenue - Las Vegas Boulevard)</td>
<td>1.36 4.54</td>
<td>11 11</td>
</tr>
<tr>
<td>12</td>
<td>Downtown</td>
<td>1.11 3.97</td>
<td>12 12</td>
</tr>
<tr>
<td>13</td>
<td>Charleston Boulevard (Nellis Road - Pecos Road)</td>
<td>1.03 3.55</td>
<td>13 13</td>
</tr>
<tr>
<td>14</td>
<td>Tropicana Avenue (Pecos Road - Spencer Street)</td>
<td>0.96 3.25</td>
<td>14 14</td>
</tr>
<tr>
<td>15</td>
<td>Flamingo Road / Boulder Highway (1200 ft)</td>
<td>0.87 2.61</td>
<td>15 15</td>
</tr>
<tr>
<td>16</td>
<td>Maryland Parkway (Tropicana Avenue - Flamingo Road)</td>
<td>0.40 1.21</td>
<td>16 16</td>
</tr>
</tbody>
</table>

Source: Pulugurtha and Nambisan (2002)

Some of the identified crash problems in the Las Vegas metropolitan area along the high risk crash locations are pedestrian crashes at signalized intersections, pedestrian crashes at midblock locations, and pedestrian crashes involving children and senior citizens.

The top nine zones based on the pedestrian crash indices were chosen as high risk pedestrian locations. Again based on the geo-coded pedestrian crash data within a zone, several sites were identified for deployment of potential countermeasures. Altogether 19 sites were identified from nine zones. Out of the 19 sites, countermeasures were proposed to be deployed at 14 sites, and the remaining five sites were considered control sites. These locations and corresponding zones are presented in Table 8. The high risk locations are also shown in Figure 3.
Table 8 Pedestrian High Risk Locations in Las Vegas Valley

<table>
<thead>
<tr>
<th>Site #</th>
<th>Locations</th>
<th>Zone Name and Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Maryland Parkway / Sierra Vista Drive</td>
<td>Maryland Parkway (Flamingo Wash - Sierra Vista Drive), (1)</td>
</tr>
<tr>
<td>2</td>
<td>Maryland Parkway / Dumont Street</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Maryland Parkway / Twain Avenue*</td>
<td>Harmon (Paradise Road - Las Vegas Boulevard), (2)</td>
</tr>
<tr>
<td>4</td>
<td>Harmon Avenue / Paradise Road</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Harmon Avenue: Paradise Road to Tropicana Wash</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Harmon Avenue / Las Vegas Boulevard</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Flamingo Road / Koval Lane</td>
<td>Flamingo Road (Paradise Road - Las Vegas Boulevard), (3)</td>
</tr>
<tr>
<td>8</td>
<td>Flamingo Road / Paradise Road*</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Bonanza Road / D Street</td>
<td>Bonanza Road (D Street - H Street), (4)</td>
</tr>
<tr>
<td>10</td>
<td>Bonanza Road / F Street</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Twain Avenue: Cambridge Street to Swenson Street</td>
<td>Twain Avenue (Cambridge Street - Palos Verdes Street), (5)</td>
</tr>
<tr>
<td>12</td>
<td>Twain Avenue: Swenson Street to Palos Verdes Street</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Lake Mead Boulevard / Las Vegas Boulevard</td>
<td>Lake Mead Boulevard (Pecos Road - Las Vegas Boulevard), (6)</td>
</tr>
<tr>
<td>14</td>
<td>Lake Mead Boulevard / McDaniel Street*</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Lake Mead Boulevard: Belmont Street to McCarran Street</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Lake Mead Boulevard / Pecos Road</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Fremont Street: 11th Street to 8th Street*</td>
<td>Fremont Street (15th Street - 6th Street), (7)</td>
</tr>
<tr>
<td>18</td>
<td>Fremont Street: 8th Street to 6th Street</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Charleston: Spencer Street to 17th Street</td>
<td>Charleston Boulevard (Maryland Parkway - Eastern Avenue), (9)</td>
</tr>
</tbody>
</table>

Source: Pulugurtha and Nambisan (2002), *Control sites

4.2 Site Descriptions

Nineteen sites were selected within the Las Vegas metropolitan area for implementation and evaluation of different safety strategies (Transportation Research Center UNLV, 2004). The countermeasures deployed at 6 out of 19 sites were evaluated in this dissertation. The general characteristics of these sites, identified problems, and potential deployed countermeasure are discussed next.
Figure 3. Study locations in the Las Vegas metropolitan area.

Source: Transportation Research Center UNLV (2004)
4.2.1 Harmon Avenue / Paradise Road

A mixed land use pattern is observed around the intersection. Land use is classified as residential, commercial, and recreational (hotels and casinos) in the vicinity of Harmon Avenue / Paradise Road. Harmon Avenue / Paradise Road is a signalized four-legged intersection. Both roads are classified as minor arterials with posted speed limits of 35 mph. Traffic counts, average daily traffic (ADT), along this segment of Harmon Avenue and Paradise Road are 18,000 and 41,000, respectively (NDOT, 2004). Problems identified at Harmon Avenue / Paradise Road are pedestrians not waiting for signals or acceptable gaps before crossing the streets, and conflicts between right turning vehicles and pedestrians. The proposed countermeasure to address these identified problems is the “Turning traffic must yield to pedestrians” sign. The proposed countermeasure is intended to caution motorists in advance. The proposed sign is expected to make motorists alert about the presence of pedestrians downstream of the intersection.

4.2.2 Bonanza Road / D Street

Both roads, Bonanza Road and D Street, are classified as minor arterials. The posted speed limits along Bonanza Road and D Street are 35 mph and 25 mph, respectively. The intersection, Bonanza Road / D Street, is a three-legged signalized intersection (T intersection). Bonanza Road spans east-west and D Street has only the north approach of the intersection. The ADT along Bonanza Road is 16,500 (NDOT, 2004). Some of the problems observed at Bonanza Road / D Street are pedestrians not using the crosswalks, inconspicuous crosswalks, pedestrians trapped in the middle of the street while crossing, motorists failing to yield, pedestrians failing to yield, and pedestrians not waiting for signals or acceptable gaps.
The installation of “In-roadway knockdown signs” informs motorists about pedestrians’ activities in the vicinity, and it also reminds motorists that the state law is that motorists must yield pedestrians in the crosswalk. The installation of “In-roadway knockdown signs” is expected to increase motorists’ yielding behavior to pedestrians.

4.2.3 Bonanza Road / F Street

Both roads, Bonanza Road and F Street, are classified as minor arterials. The posted speed limits along Bonanza Road and F Street are 35 mph and 25 mph, respectively. The intersection of Bonanza Road and F Street is a four-legged signalized intersection. The ADT along Bonanza Road is 16,500 (NDOT, 2004). The identified problems at Bonanza Road / F Street are pedestrians not using the crosswalks, inconspicuous crosswalks, motorists failing to yield, and pedestrians failing to yield.

The “In-roadway knockdown” sign reminds drivers the presence of pedestrians activities in the upstream and of the state law to yield to pedestrians in crosswalks. The deployment of this strategy is expected to increase motorists yielding.

4.2.4 Lake Mead Boulevard / Pecos Road

Land uses adjacent to the corridor include several small commercial activity units, restaurants, single family dwelling units, and high density residential apartments. Both roads are classified as minor arterials. The intersection of Lake Mead Boulevard and Pecos Road is a four-legged signalized intersection. The posted speed limits along Lake Mead Boulevard and Pecos Road are 35 mph and 35 mph, respectively. The ADT along Pecos Road is 23,100 (NDOT, 2004). The problems identified are motorists failing to yield, pedestrians failing to yield, pedestrians not waiting for signals / acceptable gaps,
and conflict between pedestrian and right turning vehicle. The proposed countermeasure is “Turning traffic must yield to pedestrians” sign.

The sign “Turning traffic must yield to pedestrians” is installed mast-arm and approximately 100 feet upstream of the intersection. This is to alert motorists in advance to yield if pedestrians are present. The installation of the sign is expected to help to enhance motorists’ awareness and yielding, to reduce conflicts between pedestrians and right turning vehicles.

4.2.5 Fremont Street: 8th Street to 6th Street

Land uses adjacent to the corridor include hotel / casinos and other commercial activities. Fremont Street between 8th Street and 6th Street, a midblock location, is classified as a minor arterial and the posted speed limit is 25 mph. The ADT at Fremont Street is 14,200 along this corridor (NDOT, 2004). Some of the problems identified at this location are pedestrians not using the crosswalks, a high percentage of elderly pedestrians involved in crashes, and pedestrians failing to yield. Speeding is another observed problem at this corridor. “Portable speed trailer” is installed at this location. The installation of a “Portable speed trailer” is expected to make motorists aware of the posted speed limit and the traveled speed, and in turn to reduce their speed.

4.2.6 Charleston Boulevard: Spencer Street to 17th Street

Land use classification along Charleston Boulevard between Spencer Street and 17th Street is office complexes, several small commercial activity units, restaurants, and apartments. Charleston Boulevard between Spencer Street and 17th Street is a midblock location. The posted speed limit is 35 mph. The ADT along Charleston Boulevard is
29,700 at the study area (NDOT, 2004). Some of the identified problems are pedestrians not using the crosswalks, a high percentage of elderly pedestrian involved in crashes, motorists failing to yield, pedestrians not waiting for signals / acceptable gaps, and more nighttime crashes. The proposed countermeasures are “Advance yield markings,” “Regulatory sign for motorists,” “Warning sign for motorists,” and “High visibility crosswalk treatment.”

No crosswalk was present at this midblock location. However, pedestrians used crosswalks located at proximate intersections. A “High visibility crosswalk” treatment is proposed at this location so as to help reduce jaywalking in the vicinity. “Advance yield marking” upstream of the crosswalk directs a motorist to yield to pedestrians in the crosswalk. A yield sign with a pedestrian pictograph is installed on the curb upstream of the crosswalk to remind motorists to yield for pedestrians.

4.2.7 Burkholder Boulevard

The study area is located along Burkholder Boulevard in the City of Henderson, in the southeast part of the Las Vegas metropolitan area, Nevada, USA. Two driveways, one on either side, are located proximate to the study location. The driveway on the north side, Cinnamon Ridge, provides access to a residential complex and the driveway on the south side is to access a park. Burkholder Boulevard consists of two through lanes, one left turning, and one curb lane in both directions. A schematic sketch of the study location is shown in Figure 4. The curb-to-curb length of the crosswalk is 84 feet. The posted speed limit is 35 mph and the average traffic volume is about 300 vehicles per hour per direction during peak hours along Burkholder Boulevard. The in-pavement lights are placed on both the upstream and downstream edges of the crosswalk. These
lights are activated by pedestrian push buttons located on either side of the street. Yield markings are placed 45 feet and 77 feet in advance of the crosswalk on eastbound and westbound direction, respectively. On both sides of the street “yield here to pedestrian” signs with pedestrian’s pictogram (Manual on Uniform Traffic Control Devices code is R1-5) are also placed.

Figure 4. Schematic layout of the study location at Burkholder Boulevard.
Source: Karkee, Namhisan, and Pulugurtha (2005)

4.2.8 Green Valley Parkway / Warm Springs

Land use classification proximate to this site is several small commercial activity units and residential complexes. The posted speed limits are 35 mph and 40 mph along Green Valley Parkway and Warm Springs, respectively. The ADT, along Green Valley
Parkway and Warm Springs are 31,000 and 29,600, respectively proximate to the study area (NDOT, 2004). Pedestrian countdown signals were installed at this site.

4.2.9 Sunset Road / Marks Street

Land use proximate to this site are several small commercial activity units and restaurants. The posted speed limits are 45 mph and 35 mph along Sunset Road and Mark Street, respectively. The ADT, along Sunset Road and Mark Street are 48,000 and 8,000, respectively proximate to the study area (NDOT, 2004).

The City of Henderson decided to replace the existing conventional pedestrian signal head with pedestrian countdown signals at two locations in November 2004. The two intersections, Green Valley Parkway / Warm Springs Road and Sunset Road / Marks Street, were considered for this study. Both of these sites are located in the City of Henderson, Nevada, USA, the southeast part of the Las Vegas metropolitan area.

4.3 Types of Countermeasures

This section deals with various types of innovative engineering countermeasures evaluated in this dissertation. Most of these countermeasures are comparatively novel in the State of Nevada. The countermeasures further divided into three categories. They are described next.

4.3.1 Signs

Various signs are proposed to be installed at high risk locations. The proposed signs are “In-roadway knockdown signs,” “Warning signs for motorists,” “Regulatory signs for
motorists,” and “Turning traffic must yield to pedestrians.” They will be discussed in detail next.

### 4.3.1.1 In-Roadway Knockdown Signs

The intent of the “In-roadway knockdown” sign is to remind motorists to yield for pedestrians in crosswalks. The “In-roadway knockdown sign,” which is shown in Figure 5, was installed upstream of the crosswalk. In Nevada, pedestrians in crosswalks and at intersections have the right-of-way (Nevada Department of Motor Vehicles, 2004). The “In-roadway knockdown” sign is suitable for unsignalized intersections and midblock locations. “In-roadway knockdown” signs shall not be installed at signalized locations because they may provide wrong information to motorists. The “In-roadway knockdown” sign is proposed to be installed along the centerline or median of the street. The MUTCD (2003 Edition) code of the proposed “In-roadway knockdown” sign upstream of the crosswalks is R1-6. Problems to be addressed by installing “In-roadway knockdown signs” are pedestrians not using the crosswalk, pedestrians trapped in the middle of the street while crossing, and motorists failing to yield.

### 4.3.1.2 Warning Sign for Motorists

The “Warning sign for motorists” provides information about the presence of pedestrians. Signs with pedestrian pictographs were installed upstream of the crosswalk to alert motorists of the potential presence of pedestrians. A black pedestrian pictograph on a diamond shaped fluorescent yellow green background was used. The illustration of this sign is shown in Figure 6. The MUTCD (2003 Edition) code of the proposed “Warning sign for motorists” is W11-2.

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Figure 5. In-roadway knockdown sign (R1-6).
Source: MUTCD, 2003 Edition

Figure 6. Warning sign for motorists.
Source: Transportation Research Center UNLV (2004)

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4.3.1.3 Regulatory Sign for Motorists

The "Regulatory signs for motorists" were installed upstream of the crosswalk locations. This sign was installed with "Advance yield markings." The "Regulatory signs for motorists" were installed 20 to 50 feet in advance of the nearest crosswalk line at unsignalized crosswalk locations (MUTCD 2003). The objective of this countermeasure is to enhance visibility and minimize inappropriate perceptions between pedestrians and motorists. The MUTCD recommends the use of an advance pedestrian crossing sign in advance of locations where pedestrians may cross but may not be expected by the motorist. Figure 7 shows the "Regulatory signs for motorists" with and without pedestrian pictograms. The "Regulatory signs for motorists" are shown in Figure 8, as installed at the site. The MUTCD code for this sign is R1-5 or R1-5a. Two of the problems to be addressed by installing "Regulatory signs for motorists" are motorists' failure to yield and conflict between pedestrians and right turning vehicles.

Figure 7. Regulatory sign for motorists.
Source: MUTCD, 2003 Edition
4.3.1.4 Turning Traffic must Yield to Pedestrians Sign

The “Turning traffic must yield to pedestrians” signs were installed at signalized intersections, where right turn on red was permitted. The proposed sign reminds motorists to yield for pedestrians before turning on red. This sign was mounted on the signal mast arm next to the traffic signal for the right most traffic lane. The sign “Turning traffic must yield to pedestrians” is listed in MUTCD 2003 edition. The MUTCD code for “Turning traffic must yield to pedestrians” sign is R10-15. Figure 9 illustrates the placement of this sign. The “Turning traffic must yield to pedestrians” sign is expected to address the following problems: motorists’ failure to yield and conflict between pedestrians and right turning vehicles.
4.3.2 Markings

The proposed types of markings are as follows: “Advance yield markings” and “High visibility crosswalk” treatment. These types of markings will be discussed in detail next.

4.3.2.1 Advance Yield Markings

The “Advance yield markings” are installed upstream of crosswalks at uncontrolled approaches. The installation of these markings is expected to make motorists aware of the presence of pedestrians on the road. On multilane roadways, these installations could help reduce crashes due to screening effects of vehicles on the adjacent lanes. However, the MUTCD specifies that the yield ahead triangular pavement markings shall not be installed at a site unless there is an advance yield to pedestrian sign. Triangular yield markings on the pavement are shown in Figure 10. Motorists are provided additional notice with the installation of the advance yield sign. The advance yield sign can be installed on the curb or on the median. If “Advance yield markings” are to be installed at
unsignalized midblock crosswalks, yield lines should be placed adjacent to “Yield here to pedestrians” signs 6.1 meter to 15 meter (20 feet to 50 feet) upstream of the crosswalk line, and parking should be prohibited between the yield lines and the crosswalk (MUTCD, 2003). The proposed “Advance yield markings” are expected to increase motorists’ yielding behavior.

![Advance yield markings](image)

**Figure 10. Advance yield markings.**

Source: Transportation Research Center (2004)

4.3.2.2 High Visibility Crosswalk Treatment

Crosswalks were repainted to make them more conspicuous. The crosswalk was painted with zebra or striped inside the outer boundary line of the crosswalk. The main aim is to increase visibility of crosswalks so that drivers can better see them. Figure 11 depicts the longitudinal white lines painted in between the transverse white boundary lines. The installation of “High visibility crosswalk” signs is expected to increase
pedestrian crosswalk usage, increase crosswalk conspicuity, and increase motorists' yielding.

Figure 11. High visibility crosswalk treatment.

4.3.3 Others

In addition to signs and markings various types of innovative countermeasures were also installed. The installed countermeasures are as follows: “Portable speed trailer,” “In-pavement flashing light system,” and “Pedestrian countdown signals.” These countermeasures are discussed next in detail.
4.3.3.1 Portable Speed Trailer

The “Portable speed trailer” detects and displays the travel speed of a vehicle and reminds motorists to slow down if they are driving over the posted speed limit. The “Portable speed trailer” was installed at the site with speeding problems. The “Portable speed trailer” was installed on the sides of the road or on a curb lane. In particular, two messages, the posted speed limit and vehicle’s speed were displayed. Figure 12 shows the portable speed trailer with the travel speed of a vehicle. Some of the targeted problems to be addressed by installing “Portable speed trailer” are motorists’ failure to yield and speeding.

![Portable speed trailer](image)

Figure 12. Portable speed trailer.
4.3.3.2 In-pavement Flashing Light System

The safety of road users could be enhanced by implementing strategies that increase the awareness of motorists’ and pedestrians’ of the crossing location and the activities in the crosswalk. One of the strategies used on roadways to enhance motorists’ and pedestrians’ awareness and to influence their behavior is the in-pavement flashing light system. These lights are installed on the crosswalk to alert both motorists as well as pedestrians. They flash when activated (actively or passively) for a preset duration while the pedestrian crosses the street. The installed in-pavement flashing light system is shown in Figure 13.

![Figure 13. In-pavement flashing light system.](image-url)
4.3.3.3 Pedestrian Countdown Timer

The pedestrian countdown signals are aimed to inform pedestrians of the time remaining to cross the roadway. Once the allocated time for the WALK signal is completed, a countdown of the time remaining (in seconds) to complete the crossing maneuver is displayed in Arabic numerals along with the flashing DON'T WALK or "steady hand" signal. Pedestrians in the process of crossing the street are to complete the crossing maneuver during the pedestrian signal. Pedestrians who arrive during the countdown phase on the signal head will have to decide whether to cross or not to cross based on the remaining time on the signal head. The pedestrian countdown timer is shown in Figure 14.

Figure 14. Pedestrian countdown timer.

4.4 Deployment of Countermeasures

Existing condition data were collected to evaluate all of the selected countermeasures (countermeasures are listed in Chapter 4). The deployed countermeasures and corresponding sites are shown in Table 9. In Table 9, the letter "X" indicates that a
A countermeasure is deployed at the corresponding site. The installed countermeasures and whether they are intended to increase pedestrian or motorist awareness are also shown in Table 10. The details of measures of effectiveness (MOEs) for all countermeasures are shown in Table 11. This table also shows the required data for each countermeasure. The dates when data were collected for each countermeasure are shown in Table 12.

### Table 9 List of Deployed Countermeasures at Various Sites

<table>
<thead>
<tr>
<th>Locations</th>
<th>Pedestrian Countdown Signals</th>
<th>In-roadway Knockdown Signs</th>
<th>Turning Traffic Must Yield to Pedestrians</th>
<th>Advance Yield Marking</th>
<th>Portable Speed Trailer</th>
<th>High-Visibility Crosswalk</th>
<th>Regulatory Sign for Motorists</th>
<th>In-pavement Flashing Light System</th>
<th>Warning Sign for Motorists</th>
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<tbody>
<tr>
<td>1. Harmon Avenue / Paradise Road</td>
<td>X</td>
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<td></td>
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<td>3. Bonanza Road / F Street</td>
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<td>4. Lake Mead Boulevard / Pecos Road</td>
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<tr>
<td>5. Fremont Street: 8th Street to 6th Street</td>
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<td>6. Burkholder Boulevard</td>
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<td>7. Green Valley Parkway / Warm Springs</td>
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<td>8. Sunset Road / Marks Street</td>
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<tr>
<td>9. Charleston Boulevard: Spencer Street to 17th Street</td>
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<td>X</td>
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</table>

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Table 10 List of Evaluated Countermeasures

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Countermeasures</th>
<th>Intended to increase awareness to</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pedestrians</td>
</tr>
<tr>
<td>1.</td>
<td>In-pavement Flashing Light System</td>
<td>X</td>
</tr>
<tr>
<td>2.</td>
<td>Pedestrian Countdown Signals</td>
<td>X</td>
</tr>
<tr>
<td>3.</td>
<td>Turning Traffic Must Yield to Pedestrians (R10-15)</td>
<td>X</td>
</tr>
<tr>
<td>4.</td>
<td>Portable Speed Trailer</td>
<td>X</td>
</tr>
<tr>
<td>5.</td>
<td>In-roadway Knockdown Sign (R1-6)</td>
<td>X</td>
</tr>
<tr>
<td>6.</td>
<td>High Visibility Crosswalk</td>
<td>X</td>
</tr>
<tr>
<td>7.</td>
<td>Warning Signs for Motorists (W11-2)</td>
<td>X</td>
</tr>
<tr>
<td>8.</td>
<td>Regulatory Signs for Motorists (R1-5a)</td>
<td>X</td>
</tr>
<tr>
<td>9.</td>
<td>Advance Yield Markings</td>
<td>X</td>
</tr>
</tbody>
</table>

4.5 Evaluation of Countermeasures

Before and after condition data were collected to evaluate the effectiveness of countermeasures. The dates for data collection for countermeasures are shown in Table 12. In some cases, before condition data were collected in fall and the after condition data were collected in the summer, and vice versa. Several statistical tools were used to evaluate the deployed countermeasures. The types of statistical tools were based on the considered MOEs for evaluation. In some cases, several statistical tools were also used to evaluate a countermeasure. The evaluation strategy and the statistical tools that were used for countermeasures are discussed next.
Table 11 List of MOEs and Countermeasures

<table>
<thead>
<tr>
<th>Measures of Effectiveness</th>
<th>Pedestrian Countdown Signals</th>
<th>In-roads Knuckledown Signs</th>
<th>Turning Traffic Must Yield to Pedestrians</th>
<th>Advance Yield Markings</th>
<th>Portable Speed Trailer</th>
<th>High Visibility Crosswalk</th>
<th>Regulatory Sign for Motorists</th>
<th>In-pavement Flashing Light System</th>
<th>Warning Sign for Motorists</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Percentage of pedestrians / vehicles taking evasive actions</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>2. Pedestrians not completing roadway crossings</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.1. Percentage of pedestrians who were in the crosswalk during the flashing DON'T WALK phase</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.2. Percentage of pedestrians who were in the crosswalk at the end of all-red</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.3. Percentage of pedestrians who were trapped in the middle of crossing</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>2.4. Percentage of pedestrians who crossed the second half of the intersection during the WALK phase</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Percentage of pedestrians who violated signal (crossing during the DON'T WALK phase)</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Percentage of pedestrians who pushed the call button</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Percentage of pedestrians who pushed the call button and waited for the WALK phase</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Percentage of pedestrians who did not push the call button and waited for the WALK phase</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Percentage of pedestrians who violated signal that involved pedestrian started to cross during the pedestrian clearance phase</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Percentage of drivers who yielded to pedestrians</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>8.1. Yielding distance to pedestrians by motorists</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.2. Percentage of vehicles that blocked the crosswalk</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.3. Percentage of drivers executing right turn on red coming to complete stop</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Percentage of pedestrians who looked at start of the WALK phase for turning vehicles</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Pedestrian delay</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Vehicle speed</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>12. Vehicular delay at intersections / midblock crossing</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 12 Data Collection Date for Before and After Condition

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Countermeasures</th>
<th>Data collection</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Before condition</td>
</tr>
<tr>
<td>1.</td>
<td>In-pavement Flashing Light System</td>
<td>11/16/2004</td>
</tr>
<tr>
<td>4.</td>
<td>Portable Speed Trailer</td>
<td>7/6/2005</td>
</tr>
<tr>
<td>5.</td>
<td>In-roadway Knockdown Sign (R1-6)</td>
<td>6/14/2005</td>
</tr>
<tr>
<td>7.</td>
<td>Warning Signs for Motorists (W11-2)</td>
<td>7/5/2005</td>
</tr>
<tr>
<td>8.</td>
<td>Regulatory Signs for Motorists (R1-5a)</td>
<td>7/5/2005</td>
</tr>
</tbody>
</table>

4.5.1 In-pavement Flashing Light System, Warning Sign for Motorists, Regulatory Sign for Motorists, and Advance Yield Markings

A before and after study strategy was conducted to evaluate the effectiveness of an in-pavement lighting system at the study location which was previously described. Data were collected in the morning and afternoon peak periods. This was done both prior to the activation of the in-pavement lighting system (the “before” condition) and after the activation of the in-pavement lighting system (the “after” condition). The yielding behavior of motorists, vehicle speeds, yielding distance, and conflicts were identified as measures of effectiveness (MOEs) for comparison of the before and after study periods. The stopping sight distance (SSD) is an important variable to observe in the study of the yielding behavior of motorists. The required distance for motorists to stop safely within the perception and brake reaction time is called SSD. The SSD is the sum of the distance

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traveled during the brake reaction time and the distance traveled for the vehicle to stop after brake is applied. The SSD is determined using Equation 5.

The site was at a level grade. The posted speed limit for the roadway at the study location is 35 mph. Before the installation of the in-pavement lighting system at the crosswalk, drivers generally are expected to be aware of potential pedestrian activities. So, a brake reaction time of 2.5 sec (as is used typically for an expected stimulus) was used to obtain the SSD. After the installation of signage and the in-pavement lighting, motorists were expected to be more aware of the pedestrian activities; therefore, a brake reaction time of 1 sec was used for SSD (Johansson and Rumar, 1971). Therefore, the SSDs for the before and after study conditions were 246 feet and 169 feet respectively, as obtained using Equation (5).

A landmark was established at a distance equal to the SSD upstream of the crosswalk for both directions of travel. The “yielding” behavior of motorists to pedestrians was observed. The yielding behavior of the motorist was observed only in the presence of pedestrians in the crosswalk or when a pedestrian was facing oncoming traffic in the crosswalk while crossing. Motorists downstream of the landmark after the pedestrian has entered the roadway can be scored as yielding to pedestrians, but not for failing to yield. Motorists upstream of the landmark when the pedestrian entered the crosswalk were scored as yielding or not yielding because they have sufficient distance to safely stop. When the pedestrian first starts to cross, only drivers in the first half of the roadway are scored for yielding. Once the pedestrian approaches middle of the roadway, the yielding behaviors of motorists in the remaining lanes of the second half of the crosswalk were scored. The yielding observations on motorists were tabulated in terms of the percentage.
of motorists "yielding" and "not yielding" to pedestrians. The "yielding" behavior of motorists beyond the SSD was scored as "yielding to pedestrians" or "not yielding to pedestrians." A motorist who allowed pedestrians, who are already in the crosswalk, to cross was scored as "yielding to pedestrians." On the contrary, motorists who speed up, or took other evasive actions such as change lane, etc., and thus who do not allow pedestrians to cross safely were scored as "not yielding to pedestrians." The yielding behaviors of the motorists due to platoon effect and motorists behind the motorists who yielded were not recorded (Karkee, Nambisan, and Pulugurtha, 2005).

The space mean speed of the vehicles was used to determine if any changes in speed occurred between the before-and-after evaluation periods. The length of a segment of 246 feet upstream from the edge of the crosswalk on either side was used to determine the speed. The mean speed, median speed, and the 85th percentile speeds were obtained for each evaluation period. These speeds were observed for three scenarios: in the absence of pedestrian(s), while pedestrian(s) were waiting to cross, and while pedestrian(s) were crossing.

The yielding distance upstream of the crosswalk in either direction was also recorded for all motorists who yielded to pedestrians. The curbs were marked on the approaches upstream of the crosswalk at 20 feet intervals to estimate the yielding distance. The yielding distance was approximately estimated if motorists yielded, not parallel to the marking on the road, but in between the markings on the curbs. When a vehicle or a pedestrian had to change the intended path due to an action of either one of them, the outcome is considered a conflict. Conflicts were also observed for both before and after evaluation periods. During long periods when pedestrians were not seen in the
crosswalk, an observer acted as a staged pedestrian and crossed the crosswalk facing the oncoming traffic. Four observers, stationed two on either side, recorded the vehicular speeds, the yielding behaviors, the yielding distance, and conflicts.

4.5.1.1 Yielding Proportion

Data were stratified and analyzed for morning and evening peak hours, direction of travel, and based on total observations. The percentages of motorists yielding were obtained for both the before and after study evaluation periods. The test for two proportions, a statistical tool, was used to determine if the proportions obtained during the two study periods are significantly different.

Let \( P_B \) = proportion of vehicles yielding during the “before” period

\( P_A \) = proportion of vehicles yielding during the “after” period

Then, the null hypothesis \( (H_0) \) is that the percentage of motorists yielding during “before” period \( (P_B) \) and “after” period \( (P_A) \) are the same. The alternative hypothesis \( (H_a) \) is the percentage of motorists yielding during “after” \( (P_A) \) period is more than the percentage of motorists yielding during “before” period \( (P_B) \). These hypotheses are expressed mathematically as follows:

\[ H_0: P_B = P_A, \quad \text{and} \]
\[ H_a: P_B < P_A \]

The one-tailed test for proportions was used to test these hypotheses at the 95 percent confidence level.

Let \( X_B \) = number of vehicles yielding in the “before” period, out of a total of \( n_B \) vehicles

\( X_A \) = number of vehicles yielding in the “after” period, out of a total of \( n_A \) vehicles

The population proportions \( P_A \) and \( P_B \) are estimated by the sample proportions:
For large sample sizes, the two sample proportions are approximately normally distributed (Navidi, 2004), and the Z-test for testing the equality of the two proportions vs. the 1-sided alternative can be used.

The test statistic used is $Z_0$, which is shown in Equation (1).

$Z_0$ is assumed to be distributed approximately $N(0, 1)$.

The significance probability or P-value for equality of proportions vs. the 1-sided alternative is calculated by:

P-value = $P(Z < Z_0)$

The null hypothesis is rejected if the P-value < 0.05 (for 95% confidence level).

4.5.1.2 Speeds

A two-sample t-test, the Welch-Satterthwaite t test, was used to compare if speeds are statistically different at two evaluation periods at the 95 percent confidence level.

The Welch’s t-test will be used to identify the difference between means of independent samples. Let

$\mu_B = \text{population mean during before evaluation period},$

$n_B = \text{number of observations during before evaluation period},$

$\bar{x}_B = \text{sample mean of } n_B \text{ observations},$

$s^2_B = \text{sample variance of observations during before study}.$

Similarly, $\mu_A$, $n_A$, $\bar{x}_A$, and $s^2_A$ are respectively the population mean, number of observations, sample mean, and sample variance of the data for the "after" evaluation period.
The null hypothesis of equal means for “before” and “after” periods vs. the 1-sided alternative is expressed as:

\( H_0: \mu_B - \mu_A = 0 \)

\( H_a: \mu_B - \mu_A > 0 \)

The test statistic is computed using Equation (2) from the sample.

The distribution of the test statistic when \( H_0 \) is true is a t-distribution with approximate degree of freedom (Devore and Farnum, 1999) given by Equation (3).

The significance probability or P-value for equality of means vs. the 1-sided alternative is calculated by:

\[ P\text{-value} = P(t_{eff} > t_0) \]

If the obtained P-value is more than the critical \( \alpha \)-value, i.e., 0.05 at the 95 percent confidence level then \( H_0 \) is accepted. Similarly, if the P-value is less than the \( \alpha \)-value, then \( H_0 \) is rejected at the 95 percent confidence level.

4.5.1.3 Speeds of Drivers Facing the Sun

The Welch-Satterthwaite t test was also used to compare the mean speed of drivers facing the sun (\( \mu_{FS} \)) and the mean speed of drivers with the sun behind them (\( \mu_{BS} \)). The speeds for drivers facing the sun are observations on eastbound during AM peak hours and westbound during PM hours. Similarly, the speeds for drivers with the sun behind them are observations on eastbound PM hours and westbound AM peak hours. Then, the hypotheses are express as follows:

The null hypothesis, \( H_0: \mu_{FS} = \mu_{BS} \)

The alternative hypothesis, \( H_a: \mu_{FS} \neq \mu_{BS} \)

The P-value for the Welch-Satterthwaite t test in this case is given by:
P-value = 2 P(t_{df} > |t_0|).

The null hypothesis of equal means is rejected if P-value < 0.05.

4.5.1.4 Yielding Distance

The Welch-Satterthwaite t test was used to compare the yielding distance before and after the installation of the in-pavement lighting system. The null hypothesis of equal the means of yielding distances before study period, \( \mu_{BY} \), and after study period, \( \mu_{AY} \) vs. the 1-sided alternative is expressed as:

\[
H_0: \mu_{BY} = \mu_{AY} \\
H_a: \mu_{BY} < \mu_{AY}
\]

The P-value for the Welch-Satterthwaite t test in this case is given by:

P-value = P(t_{df} > |t_0|)

The null hypothesis of equal means is rejected if P-value < 0.10 at the 90 percent confidence level.

4.5.1.5 Conflicts

The test for two proportions was used to compare the percentages of conflicts before and after the installation of the in-pavement lighting system. The null hypothesis (\( H_0 \)) is that the percentage of conflicts before (\( P_{BC} \)) and after (\( P_{AC} \)) the installation of the in-pavement lighting system are the same. The alternative hypothesis (\( H_a \)) is 2-sided, i.e., the two proportions are different. These hypotheses are expressed mathematically as follows:

\[
H_0: P_{BC} = P_{AC}, \text{ and} \\
H_a: P_{BC} \neq P_{AC}.
\]
The two-tailed test for proportions was used to test these hypotheses at the 95 percent confidence level. The P-value is calculated from:

\[ P \text{-value} = 2 \cdot P(Z > |Z_0|) \]

The null hypothesis of equal proportions is rejected if P-value < 0.05.

4.5.2 Pedestrian Countdown Signal Based on Pedestrian Actions

Based on the desired MOEs, before and after condition data were collected during the morning and evening peak periods. The existing condition data were collected in November 2004, and the after installation data were collected several months after installation. A before-and-after study strategy was used to compare the collected data during conventional pedestrian signal was placed on site and the collected data after installation of the pedestrian countdown signals. The obtained MOEs data from the two study periods were converted to proportions. A test for two proportions was used to compare the significant difference in two study periods.

The test for two proportions, a statistical tool, was used to determine if the proportions obtained during the two study periods are significantly different.

Let \( P_B \) = proportion of pedestrians’ behavior during the “before” period

\( P_A \) = proportion of pedestrians’ behavior during the “after” period

Then, the null hypothesis (\( H_0 \)) is that the proportions of pedestrians’ behavior during “before” period (\( P_B \)) and “after” period (\( P_A \)) are the same. The alternative hypothesis (\( H_a \)) is the proportion of pedestrians’ behavior during “after” (\( P_A \)) period is more than the proportion of pedestrians’ behavior during “before” period (\( P_B \)). These hypotheses are expressed mathematically as follows:

\( H_0: P_B = P_A \), and
The one-tailed test for proportions was used to test these hypotheses at the 95 percent confidence level.

Let $X_B =$ number of pedestrians observed for a particular behavior in the “before” period, out of a total of $n_B$ pedestrians

$X_A =$ number of pedestrians observed for a particular behavior in the “after” period, out of a total of $n_A$ pedestrians

The population proportions $P_A$ and $P_B$ are estimated by the sample proportions:

$\hat{P}_A = \frac{X_A}{n_A}$ and $\hat{P}_B = \frac{X_B}{n_B}$

For large sample sizes, the two sample proportions are approximately normally distributed (Navidi, 2004), and the $Z$-test for testing the equality of the two proportions vs. the 1-sided alternative can be used. The significance probability or $P$-value for equality of proportions vs. the 1-sided alternative is calculated by:

$P$-value $= P(Z < Z_0)$

The null hypothesis is rejected if the $P$-value $< 0.05$ (for 95 percent confidence level).

4.5.3 Pedestrian Countdown Signal Based on Vehicle Speed

Motorists’ speeds were observed at two locations upstream of the intersection and the corresponding signs on the pedestrian countdown signal heads were also noted. Data were collected in August 2005. A segment of 200 feet from the stop bar upstream of the intersection was measured to obtain space mean speed. Landmarks were established at points 100 feet and 200 feet upstream so as to define two segments each of 100 feet long. The time taken by a vehicle to travel each of these 100 feet segments was recorded. The time taken to travel the first 100 feet segment is denoted $t_1$ sec and the corresponding
speed is \( V_1 \). Similarly, \( t_2 \) and \( V_2 \) are the time taken to travel the second 100 feet segment in sec (near to the intersection) and speed in mph, respectively. The corresponding signals on the pedestrian signal head, either pedestrian WALK or countdown timings (>15 sec, 15-10 sec, 10-5 sec, <5 sec), were also noted while recording speed of a vehicle.

These two speeds, \( V_1 \) and \( V_2 \), were compared to the various timings on the pedestrian signal head including pedestrian WALK signal. Motorists’ speeds for various timings on the pedestrian signal head were compared to see if there were any differences in speed due to the pedestrian countdown signal. A paired t-test was used at the 95 percent confidence level.

Two Sample t-test

The speeds, \( V_1 \) and \( V_2 \), were compared when the pedestrian WALK signal and the countdown numerals were displayed on the pedestrian signal head. A two-sample t-test was used at the 95 percent confidence level to compare speeds for the WALK signal and the time shown on the countdown timer on the pedestrian signal head. A two-sample t-test, the Welch-Satterthwaite t-test, was used to compare if the speeds are statistically different at the 95 percent confidence level. The Welch’s t-test will be used to identify the difference between means of independent samples. Let

\[
\begin{align*}
\mu_W &= \text{population mean speed of vehicles during pedestrian WALK signal}, \\
\bar{x}_W &= \text{sample mean of } n_W \text{ observations}, \\
s^2_W &= \text{sample variance of } n_W \text{ observations}.
\end{align*}
\]
Similarly, $\mu_C$, $n_C$, $\bar{x}_C$, and $s_C^2$ are respectively the population mean, number of observations, sample mean, and sample variance of speeds, while the pedestrian countdown timer is displayed on the pedestrian signal head.

The null hypothesis of equal means of speeds with “pedestrian WALK signal” and “countdown timer” vs. the 1-sided alternative is expressed as:

- $H_0: \mu_C - \mu_W = 0$
- $H_a: \mu_C - \mu_W > 0$

The test statistic is computed using Equation (2) from the sample.

The distribution of the test statistic is a $t$-distribution with approximate degree of freedom (Devore and Farnum, 1999) given by Equation (3).

The significance probability or P-value for equality of means vs. the 1-sided alternative is calculated by:

$$P-value = P(t_{df} > t_0)$$

If the obtained P-value is more than the critical $\alpha$-value, i.e., 0.05 at the 95 percent confidence level, then $H_0$ is accepted. Similarly, if the P-value is less than the $\alpha$-value, then $H_0$ is rejected at the 95 percent confidence level.

Paired t-test

A paired t-test was conducted to test the motorists’ speeds with different times remaining on the pedestrian signal head. A set of $n$ paired of speed observations were taken between 100 feet and 200 feet upstream of the stop bar, where the mean and variance are represented by $\mu_1$ and $\sigma_1^2$, respectively, for the first pair. The mean, $\mu_2$, and variance, $\sigma_2^2$ for the second pair speed observations were taken between the stop bar and 100 feet away from the stop bar. Hypotheses test about the difference between $\mu_1$ and $\mu_2$
are accomplished by performing a one-sample t-test on \( \mu_D \), where \( \mu_D \) is the difference between paired means (Montgomery and Runger, 2003).

The null hypothesis of no difference in speeds at two locations vs. the 1-sided alternative is expressed as:

\[
\begin{align*}
H_0: \mu_D &= 0 \\
H_a: \mu_D &> 0
\end{align*}
\]

The test statistic is computed by using Equation (4) from the sample.

The significance probability or P-value is calculated by:

\[
P\text{-value} = P(t_{df} > t_0)
\]

If the obtained P-value is more than the critical \( \alpha \)-value, i.e., 0.05 at the 95 percent confidence level, then \( H_0 \) is accepted. Similarly, if the P-value is less than the \( \alpha \)-value, then \( H_0 \) is rejected at the 95 percent confidence level.

4.5.4 Turning Traffic Must Yield to Pedestrians

The test for two proportions and two sample t-test were used to compare the two sets of data for the two study periods. Most of MOEs are obtained in terms of proportion of the total observations. The test for two proportions was used to evaluate any differences in proportions in the before and after study periods. Two sample t-test was used to evaluate differences in pedestrian delay and vehicle speeds.

4.5.5 Portable Speed Trailer

The two-sample t-test was used to find any differences in speeds before and after deployment of the portable speed trailer. The significance level of this test is done at the 95 percent confidence level.
4.5.6 In-roadway Knockdown Signs

The test for two proportions and the two sample t-test were used to compare two sets of data in two study periods. Most of MOEs are obtained in terms of proportion of the total observations. The test for two proportions was used to evaluate any differences in proportions in the before and after study periods. The two sample t-test was used to evaluate differences in pedestrian delay and vehicle speeds.

4.5.7 High Visibility Crosswalk, Warning Sign for Motorists, Regulatory Sign for Motorists, and Advance Yield Markings

Pedestrians who were trapped in the middle during the crossing maneuver, who took evasive actions, and motorists yielding were obtained in proportions of the total observations. Therefore, the test for two proportions was used to evaluate these MOEs. The two sample t-test was used to evaluate vehicle speed and pedestrian delay.
CHAPTER 5

ANALYSIS OF EXISTING CONDITIONS

A summary of the existing crossing behaviors of pedestrians is documented in Chapter 5. Existing condition data pertaining to pedestrians' behavior were collected at the selected locations. These data were analyzed to support potential countermeasures at these locations. The behaviors of interest were pedestrians' yielding to motorists and pedestrians' trapped in the middle of the street while crossing. These observations were taken at two types of locations, at a crosswalk and away from a crosswalk. These observations were made at several sites. Based on these crossing behaviors, some of the potential countermeasures were suggested to enhance safety. A brief description of the methodology used for data analysis, results, conclusions, and some recommended countermeasures will be discussed in this chapter.

5.1 Introduction

Understanding pedestrians' crossing behavior is an important factor for enhancing pedestrian and traffic safety. Pedestrians crossing a street at grade could have conflicts with motor vehicles. When such conflicts arise, a crash would occur if either the pedestrian or the motorist does not yield to the other. The behavior of pedestrians with respect to the motorists is categorized as "yielding" and "non-yielding" while crossing a
street. A behavior is categorized as yielding if a motorist has the right of way and a pedestrian allows the motorist to pass safely without intervening. A behavior is considered as non-yielding if a motorist has to change an intended path due to pedestrian’s action or a pedestrian changes speed or course while crossing. The yielding behavior of pedestrians is observed at two locations: at a crosswalk and away from it. When pedestrians do not see a potential threat from a motor vehicle, either the motorist or a pedestrian has to take an evasive action in order to avoid a crash. Even at a signalized intersection, pedestrians do not always wait and cross during the pedestrian WALK signal. Pedestrians’ activities are observed at midblock locations upstream and downstream of intersections. The crossing behavior at such locations are compared to those at crosswalks and analyzed to see if there are any differences.

Pedestrians’ crossing behavior can also be qualitatively evaluated, as in how safely pedestrians cross a street. If pedestrians do not have enough gap for safely completing a crossing they will wait in the middle of the street until they perceive an acceptable gap for crossing the second half of the street. This type of behavior is observed for both types of crossing locations: at a crosswalk and away from a crosswalk. The frequency of pedestrians trapped in the middle of the street while crossing at a crosswalk and away from a crosswalk location can be compared. Ultimately, the pedestrians’ risk exposure to vehicles is compared at these two locations.

5.2 Site Descriptions

As a part of a pedestrian safety project in the Las Vegas metropolitan area funded by the FHWA, 19 sites were identified for study (Transportation Research Center
UNLV, 2004). The study locations funded by the FHWA and sites considered in this dissertation research are shown in Table 13. Existing condition data were collected to support the potential countermeasures at sites under the FHWA pedestrian safety project.

In this dissertation, 6 sites from the FHWA pedestrian safety project and 3 other locations are considered. The site characteristics of these 9 sites have been discussed in Chapter 4. Site numbers 20, 21, and 22 are not included in the FHWA study; these sites are shown in Table 13 but not in Figure 3.

Table 13 List of Sites Considered in FHWA Pedestrian Safety Project and Sites Considered in Dissertation

<table>
<thead>
<tr>
<th>Site No.</th>
<th>Sites</th>
<th>FHWA Study</th>
<th>Dissertation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Maryland Parkway / Sierra Vista</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Maryland Parkway / Dumont Street</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Maryland Parkway / Twain Avenue</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Harmon Avenue / Paradise Road</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>5</td>
<td>Harmon Avenue: Paradise Road to Tropicana Wash</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Harmon Avenue / Las Vegas Boulevard</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Flamingo Road / Koval Lane</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Flamingo Road / Paradise Road</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Bonanza Road / D Street</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>10</td>
<td>Bonanza Road / F Street</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>11</td>
<td>Twain Avenue (Cambridge to Swenson)</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Twain Avenue (Swenson to Palos Verdes)</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Lake Mead Boulevard / Las Vegas Boulevard</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Lake Mead Boulevard / McDaniel Street</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Lake Mead Boulevard (Belmont to McCarran)</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Lake Mead Boulevard / Pecos Road</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>17</td>
<td>Fremont Street (8th to 11th Street)</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>18</td>
<td>Fremont Street (6th to 8th Street)</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>19</td>
<td>Charleston Boulevard: Spencer Street to 17th Street</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>20</td>
<td>Burkholder Boulevard</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Green Valley Parkway / Warm Springs</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Sunset Road / Marks Street</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>
Even though only 6 sites from the FHWA pedestrian safety project were considered in this dissertation, the analysis of existing conditions of 16 sites are discussed here. Out of these 16 considered sites, 11 locations are intersections and the remaining five locations are midblocks. A total of about 18,000 pedestrians were observed at these 16 sites. The posted speed limits at these sites vary from 25 mph to 45 mph. The location of the sites is shown in Figure 3. Site numbers 5, 6, and 19 are shown in Figure 3 but not considered for analysis. The observed numbers of pedestrians for all 16 sites are listed in Table 14. The average daily traffic (ADT) varies from 14,200 to 71,000, which is also depicted in Table 14.

Table 14 Observed Pedestrians, Posted Speed Limits, and Traffic Counts at Study Locations

<table>
<thead>
<tr>
<th>Site No.</th>
<th>Sites</th>
<th>Types of location</th>
<th>Observed pedestrians</th>
<th>Speed limit, mph</th>
<th>ADT(^a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Maryland Parkway / Sierra Vista</td>
<td>Intersection</td>
<td>692</td>
<td>30/25</td>
<td>40,500/**</td>
</tr>
<tr>
<td>2</td>
<td>Maryland Parkway / Dumont Street</td>
<td>Intersection</td>
<td>629</td>
<td>30/25</td>
<td>40,500</td>
</tr>
<tr>
<td>3</td>
<td>Maryland Parkway / Twain Avenue</td>
<td>Intersection</td>
<td>1,287</td>
<td>30/35</td>
<td>40,500/20,500</td>
</tr>
<tr>
<td>4</td>
<td>Harmon Avenue / Paradise Road</td>
<td>Intersection</td>
<td>1,943</td>
<td>35/35</td>
<td>18,000/41,000</td>
</tr>
<tr>
<td>7</td>
<td>Flamingo Road / Koval Lane</td>
<td>Intersection</td>
<td>2,555</td>
<td>35/35</td>
<td>71,000/29,700</td>
</tr>
<tr>
<td>8</td>
<td>Flamingo Road / Paradise Road</td>
<td>Intersection</td>
<td>2,076</td>
<td>45/35</td>
<td>71,000/34,000</td>
</tr>
<tr>
<td>9</td>
<td>Bonanza Road / D Street</td>
<td>Intersection</td>
<td>605</td>
<td>25/25</td>
<td>16,500/**</td>
</tr>
<tr>
<td>10</td>
<td>Bonanza Road / F Street</td>
<td>Intersection</td>
<td>382</td>
<td>25/25</td>
<td>16,500/**</td>
</tr>
<tr>
<td>11</td>
<td>Twain Avenue (Cambridge to Swenson)</td>
<td>Midblock</td>
<td>1,295</td>
<td>35</td>
<td>20,500</td>
</tr>
<tr>
<td>12</td>
<td>Twain Avenue (Swenson to Palos Verdes)</td>
<td>Midblock</td>
<td>969</td>
<td>35</td>
<td>20,500</td>
</tr>
<tr>
<td>13</td>
<td>Lake Mead Boulevard / Las Vegas Boulevard</td>
<td>Intersection</td>
<td>744</td>
<td>35/35</td>
<td>38,000/21,500</td>
</tr>
<tr>
<td>14</td>
<td>Lake Mead Boulevard / McDaniel Street</td>
<td>Intersection</td>
<td>847</td>
<td>35/25</td>
<td>38,000/**</td>
</tr>
<tr>
<td>15</td>
<td>Lake Mead Boulevard (Belmont to McCarran)</td>
<td>Midblock</td>
<td>151</td>
<td>35</td>
<td>38,000</td>
</tr>
<tr>
<td>16</td>
<td>Lake Mead Boulevard / Pecos Road</td>
<td>Intersection</td>
<td>746</td>
<td>35/45</td>
<td>38,000/23,100</td>
</tr>
<tr>
<td>17</td>
<td>Fremont Street (8th to 11th Street)</td>
<td>Midblock</td>
<td>1,539</td>
<td>25</td>
<td>14,200</td>
</tr>
<tr>
<td>18</td>
<td>Fremont Street (6th to 8th Street)</td>
<td>Midblock</td>
<td>1,474</td>
<td>25</td>
<td>14,200</td>
</tr>
<tr>
<td><strong>Total observed pedestrians</strong></td>
<td></td>
<td></td>
<td><strong>17,934</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: *ADT – Average daily traffic volume (Source: Nevada Department of Transportation, 2004)  
**Data not available for minor streets
5.3 Objective

The main objective of this study is to compare pedestrians' risk while crossing at a crosswalk and away from a crosswalk. Site-wise as well as an area-wide comparisons are done. The yielding behavior of pedestrians to motorists and the behavior of pedestrians trapped in the middle of the street are evaluated. These pedestrians’ crossing behaviors are compared and checked to see if these differences are significant at two crossing locations.

5.4 Methodology

Data on the number of pedestrians crossing the street were collected at each of the 16 locations. Data were collected for seven hours on each day. Of the seven hours, four hours were during the morning and evening peak hours for vehicular traffic, two hours each, and the remaining hours were outside of these peak times. The data collection days were weekdays and weekends based on the land use proximate to the site. Pedestrian activities proximate to recreational and shopping areas are expected to be more during the weekends. At other locations, such as the residential and small commercial locations, more pedestrian activities are expected during weekdays. The pedestrians’ crossing behaviors were observed at a crosswalk and approximately within 200 feet from a crosswalk at all approaches of an intersection. All pedestrians were observed at midblock locations, where distance from a crosswalk was not a deciding factor. The yielding behavior and whether a pedestrian was trapped or not trapped in the middle of the street while crossing were recorded.
All observed pedestrian data were analyzed based on crossing locations. Both of the crossing behaviors consist of two options for each observation. The yielding behavior consists of two options, either “yielding” or “not yielding.” Likewise, the observation on pedestrians trapped in the middle of the street has two options either “trapped” or “not trapped” while crossing. Therefore, a binomial test for two proportions was conducted to compare subjects of interest at a crosswalk and away from a crosswalk. The observations on pedestrians were converted into proportions. These proportions were: proportions of pedestrians’ yielding to motorists crossing at a crosswalk (p_1) and for those crossing away from a crosswalk (p_2); also the proportions of pedestrians trapped in the middle of the street while crossing at a crosswalk (p_3) and away from a crosswalk (p_4).

The observed pedestrians presented in Table 15 consist of two variables and each variable has two categories. The variables are crossing locations and pedestrians’ yielding to motorists. In Table 15, consider site 11, Twain Avenue from Cambridge Street to Swenson Street the observed numbers of pedestrians yielding to motorists were 566 and 516 crossing at a crosswalk and away from a crosswalk, respectively. In the same way, 130 and 83 pedestrians, crossing at and away from a crosswalk, respectively, did not yield to motorists.

The proportion of yielding for pedestrians crossing at a crosswalk is obtained by dividing the number of pedestrians yielding to motorists by the total number of pedestrians using crosswalk. The proportion of yielding at a midblock location, Twain Avenue from Cambridge Street to Swenson Street, is 0.81 [566/(566 + 130) = 0.81]. The proportion of pedestrians not using crosswalk and yielding to motorists is obtained in the same manner, i.e., 0.86 for Twain Avenue from Cambridge Street to Swenson Street,
which is depicted in Table 15. Similarly, the observed number of pedestrians, the behavior of pedestrians trapped in the middle, and the corresponding proportions based on the crossing locations are presented in Table 16.

### Table 15 Pedestrian Counts and Proportions for Pedestrians' Yielding to Motorists

<table>
<thead>
<tr>
<th>Site No.</th>
<th>Sites</th>
<th>Number of pedestrians yielding at crosswalk</th>
<th>Number of pedestrians not yielding at crosswalk</th>
<th>Number of pedestrians yielding not at crosswalk</th>
<th>Number of pedestrians not yielding not at crosswalk</th>
<th>Proportion of yielding at crosswalk</th>
<th>Proportion of yielding not at crosswalk</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Maryland Parkway / Sierra Vista</td>
<td>459</td>
<td>99</td>
<td>94</td>
<td>40</td>
<td>0.83</td>
<td>0.71</td>
</tr>
<tr>
<td>2</td>
<td>Maryland Parkway / Dumont Street</td>
<td>417</td>
<td>195</td>
<td>0</td>
<td>17</td>
<td>1.00</td>
<td>0.92</td>
</tr>
<tr>
<td>3</td>
<td>Maryland Parkway / Twain Avenue</td>
<td>774</td>
<td>257</td>
<td>155</td>
<td>101</td>
<td>0.83</td>
<td>0.72</td>
</tr>
<tr>
<td>4</td>
<td>Harmon Avenue / Paradise Road</td>
<td>1,624</td>
<td>220</td>
<td>32</td>
<td>67</td>
<td>0.98</td>
<td>0.77</td>
</tr>
<tr>
<td>7</td>
<td>Flamingo Road / Koval Lane</td>
<td>2,428</td>
<td>63</td>
<td>42</td>
<td>22</td>
<td>0.98</td>
<td>0.74</td>
</tr>
<tr>
<td>8</td>
<td>Flamingo Road / Paradise Road</td>
<td>1,332</td>
<td>53</td>
<td>642</td>
<td>49</td>
<td>0.67</td>
<td>0.52</td>
</tr>
<tr>
<td>9</td>
<td>Bonanza Road / D Street</td>
<td>130</td>
<td>204</td>
<td>37</td>
<td>234</td>
<td>0.78</td>
<td>0.47</td>
</tr>
<tr>
<td>10</td>
<td>Bonanza Road / F Street</td>
<td>232</td>
<td>95</td>
<td>24</td>
<td>31</td>
<td>0.91</td>
<td>0.75</td>
</tr>
<tr>
<td>11</td>
<td>Twain Avenue (Cambridge to Swenson)</td>
<td>566</td>
<td>516</td>
<td>130</td>
<td>83</td>
<td>0.81</td>
<td>0.86</td>
</tr>
<tr>
<td>12</td>
<td>Twain Avenue (Swenson to Palos Verdes)</td>
<td>380</td>
<td>388</td>
<td>97</td>
<td>104</td>
<td>0.80</td>
<td>0.79</td>
</tr>
<tr>
<td>13</td>
<td>Lake Mead Boulevard / Las Vegas Boulevard</td>
<td>616</td>
<td>109</td>
<td>6</td>
<td>13</td>
<td>0.99</td>
<td>0.89</td>
</tr>
<tr>
<td>14</td>
<td>Lake Mead Boulevard / McDaniel Street</td>
<td>332</td>
<td>330</td>
<td>98</td>
<td>87</td>
<td>0.77</td>
<td>0.79</td>
</tr>
<tr>
<td>15</td>
<td>Lake Mead Boulevard (Belmont to McCarran)</td>
<td>23</td>
<td>88</td>
<td>11</td>
<td>29</td>
<td>0.68</td>
<td>0.75</td>
</tr>
<tr>
<td>16</td>
<td>Lake Mead Boulevard / Pecos Road</td>
<td>616</td>
<td>111</td>
<td>6</td>
<td>13</td>
<td>0.99</td>
<td>0.90</td>
</tr>
<tr>
<td>17</td>
<td>Fremont Street (8th to 11th Street)</td>
<td>912</td>
<td>384</td>
<td>163</td>
<td>80</td>
<td>0.85</td>
<td>0.83</td>
</tr>
<tr>
<td>18</td>
<td>Fremont Street (6th to 8th Street)</td>
<td>629</td>
<td>373</td>
<td>349</td>
<td>123</td>
<td>0.64</td>
<td>0.75</td>
</tr>
<tr>
<td>Total sites</td>
<td></td>
<td>11,470</td>
<td>3,485</td>
<td>1,886</td>
<td>1,093</td>
<td>0.86</td>
<td>0.76</td>
</tr>
</tbody>
</table>

The parameters of interest are $p_1$ and $p_2$, and the problem is to test the equality of the two proportions. Two independent random samples of sizes $n_1$ and $n_2$ are taken from the two populations. Let $X_1$ and $X_2$ be the number of observations belonging to a class of interest in samples 1 and 2, respectively. If the normal approximation is applied for both populations, the estimators of the population proportions $\hat{p}_1 = X_1 / n_1$ and $\hat{p}_2 = X_2 / n_2$ also have approximate normal distributions (Montgomery and Runger, 2003). The hypotheses then are
Table 16 Proportions of Pedestrians Trapped in the Middle of the Street

<table>
<thead>
<tr>
<th>Site No.</th>
<th>Site</th>
<th>Number of pedestrians trapped in the middle</th>
<th>Number of pedestrians not trapped in the middle</th>
<th>Proportion of trapped in the middle at crosswalk (p₁)</th>
<th>Proportion of trapped in the middle not at crosswalk (p₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Maryland Parkway / Sierra Vista</td>
<td>10</td>
<td>647</td>
<td>0.02</td>
<td>0.28</td>
</tr>
<tr>
<td>2</td>
<td>Maryland Parkway / Dumont Street</td>
<td>43</td>
<td>376</td>
<td>0.10</td>
<td>0.14</td>
</tr>
<tr>
<td>3</td>
<td>Maryland Parkway / Twain Avenue</td>
<td>3</td>
<td>929</td>
<td>0.00</td>
<td>0.22</td>
</tr>
<tr>
<td>4</td>
<td>Harmon Avenue / Paradise Road</td>
<td>26</td>
<td>1,629</td>
<td>0.02</td>
<td>0.12</td>
</tr>
<tr>
<td>7</td>
<td>Flamingo Road / Koval Lane</td>
<td>75</td>
<td>2,396</td>
<td>0.03</td>
<td>0.40</td>
</tr>
<tr>
<td>8</td>
<td>Flamingo Road / Paradise Road</td>
<td>42</td>
<td>1,936</td>
<td>0.02</td>
<td>0.34</td>
</tr>
<tr>
<td>9</td>
<td>Bonanza Road / D Street</td>
<td>5</td>
<td>162</td>
<td>0.03</td>
<td>0.32</td>
</tr>
<tr>
<td>10</td>
<td>Bonanza Road / F Street</td>
<td>9</td>
<td>253</td>
<td>0.03</td>
<td>0.11</td>
</tr>
<tr>
<td>11</td>
<td>Twain Avenue (Cambridge to Swenson)</td>
<td>12</td>
<td>684</td>
<td>0.02</td>
<td>0.19</td>
</tr>
<tr>
<td>12</td>
<td>Twain Avenue (Swenson to Palos Verdes)</td>
<td>78</td>
<td>400</td>
<td>0.16</td>
<td>0.24</td>
</tr>
<tr>
<td>13</td>
<td>Lake Mead Boulevard / Las Vegas Boulevard</td>
<td>13</td>
<td>609</td>
<td>0.02</td>
<td>0.17</td>
</tr>
<tr>
<td>14</td>
<td>Lake Mead Boulevard / McDaniel Street</td>
<td>12</td>
<td>421</td>
<td>0.03</td>
<td>0.34</td>
</tr>
<tr>
<td>15</td>
<td>Lake Mead Boulevard (Belmont to McCarran)</td>
<td>10</td>
<td>24</td>
<td>0.29</td>
<td>0.24</td>
</tr>
<tr>
<td>16</td>
<td>Lake Mead Boulevard / Pecos Road</td>
<td>13</td>
<td>609</td>
<td>0.02</td>
<td>0.18</td>
</tr>
<tr>
<td>17</td>
<td>Fremont Street (8th to 11th Street)</td>
<td>26</td>
<td>1,049</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>18</td>
<td>Fremont Street (6th to 8th Street)</td>
<td>58</td>
<td>920</td>
<td>0.06</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>Total sites</td>
<td>435</td>
<td>13,044</td>
<td>0.03</td>
<td>0.20</td>
</tr>
</tbody>
</table>

The null hypothesis, \[ H₀: p₁ = p₂ \]

The alternative hypothesis, \[ H₁: p₁ \neq p₂ \]

The test statistic used is \( Z₀ \), which is obtained from Equation (1)

\[ Z₀ \text{ is } N(0,1). \]

An estimator of the common parameter is \( \hat{P} = \frac{X₁ + X₂}{n₁ + n₂} \). Let \( \hat{P}_₁ \) and \( \hat{P}_₂ \) be the observed sample proportions in two independent random samples of sizes \( n₁ \) and \( n₂ \), respectively.

An approximate two-sided confidence interval 100(1-\(\alpha\))% on the difference in the true proportions (\( p₁ - p₂ \)) is

\[
\hat{P}_₁ - \hat{P}_₂ \pm z_{α/2} \sqrt{\frac{\hat{P}_₁(1-\hat{P}_₁)}{n₁} + \frac{\hat{P}_₂(1-\hat{P}_₂)}{n₂}} \tag{6}
\]
5.4.1 Site-wise Comparison

A binomial test for two proportions was again used to test the equality of two proportions. The null hypothesis is that the proportion of pedestrians yielding to motorists at crosswalks ($p_1$) is the same as those not using a crosswalk ($p_2$), i.e., $H_0: p_1 = p_2$.

Then, the alternative hypothesis is $H_1: p_1 \neq p_2$

Similarly, hypotheses were set up for pedestrians trapped in the middle of the street as follows. The null hypothesis is that the proportion of pedestrians trapped in the middle of the street is the same for both pedestrians crossing at a crosswalk ($p_3$) and away from a crosswalk ($p_4$), i.e., $H_0: p_3 = p_4$. The alternative hypothesis is that the proportion of pedestrians trapped in the middle of the street is not the same for both pedestrians crossing at a crosswalk and away from a crosswalk, i.e., $H_1: p_3 \neq p_4$. The two-tailed test for proportions was used to test these hypotheses at the 95 percent confidence level. The P-value is calculated from:

$$P-value = 2 \ P(Z > |Z_0|),$$

where $Z$ is obtained from a table of the standard normal distribution and $Z_0$ is the calculated $Z$-value from given data. The null hypothesis of equal proportions is rejected if $P-value < 0.05$.

5.4.2 Area-wide Comparison

The site-wise comparison for pedestrians' yielding to motorists and behavior of pedestrian trapped in the middle showed the difference in proportions within a site. However, the directionality and significance of the difference are also important. The observed pedestrian samples are independent at the 16 sites. The locations have reasonably similar traffic patterns and geometric configurations. Therefore, a paired t-test is appropriate for statistical analysis. The difference in proportions of the pedestrians'
behaviors is obtained for each site. The difference of the means at the two types of locations is compared. A paired t-test is conducted to test the significance of the difference. The difference in proportion of pedestrians’ yielding to the motorists follows normality as indicated by the P-values. The P-values for the normality plot for pedestrians’ yielding to motorists and the behavior of pedestrians trapped in the middle are 0.90 and 0.67, respectively. In general, minimum P-values of 0.05 to 0.10 are acceptable for the normality assumption. The obtained P-values are greater than the minimum P-value indicating that the normality assumption is valid for the proposed paired t-test. Area-wide hypotheses were tested by considering all 16 locations to see if there is a significant difference in the crossing behaviors at the two types of locations.

5.4.2.1 Parametric Test

5.4.2.1.1 Hypothesis Test for Yielding Proportions

The null hypothesis, $H_0$, is that the mean proportion of pedestrians’ yielding to motorists while crossing at a crosswalk location ($\mu_1$) is the same as the mean proportion of pedestrians yielding to motorists crossing away from a crosswalk ($\mu_2$). It is assumed that the pedestrians crossing at a crosswalk location are more cautious and are more likely to comply with traffic regulations. Therefore, the alternative hypothesis would be the mean proportion of pedestrians yielding to motorists at a crosswalk location ($\mu_1$) is greater than the mean proportion of pedestrians yielding to motorists away from a crosswalk ($\mu_2$). Thus,

Null hypothesis, $H_0$: $\mu_1 = \mu_2$

Alternative hypothesis, $H_1$: $\mu_1 > \mu_2$

The test statistic computed from the sample is:
where $\overline{p}$ is the sample average of differences in proportions at two crossing locations, $SD$ is the sample standard deviation of the difference of proportions, and $n$ is number of paired observations (Montgomery and Runger, 2003). The significance probability or P-value for equality of means vs. the 1-sided alternative is calculated by:

$$P\text{-value} = P(t_{df} > t_0)$$

If the obtained P-value is more than the critical $\alpha$-value, i.e., 0.05 at the 95 percent confidence level then $H_0$ is accepted. Similarly, if the P-value is less than the $\alpha$-value, then $H_0$ is rejected at the 95 percent confidence level.

5.4.2.1.2 Hypothesis Test for Pedestrians Trapped in the Middle of the Street

Hypotheses were set up for pedestrians trapped in the middle of the street. Pedestrians crossing at a crosswalk are more likely to follow traffic rules and there is a lesser chance for them to be trapped in the middle of the street or at a median. All of the signalized intersections are equipped with a pedestrian WALK signal and pedestrians are generally able to cross in one attempt. Theoretically, they do not have to wait in the middle of the road for another WALK signal. Pedestrians crossing away from a crosswalk might have to wait in the middle of the street after crossing the first half of the road for an acceptable gap to cross the second half of the road. Therefore, these groups of pedestrians are more likely to be trapped in the middle of the street. The assumption for null hypothesis ($H_0$) is that the mean proportion of pedestrians trapped in the middle of the street is the same whether they crossed at a crosswalk ($\mu_3$) or away from a crosswalk ($\mu_4$). The alternative hypothesis is that the mean proportion of pedestrians trapped in the middle while crossing...
away from a crosswalk location ($\mu_4$) is greater than the mean proportion of pedestrians
trapped in the middle while crossing at a crosswalk ($\mu_3$). Thus,

Null hypothesis, \[ H_0: \mu_3 = \mu_4 \]

Alternative hypothesis, \[ H_1: \mu_3 < \mu_4 \]

The significance probability or P-value for equality of means vs. the 1-sided alternative is
calculated by:

\[ P\text{-value} = P(t_{df} > t_0) \]

The null hypothesis of equal proportions is rejected if P-value < 0.05.

5.4.2.2 Nonparametric Test

A nonparametric test is used to test area-wide difference between two proportions, the
pedestrians’ yielding to motorists and pedestrians trapped in the middle. A nonparametric
sign test only provides the plus and minus sign of the differences between the
observations and the median ($\tilde{\mu}$). The Wilcoxon signed-rank test is applied for a non
parametric analysis. The Wilcoxon signed-rank test does not provide the magnitude of
the differences. The test applies to the case of symmetric continuous distribution, which
assumes the mean equals to the median. The differences from a collection of paired
observations from two continuous distributions are first ranked in the ascending order of
their absolute values (Montgomery and Runger, 2003).

The Wilcoxon test statistic ($W$) is the number of Walsh averages exceeding the
hypothesized median plus one half of the Walsh averages that equal to the hypothesized
median. Pairwise (Walsh) averages are formed to calculate the Wilcoxon test statistics.
At first, the hypothesized median is subtracted from each observation, $X_i$, where $i = 1, 2… n$. A total of $n(n+1)/2$ pairwise averages are obtained. The obtained Walsh averages
are ranked in an ascending order. Let $W_1 \leq W_2 \leq \ldots \leq W_M$ denote the ordered values of Walsh averages, where $M = n(n+1)/2$. The median value for the Walsh averages is obtained (Minitab 14 User’s Guide).

The normal approximation of Wilcoxon statistics with mean ($\mu_w$) and variance ($\sigma^2_w$) is given by

$$Z_w = \left| W - \frac{n(n + 1)}{4} \right| - 0.5 - \frac{0.5}{\sqrt{\frac{n(n + 1)(2n + 1)}{24}}}$$

where,

$Z_w$ = the calculated Z-value

$\mu_w = \frac{n(n + 1)}{4}$

$\sigma^2_w = \frac{n(n + 1)(2n + 1)}{24}$

The significance of the test is obtained based on the confidence level of the test and corresponding P-value. The P-value is calculated from:

$P-value = 2 \cdot P(Z > |Z_w|)$, where $Z$ is obtained from a table of the standard normal distribution. The null hypothesis of equal proportions is rejected if P-value < 0.05. The Wilcoxon signed-rank test is conducted at the 95 percent confidence level (one-sided).

The assumed hypotheses are similar as stated in parametric analysis.

Null hypothesis, $H_0$: $\mu_1 = \mu_2$

Alternative hypothesis, $H_1$: $\mu_1 > \mu_2$

Null hypothesis, $H_0$: $\mu_3 = \mu_4$

Alternative hypothesis, $H_1$: $\mu_3 < \mu_4$
A statistical software, Minitab, was used for statistical analysis.

5.5 Results

A binomial test was performed to check whether the proportions are different at two locations within a site. A site-wise comparison was done for all 16 sites individually and also for the total observed pedestrians at all sites. The binomial test was conducted at the 95 percent confidence level ($\alpha = 0.05$). The results of the analyses are shown in Table 17 and Table 18. If the P-value is less than the $\alpha$ (0.05), the initial assumption is false the null hypothesis is rejected. Conversely, if the P-value is more than $\alpha$ (0.05) the initial assumption is correct and the null hypothesis cannot be rejected. The Z-values, corresponding P-values, the difference in proportion, and confidence intervals are shown in Table 17 and Table 18 for pedestrians' yielding and the behavior of pedestrians trapped in the middle, respectively. The test reveals that the proportions of pedestrians' yielding to motorists at 12 sites are significantly different and those in the remaining four sites are not significantly different at the 95 percent confidence level ($\alpha = 0.05$). Similarly, the proportions of pedestrians trapped in the middle while crossing are different at 12 sites and are not different at the remaining four sites at the 95 percent confidence level. However, based on the total number of pedestrians observed at all the sites, the binomial test shows that both the proportion of pedestrians' yielding to motorists and the proportion of pedestrians trapped in the middle of the street are different at crosswalks when compared to those away from crosswalks a very high level of significance. These results are shown in Table 17. If the obtained P-value is less than the critical P-value the null hypothesis is rejected and the alternative hypothesis is
<table>
<thead>
<tr>
<th>Site No.</th>
<th>Sites</th>
<th>Difference $(P_1 - P_2)$</th>
<th>95% confidence interval for difference</th>
<th>z-value</th>
<th>p-value</th>
<th>Null Hypothesis $(P_1 = P_2)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Maryland Parkway / Sierra Vista</td>
<td>0.118 (0.036, 0.199)</td>
<td>2.83</td>
<td>0.005</td>
<td></td>
<td>Reject</td>
</tr>
<tr>
<td>2</td>
<td>Maryland Parkway / Dumont Street</td>
<td>0.080 (0.043, 0.116)</td>
<td>4.3</td>
<td>&lt;0.001</td>
<td>Reject</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Maryland Parkway / Twain Avenue</td>
<td>0.115 (0.062, 0.167)</td>
<td>4.31</td>
<td>&lt;0.001</td>
<td>Reject</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Harmon Avenue / Paradise Road</td>
<td>0.214 (0.164, 0.263)</td>
<td>8.5</td>
<td>&lt;0.001</td>
<td>Reject</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Flamingo Road / Koval Lane</td>
<td>0.242 (0.148, 0.335)</td>
<td>5.08</td>
<td>&lt;0.001</td>
<td>Reject</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Flamingo Road / Paradise Road</td>
<td>0.155 (0.056, 0.254)</td>
<td>3.07</td>
<td>&lt;0.002</td>
<td>Reject</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Bonanza Road / D Street</td>
<td>0.313 (0.312, 0.391)</td>
<td>7.82</td>
<td>&lt;0.001</td>
<td>Reject</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Bonanza Road / F Street</td>
<td>0.152 (0.069, 0.235)</td>
<td>3.59</td>
<td>&lt;0.001</td>
<td>Reject</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Twain Avenue (Cambridge to Swenson)</td>
<td>-0.048 (-0.088, -0.008)</td>
<td>-2.36</td>
<td>0.018</td>
<td>Reject</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Twain Avenue (Swenson to Palos Verdes)</td>
<td>0.008 (-0.043, 0.059)</td>
<td>0.31</td>
<td>0.758</td>
<td>Do not reject</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Lake Mead Boulevard / Las Vegas Boulevard</td>
<td>0.097 (0.041, 0.152)</td>
<td>3.44</td>
<td>&lt;0.001</td>
<td>Reject</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Lake Mead Boulevard / McDaniel Street</td>
<td>-0.019 (0.074, 0.036)</td>
<td>-0.68</td>
<td>0.497</td>
<td>Do not reject</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Lake Mead Boulevard / Bellmont to McCarran</td>
<td>-0.076 (-0.251, 0.099)</td>
<td>-0.84</td>
<td>0.398</td>
<td>Do not reject</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Lake Mead Boulevard / Pecos Road</td>
<td>0.095 (0.040, 0.149)</td>
<td>3.43</td>
<td>&lt;0.001</td>
<td>Reject</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Fremont Street (8th to 11th Street)</td>
<td>0.021 (-0.019, 0.061)</td>
<td>1.01</td>
<td>0.315</td>
<td>Do not reject</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Fremont Street (6th to 8th Street)</td>
<td>-0.109 (-0.157, -0.060)</td>
<td>-4.41</td>
<td>&lt;0.001</td>
<td>Reject</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Total sites</td>
<td>0.098 (0.083, 0.111)</td>
<td>13.97</td>
<td>&lt;0.001</td>
<td>Reject</td>
<td></td>
</tr>
</tbody>
</table>

*Values are not significant at $\alpha = 0.05$"
accepted. Similarly, if the obtained P-value is more than the critical P-value the null hypothesis cannot be rejected so that the assumed null hypothesis is accepted. The obtained P-values and the acceptance and rejection of null hypothesis are shown Table 17 and Table 18.

The proportion of pedestrians crossing at a crosswalk who yield to motorists is more than those of pedestrians crossing away from a crosswalk at 12 sites out of 16 sites but the difference is not statistically significant at the 95 percent confidence level at sites 12 and 17. The proportion of pedestrians crossing away from a crosswalk who yield to motorists is more than that for pedestrians crossing at a crosswalk at two sites, namely, site number, 14 and 15. However, the difference is not statistically significant at the 95 percent confidence level.

The proportion of pedestrians trapped in the middle of the street is more at 14 out of 16 sites for pedestrians crossing away from a crosswalk than for those crossing at a crosswalk location except two sites, 15 and 17, but this difference is not significant at the 95 percent confidence level. At sites 2 and 18, even though the proportion of pedestrians trapped in the middle of the street is more for those crossing not at a crosswalk, the difference is not statistically significant at the 95 percent confidence level. The lack of statistically significant difference is also indicated by the confidence intervals which contain zero as reported in Table 18 for the four sites (number 2, 15, 17, and 18).

An area-wide comparison was performed to test the significance of the differences of the two crossing behaviors in the Las Vegas metropolitan area. The paired t-test was conducted to compare the difference of means of the two samples. If the obtained P-value is less than the desired confidence level ($\alpha = 0.05$), then the null hypothesis is rejected.
and the alternative hypothesis is accepted. Likewise, if the obtained P-value is more than the desired $\alpha$ value (0.05), then the null hypothesis is accepted. In both cases, P-value is less than $\alpha$ (0.05 at a 95 percent confidence interval) so that the null hypothesis is rejected. In the first case, the pedestrians’ yielding behavior to motorists is different for pedestrians crossing at crosswalks and away from crosswalks. The obtained P-value from the paired t-test, and proportions of yielding at two locations are depicted in Table 19. In the second case, the behavior of pedestrians trapped in the middle of the street is also different at crosswalks and away from crosswalks. The proportions of pedestrians trapped in the middle and of those crossing at crosswalks and away from crosswalks, corresponding proportions, and P-value obtained from the paired-test are shown in Table 19. The test reveals that the means of the difference of the proportions of pedestrians yielding to motorists crossing at a crosswalk and away from a crosswalk are different at the desired significance level of (P<0.05). Likewise, the means of the difference of the proportions of the behavior of pedestrians trapped in the middle of the street for pedestrians crossing at a crosswalk and away from a crosswalk are different at the desired significance level of (P<0.05).

Table 19 The Summary Statistics of Pedestrians’ Yielding to Motorists and Pedestrians Trapped in the Middle While Crossing in a Crosswalk and Away from a Crosswalk

<table>
<thead>
<tr>
<th>Difference of mean ($\bar{p}$)</th>
<th>Estimated difference of means</th>
<th>t-value</th>
<th>P-value</th>
<th>95% confidence interval for difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu_1 - \mu_2$</td>
<td>0.085</td>
<td>2.95</td>
<td>0.01</td>
<td>(0.02, 0.15)</td>
</tr>
<tr>
<td>$\mu_3 - \mu_4$</td>
<td>-0.157</td>
<td>-4.94</td>
<td>&lt;0.001</td>
<td>(-0.22, -0.09)</td>
</tr>
</tbody>
</table>
The difference in proportions of pedestrians' yielding to motorists and pedestrians trapped in the middle of the street crossing at crosswalks and away from crosswalks is further supported by the nonparametric test. A nonparametric test, the Wilcoxon signed-rank test, was used. The nonparametric test shows that the proportions of pedestrians' yielding to motorists and pedestrians trapped in the middle are significantly different at P<0.05 at crosswalks and away from crosswalks. The estimated median of the difference in proportions, confidence interval of the differences of medians, and P-values are shown for both crossing behaviors in Table 20. The obtained confidence interval also suggests that the difference of two proportions is not the same because both of the confidence intervals do not contain zero. The summary of result of the test is shown in Table 20. The mean proportion of pedestrians' yielding to motorists is more for the pedestrians crossing at crosswalk locations. Likewise, the mean proportion of pedestrians trapped in the middle is more for pedestrians crossing away from crosswalk locations. Both of these results are consistent with the results obtained from a parametric analysis.

Table 20 The Summary of Wilcoxon Signed-rank Test Result

<table>
<thead>
<tr>
<th>Difference of median (( \bar{p} ))</th>
<th>Wilcoxon statistic</th>
<th>Estimated median</th>
<th>P-value</th>
<th>95% confidence interval for difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \bar{\mu}_1 - \bar{\mu}_2 )</td>
<td>0.085</td>
<td>2.95</td>
<td>0.01</td>
<td>(0.02, 0.15)</td>
</tr>
<tr>
<td>( \bar{\mu}_3 - \bar{\mu}_4 )</td>
<td>-0.157</td>
<td>-4.94</td>
<td>&lt;0.001</td>
<td>(-0.23, -0.08)</td>
</tr>
</tbody>
</table>

5.6 Conclusions

An individual site-wise analysis of several locations in the Las Vegas metropolitan area indicated that the proportion of pedestrians yielding to motorists at crosswalks is
significantly greater than this proportion for pedestrians who cross at locations away from crosswalks. Further, the results based on area-wide analysis show that these two proportions are significantly different (at 99 percent confidence level). Similarly, the mean proportion of pedestrians trapped in the middle of the street while crossing at a crosswalk location is less than that for those of crossing away from a crosswalk. The results based on the area-wide analysis show that these two proportions are significantly different (at 99.9 percent confidence level). Therefore, both site-wise as well as area-wide analysis showed that the mean proportions of pedestrians’ yielding to motorists and pedestrians trapped in the middle are different for crossing at a crosswalk and away from a crosswalk. These conclusions based on parametric analysis are further supported by similar findings from non-parametric analysis.

In summary, pedestrians who cross at a crosswalk are more likely to yield to motorists than those of crossing away from a crosswalk. Likewise, pedestrians are less likely to be trapped in the middle of the street while crossing at a crosswalk than those of crossing away from a crosswalk.

The proportion of pedestrians yielding to motorists at a crosswalk is more, suggesting that pedestrians crossing at this location are likely to take comparatively less risk than pedestrians crossing away from a crosswalk. Pedestrians crossing at a crosswalk are more likely to follow traffic regulations; therefore, they are less likely need to take evasive action. Pedestrians crossing away from a crosswalk are more likely to be exposed to traffic more frequently because more proportions of pedestrians trapped in the middle of the street crossing at this location. Pedestrians crossing at this location have taken more
risk if there is no median refuge. The time of exposure could also be more due to unavailability of an acceptable gap to cross the second half of the road.

5.7 Recommendations

In the presence of a pedestrian WALK signal, a few instances of evasive actions by a motorist or a pedestrian were observed. In the Las Vegas metropolitan area, arterial streets typically are more than 80 feet wide. Some of the reasons for taking evasive actions might be pedestrian WALK signals are not conspicuous due to wide streets, and signal violations by turning vehicles. Innovative traffic engineering countermeasures could enhance pedestrian safety. Some of the potential countermeasures could be median refuge and Danish offset to protect pedestrians who are trapped in the middle. Danish offset indirectly compels pedestrians to face oncoming traffic. Pedestrian channelization on either side of the midblock location could reduce jaywalking and increase the use of crosswalk by pedestrians. Other strategies such as enlarged pedestrian signal heads and pedestrian countdown timers could help pedestrians to better see the pedestrian signal on other side of the street, and judge the remaining time to complete the crossing maneuver.
CHAPTER 6

ANALYSES OF COUNTERMEASURES

The results obtained from the before and after evaluation of the proposed countermeasures are discussed next. A summary of the results of the evaluated countermeasures are documented in Chapter 6. The countermeasures evaluated include the following: “In-pavement flashing light system,” “Pedestrian countdown signals,” “Turning traffic must yield to pedestrians” signs, “Portable speed trailer,” “In-roadway knockdown signs,” “High visibility crosswalk,” “Warning signs for motorists,” “Regulatory signs for motorists,” and “Yield markings.”

6.1 In-pavement Flashing Light System, Warning Sign for Motorists, Regulatory Sign for Motorists, and Advance Yield Markings

The result of the evaluation of the “In-pavement flashing light system” is discussed next. The MOEs include motorists’ yielding, speeds, yielding distance, and conflicts.

6.1.1 Motorists’ Yielding

The proportion of motorists yielding to pedestrians during the two study periods is summarized in Table 21. The proportion of motorists yielding before the installation of the in-pavement lighting system were about 34, 38, and 36 percent for AM, PM, and AM
and PM combined observations, respectively. These motorists yielding proportions after the installation of the in-pavement lighting system increased by about 31, 40, and 37 percent for AM, PM, and AM and PM combined, respectively. The increase in the proportion of motorists’ yielding during after study period was highly significant. The P-values are presented in Table 21. The P-values are less than the critical α-value (0.05 for 95 percent confidence) so that the null hypothesis was rejected. Hence the in-pavement lighting system was seen to help increase motorists’ yielding. Motorists are more cautious about the presence of signage, markings, and illumination of the in-pavement lighting.

Table 21 Motorists Yielding to Pedestrians Before and After In-Pavement Light System Installation

<table>
<thead>
<tr>
<th>Data collection periods</th>
<th>Before</th>
<th>After</th>
<th>Hypotheses test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total sample size</td>
<td>Number of motorists yielding</td>
<td>Percentage of motorists yielding</td>
</tr>
<tr>
<td>AM</td>
<td>62</td>
<td>21</td>
<td>33.87</td>
</tr>
<tr>
<td>PM</td>
<td>56</td>
<td>21</td>
<td>37.50</td>
</tr>
<tr>
<td>AM and PM</td>
<td>118</td>
<td>42</td>
<td>35.59</td>
</tr>
</tbody>
</table>

Note: $H_0: P_B = P_A, H_1: P_B < P_A$, and $\alpha = 0.05$

6.1.2 Speeds

The average, median, and the 85th percentile speeds in three scenarios: no pedestrians in the crosswalk, pedestrians waiting to cross, and pedestrians crossing in the crosswalk are shown in Table 22, Table 23, and Table 24, respectively. The observed speeds with no pedestrians during the two study periods were not significantly different for the various study periods. In this case, average speeds were not significantly different before and after the installation of the in-pavement lighting system while no pedestrians were
Table 22 Vehicle Speeds with No Pedestrians in the Crosswalk Before and After In-Pavement Light System Installation

<table>
<thead>
<tr>
<th>Description</th>
<th>Before</th>
<th></th>
<th></th>
<th>After</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average speed (mph)</td>
<td>Median speed (mph)</td>
<td>85th percentile speed (mph)</td>
<td>Sample size (n)</td>
<td>Average speed (mph)</td>
<td>Median speed (mph)</td>
</tr>
<tr>
<td>AM</td>
<td>36.25</td>
<td>36.07</td>
<td>42.16</td>
<td>78</td>
<td>32.42</td>
<td>32.88</td>
</tr>
<tr>
<td>PM</td>
<td>38.54</td>
<td>36.54</td>
<td>49.70</td>
<td>103</td>
<td>40.88</td>
<td>41.31</td>
</tr>
<tr>
<td>AM and PM</td>
<td>37.55</td>
<td>36.22</td>
<td>46.90</td>
<td>181</td>
<td>37.87</td>
<td>38.12</td>
</tr>
<tr>
<td>Eastbound</td>
<td>36.10</td>
<td>34.47</td>
<td>43.00</td>
<td>98</td>
<td>35.89</td>
<td>35.61</td>
</tr>
<tr>
<td>Westbound</td>
<td>39.27</td>
<td>37.86</td>
<td>50.60</td>
<td>83</td>
<td>40.17</td>
<td>39.32</td>
</tr>
<tr>
<td>Eastbound (AM) and westbound (PM)</td>
<td>38.28</td>
<td>34.51</td>
<td>49.00</td>
<td>99</td>
<td>36.80</td>
<td>36.50</td>
</tr>
<tr>
<td>Eastbound (PM) and westbound (AM)</td>
<td>36.68</td>
<td>37.15</td>
<td>43.93</td>
<td>82</td>
<td>39.15</td>
<td>39.23</td>
</tr>
</tbody>
</table>

Table 23 Vehicle Speeds with Pedestrians Waiting to Cross Before and After In-Pavement Light System Installation

<table>
<thead>
<tr>
<th>Description</th>
<th>Before</th>
<th></th>
<th></th>
<th>After</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average speed (mph)</td>
<td>Median speed (mph)</td>
<td>85th percentile speed (mph)</td>
<td>Sample size (n)</td>
<td>Average speed (mph)</td>
<td>Median speed (mph)</td>
</tr>
<tr>
<td>AM</td>
<td>37.49</td>
<td>35.46</td>
<td>45.36</td>
<td>69</td>
<td>28.37</td>
<td>28.38</td>
</tr>
<tr>
<td>PM</td>
<td>33.43</td>
<td>35.54</td>
<td>43.04</td>
<td>15</td>
<td>38.43</td>
<td>42.14</td>
</tr>
<tr>
<td>AM and PM</td>
<td>35.90</td>
<td>34.99</td>
<td>46.04</td>
<td>84</td>
<td>31.14</td>
<td>30.61</td>
</tr>
<tr>
<td>Eastbound</td>
<td>33.76</td>
<td>33.08</td>
<td>39.93</td>
<td>53</td>
<td>28.25</td>
<td>27.93</td>
</tr>
<tr>
<td>Westbound</td>
<td>41.92</td>
<td>41.41</td>
<td>50.74</td>
<td>31</td>
<td>34.29</td>
<td>33.55</td>
</tr>
<tr>
<td>Eastbound (AM) and westbound (PM)</td>
<td>33.68</td>
<td>32.89</td>
<td>37.99</td>
<td>40</td>
<td>31.50</td>
<td>29.43</td>
</tr>
<tr>
<td>Eastbound (PM) and westbound (AM)</td>
<td>39.58</td>
<td>40.09</td>
<td>49.48</td>
<td>44</td>
<td>30.68</td>
<td>31.50</td>
</tr>
</tbody>
</table>

present in the crosswalk. Therefore, the null hypothesis cannot be rejected except for AM data set. The statistical summary of the differences of means is shown in Table 25. Along with the implementation of the in-pavement lighting, other signage, and pavement markings were also installed; these devices help alert the motorists. Consequently, this affects the vehicle speed after implementation of the in-pavement lighting system even though no pedestrians were present at the crosswalk. Another reason may be that if
motorists who are far upstream on the crosswalk see flashing lights on the crosswalk while pedestrians are crossing on the crosswalk they may reduce their speed. By the time they reach the landmark, their speed could be reduced even though the in-pavement lights were turned off. Thus, their speeds are lower even though no pedestrians are present in the crosswalk.

Table 24 Vehicle Speeds with Pedestrians Crossing Before and After In-Pavement Light System Installation

<table>
<thead>
<tr>
<th>Description</th>
<th>Before</th>
<th></th>
<th>After</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average speed (mph)</td>
<td>Median speed (mph)</td>
<td>85th percentile speed (mph)</td>
<td>Sample size (n)</td>
</tr>
<tr>
<td>AM</td>
<td>26.71</td>
<td>24.27</td>
<td>35.89</td>
<td>41</td>
</tr>
<tr>
<td>PM</td>
<td>28.38</td>
<td>23.72</td>
<td>38.71</td>
<td>41</td>
</tr>
<tr>
<td>AM and PM</td>
<td>27.55</td>
<td>26.73</td>
<td>37.30</td>
<td>82</td>
</tr>
<tr>
<td>Eastbound</td>
<td>28.23</td>
<td>27.72</td>
<td>37.41</td>
<td>53</td>
</tr>
<tr>
<td>Westbound</td>
<td>26.30</td>
<td>22.91</td>
<td>37.06</td>
<td>29</td>
</tr>
<tr>
<td>Eastbound (AM) and westbound (PM)</td>
<td>27.52</td>
<td>26.81</td>
<td>33.54</td>
<td>16</td>
</tr>
<tr>
<td>Eastbound (PM) and westbound (AM)</td>
<td>27.55</td>
<td>26.73</td>
<td>38.04</td>
<td>66</td>
</tr>
</tbody>
</table>

The average speeds before the installation of the in-pavement lighting system were higher than after the installation of the in-pavement lighting system while pedestrians were waiting to cross except during the PM observations. These speed data are shown in Table 23 and their statistical significance before and after evaluation periods are shown in Table 25. The P-values to compare the means between the two study periods are less than 0.05 so that the mean speeds are different except for the PM observations at the 95 percent confidence level. The average speed after the installation of the in-pavement lighting system was reduced by 4.7 mph based on the observations during the AM and PM periods.
The average, median, and the 85th percentile speeds decreased after the installation of the in-pavement lighting system while pedestrians were crossing in the crosswalk. These values are depicted in Table 24. The means of the speeds at different data collection timings are significantly lower after the installation of the in-pavement lighting system at the 95 percent confidence level. The P-values are lower than 0.05 so the null hypothesis is rejected.

The mean speeds were also compared to evaluate if there is any significant difference in speeds when facing the sun while driving, i.e., facing the sun while driving eastbound in the morning peak hours and westbound in the evening peak hours. Therefore, the mean speeds of two peak hours eastbound (AM) and westbound (PM), \( \mu_{ES} \), and eastbound (PM) and westbound (AM), \( \mu_{HS} \), were compared for three scenarios: while pedestrians in the crosswalk, pedestrians waiting to cross, and pedestrians crossing for both before and after study periods. The mean, median, and the 85th percentile speeds are shown in Table 22, Table 23, and Table 24, and the difference of the mean speeds and their statistical significance are shown in Table 26. However, the differences in means as shown in Table 26 are statistically different only in two cases: pedestrians were waiting to cross before the installation of the in-pavement lighting system and no pedestrians were present in the

<table>
<thead>
<tr>
<th>Description</th>
<th>No pedestrians</th>
<th>Pedestrians waiting to cross</th>
<th>Pedestrians crossing</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM</td>
<td>3.82 &lt;0.001 Reject</td>
<td>7.09 &lt;0.001 Reject</td>
<td>3.88 0.013 Reject</td>
</tr>
<tr>
<td>PM</td>
<td>-2.35 0.972 Do not reject</td>
<td>-5.00 0.925 Do not reject</td>
<td>7.65 &lt;0.001 Reject</td>
</tr>
<tr>
<td>AM and PM</td>
<td>-0.32 0.648 Do not reject</td>
<td>4.75 0.001 Reject</td>
<td>5.78 &lt;0.001 Reject</td>
</tr>
<tr>
<td>Eastbound</td>
<td>0.20 0.418 Do not reject</td>
<td>5.50 &lt;0.001 Reject</td>
<td>6.74 &lt;0.001 Reject</td>
</tr>
<tr>
<td>Westbound</td>
<td>-0.91 0.741 Do not reject</td>
<td>7.62 &lt;0.001 Reject</td>
<td>4.24 0.037 Reject</td>
</tr>
</tbody>
</table>

Note: \( H_0: \mu_B - \mu_A = 0, H_1: \mu_B > \mu_A, \) and \( \alpha = 0.05 \)
crosswalk after the installation of the in-pavement lighting system. This does not lead to any conclusive finding in this regard.

Table 26 Comparison of Speeds for Drivers Facing the Sun in Eastbound (AM) and Westbound (PM) Vs. Drivers with the Sun Behind Them Eastbound (PM) and Westbound (AM)

<table>
<thead>
<tr>
<th>Description</th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>No pedestrians</td>
<td>1.60</td>
<td>0.219</td>
</tr>
<tr>
<td>Pedestrians waiting to cross</td>
<td>-5.89</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Pedestrians crossing</td>
<td>-0.03</td>
<td>0.987</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description</th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P-value</td>
<td>Null hypothesis</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No pedestrians</td>
<td>0.219</td>
<td>Do not reject</td>
</tr>
<tr>
<td>Pedestrians waiting to cross</td>
<td>&lt;0.001</td>
<td>Reject</td>
</tr>
<tr>
<td>Pedestrians crossing</td>
<td>0.987</td>
<td>Do not reject</td>
</tr>
</tbody>
</table>

Note: $H_0$: $\mu_{BS} = \mu_{BS}$, $H_1$: $\mu_{BS} \neq \mu_{BS}$, and $\alpha = 0.05$

6.1.3 Yielding Distance

Yield markings were placed 45 feet and 77 feet away from the crosswalk in eastbound and westbound directions, respectively. Results show that motorists yielded on an average about 9 feet further upstream of the crosswalk for the eastbound direction after installation of the in-pavement lighting. However, for the westbound direction motorists' average yielding distance was reduced by an average about 20 feet toward crosswalk after the installation of the in-pavement lighting. The crosswalk in the westbound direction is located downstream the driveway. Motorists yield to pedestrians upstream of the driveway. For the “before condition,” they used to yield upstream of the driveway. After installation of the in-pavement lighting, they generally yielded close to the yield marking, which is 77 feet away from the crosswalk. Interestingly, the average
yielding distance was on an average about 10 feet further upstream from the yield marking in both directions. The mean yielding distance and corresponding sample size for before and after the installation of the in-pavement lighting system are shown in Table 27. The yielding distances before and after study evaluation periods were significantly different at the 90 percent confidence level. The estimated difference of means for eastbound and westbound directions and P-values are shown in Table 28. It is interesting to note that the mean yielding distance in the westbound direction was greater in the “before” scenario than in the “after” scenario. This is possibly because of the fact that in the “before” scenario there was no clear identification of the location where vehicles were expected to stop (because of the driveway that was located immediately upstream of the crosswalk). This could have led the motorists to stop (yield) well in advance of where the yield markings were subsequently put in place.

Table 27 Yielding Distance Before and After In-Pavement Light System Installation

<table>
<thead>
<tr>
<th>Direction</th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean yielding distance (ft)</td>
<td>Median yielding distance (ft)</td>
</tr>
<tr>
<td>Eastbound</td>
<td>44.4</td>
<td>45.0</td>
</tr>
<tr>
<td>Westbound</td>
<td>110.1</td>
<td>100.0</td>
</tr>
</tbody>
</table>

6.1.4 Conflicts

The conflict observations were recorded when a pedestrian interacts with one or more motorists while crossing in the crosswalk. Before and after the installation of the in-pavement light about 10 and 12 percent conflicts were observed, respectively. A
marginal difference in conflicts was found before and after the installation of the in-pavement lighting system. However, the observed difference in conflicts was not statistically significant at the 95 percent confidence level. The number of observations, the percentage of conflicts, and the P-value are shown in Table 29.

Table 28 Comparison of Yielding Distance Before and After In-Pavement Light System Installation

<table>
<thead>
<tr>
<th>Description</th>
<th>Estimated difference of means (before - after), ft</th>
<th>P-value</th>
<th>Null hypothesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastbound</td>
<td>-9.05</td>
<td>0.078</td>
<td>Do not reject</td>
</tr>
<tr>
<td>Westbound</td>
<td>20.40</td>
<td>0.063</td>
<td>Do not reject</td>
</tr>
</tbody>
</table>

Note: $H_0$: $\mu_{BY} = \mu_{AY}$, $H_a$: $\mu_{BY} < \mu_{AY}$, and $\alpha = 0.10$

Table 29 Conflict Observations Before and After In-Pavement Light System Installation

<table>
<thead>
<tr>
<th>Study periods</th>
<th>Number of observations</th>
<th>Number of conflicts</th>
<th>Conflicts (%)</th>
<th>Estimated difference of means (before - after), %</th>
<th>P-value</th>
<th>Null hypothesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before</td>
<td>118</td>
<td>12</td>
<td>10.17</td>
<td>-1.93</td>
<td>0.578</td>
<td>Do not reject</td>
</tr>
<tr>
<td>After</td>
<td>248</td>
<td>30</td>
<td>12.10</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: $H_0$: $P_{BC} = P_{AC}$, $H_a$: $P_{BC} \neq P_{AC}$, and $\alpha = 0.05$

6.2 Pedestrian Countdown Signal Based on Pedestrian Actions

The results show that the percentage of pedestrians who pushed the call button increased during the "after" study period by 9 percent. This is statistically significant ($P = 0.034$) at the 95 percent confidence level. The increase in the percent of pedestrians who pushed the call button during the "after" study period suggests an improvement in the crossing behavior. The percentage of pedestrians who pushed the call button and waited for the WALK increased by 4 percent during the "after" study period ($P = 0.218$). On the
other hand, the percentage of pedestrians who waited for the WALK phase without pushing call button decreased by 10 percent ($P = 0.004$). The observed pedestrians' behavior on pushing the call button are positive, a majority of pedestrians pushed call button and waited for the WALK signal. The summary of all MOEs corresponding proportions during before and after study periods, sample sizes, the differences of proportion between before and after study periods, and their statistical significance are shown in Table 30. The differences of proportion of MOEs in each study period are depicted in Figure 15.

Figure 15. Difference in MOEs during before and after study periods due to the installation of pedestrian countdown signals based on pedestrian actions.
Table 30 Proportions, Sample Size, and Significance of Differences of MOEs During Before and After Study Periods Due to the Installation of Pedestrian Countdown Signals

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Descriptions</th>
<th>Sample size</th>
<th>Proportion before</th>
<th>Proportion after</th>
<th>Difference (before - after)</th>
<th>P-value</th>
<th>Null hypothesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pedestrians who pushed the call button</td>
<td>162</td>
<td>0.71</td>
<td>0.80</td>
<td>-0.09</td>
<td>0.034</td>
<td>Reject</td>
</tr>
<tr>
<td>2</td>
<td>Pedestrians who pushed the call button and waited for the WALK</td>
<td>162</td>
<td>0.71</td>
<td>0.75</td>
<td>-0.04</td>
<td>0.218</td>
<td>Do not reject</td>
</tr>
<tr>
<td>3</td>
<td>Pedestrians who were trapped in the middle while crossing</td>
<td>163</td>
<td>0.01</td>
<td>0.04</td>
<td>-0.03</td>
<td>0.141</td>
<td>Do not reject</td>
</tr>
<tr>
<td>4</td>
<td>Pedestrians who crossed the second half of the road during the flashing DON'T WALK phase</td>
<td>163</td>
<td>0.18</td>
<td>0.34</td>
<td>-0.16</td>
<td>0.001</td>
<td>Reject</td>
</tr>
<tr>
<td>5</td>
<td>Pedestrians did not push call button but waited for the WALK</td>
<td>148</td>
<td>0.18</td>
<td>0.08</td>
<td>0.10</td>
<td>0.004</td>
<td>Reject</td>
</tr>
<tr>
<td>6</td>
<td>Evasive actions either by motorists or pedestrians</td>
<td>163</td>
<td>0.15</td>
<td>0.08</td>
<td>0.07</td>
<td>0.014</td>
<td>Reject</td>
</tr>
<tr>
<td>7</td>
<td>Pedestrians who were in the crosswalk during the flashing</td>
<td>163</td>
<td>0.67</td>
<td>0.59</td>
<td>0.08</td>
<td>0.068</td>
<td>Do not reject</td>
</tr>
<tr>
<td>8</td>
<td>Pedestrians who started crossing during the DON'T WALK phase</td>
<td>163</td>
<td>0.22</td>
<td>0.12</td>
<td>0.10</td>
<td>0.008</td>
<td>Reject</td>
</tr>
<tr>
<td>9</td>
<td>Pedestrians who were in the crosswalk at the end of all-red time</td>
<td>163</td>
<td>0.11</td>
<td>0.05</td>
<td>0.06</td>
<td>0.024</td>
<td>Reject</td>
</tr>
</tbody>
</table>

Note: α = 0.05

Other major surrogate MOEs directly related to pedestrian safety are evasive actions either by pedestrians or motorists, signal violation, and pedestrians in the crosswalk at the end of all-red time. These MOEs were decreased during the after study as compared to the before study period. The percentages of evasive actions, pedestrians who started crossing during the DON'T WALK (signal violation), and pedestrians who were in the crosswalk at the end of the all red time, were decreased by 8 percent (P = 0.014), 10 percent (P = 0.008), and 6 percent (P = 0.024), respectively. These differences were significantly different at the 95 percent confidence level. These are the indication of changing pedestrians' behaviors in improving pedestrian safety because of installation of the pedestrian countdown signal.
The percentage of pedestrians who were in the crosswalk during the flashing DON'T WALK phase decreased by 8 percent (P = 0.068), which indicates a few pedestrians in the crosswalk during the flashing DON'T WALK phase. On the contrary, the percentage of pedestrians who were in the second half of the crosswalk during the flashing DON'T WALK phase decreased by 16 percent (P = 0.001). Before the installation of the pedestrian countdown signal, pedestrians might have sped up to finish crossing during the flashing DON'T WALK signal without knowing the time remaining for completing the crossing maneuver. However, after the installation of the pedestrian countdown signal, the remaining time to complete the crossing maneuver was displayed on the pedestrian signal head. This would be expected to help pedestrians to complete crossing within the stipulated time. Therefore, more pedestrians were present in the crosswalk during the after study period as compared to the before study period while the flashing DON'T WALK was displayed on the pedestrian countdown signal.

The percentage of pedestrians who were trapped in the middle of the road while crossing increased by 3 percent (P = 0.141). The installed pedestrian countdown signal might help pedestrians by reminding of the remaining time to complete crossing. As a result, pedestrians who believe that they do not have enough time to cross might wait in the middle for an acceptable gap. On the other hand, a comparatively lower percentage of pedestrians trapped in the middle of the road during the "before" study period. This might be due to pedestrians rushing during the flashing DON'T WALK phase because they do not know the exact timing when the flashing DON'T WALK phase changes to the DON'T WALK phase. They might not wait in the middle of the road, and rather speed up

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and complete the crossing. This crossing behavior is also justified by higher percentage of pedestrians taking evasive actions that might be related to pedestrians not yielding.

6.3 Pedestrian Countdown Signal Based on Vehicle Speed

Motorists sped up when countdown timer was displayed on the pedestrian signal head. The difference of mean speeds between the pedestrian WALK signal and the countdown timer at Green Valley Parkway / Warm Springs Road in both eastbound and westbound direction were significantly different at the 95 percent confidence level ($P < 0.001$). The mean speeds while the pedestrian countdown timer was displayed on the pedestrian signal head were 3.78 mph and 2.75 mph more than those of the mean speeds with the pedestrian WALK signals for eastbound and westbound direction, respectively. Similar trends were observed at Sunset Road / Marks Street. The mean speeds with the pedestrian countdown timer were 2.49 mph and 2.81 mph more than those of the mean speeds with the pedestrian WALK signal in eastbound and westbound direction, respectively. The observed speeds were greater at Sunset Road / Marks Street when the countdown timers were displayed on the pedestrian countdown signal head and the difference is significant at the 90 percent confidence level for westbound ($P = 0.005$) and eastbound direction ($P = 0.070$). The mean speeds with the pedestrian WALK signal and the countdown timers, difference of mean speeds, and $P$-values are shown in Table 31.

Motorists might observe only the WALK signal and the flashing DON'T WALK. Once the signal on the pedestrian signal head changes from the WALK to the flashing DON'T WALK along with the countdown in Arabic numerals, motorists tend to speed up no matter what the number is on the pedestrian signal head.
Table 31 Difference in Mean Speeds between Pedestrian WALK Signal and Countdown Timer

<table>
<thead>
<tr>
<th>Locations</th>
<th>Mean speed (mph)</th>
<th>Difference in mean, mph</th>
<th>P-value</th>
<th>Null hypothesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green Valley Parkway / Warm Springs Road (Eastbound)</td>
<td>36.48 (78)</td>
<td>40.26 (249)</td>
<td>3.78</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>37.21 (48)</td>
<td>39.96 (145)</td>
<td>2.75</td>
<td>0.001</td>
</tr>
<tr>
<td>Sunset Road / Marks Street (Eastbound)</td>
<td>38.76 (31)</td>
<td>41.25 (140)</td>
<td>2.49</td>
<td>0.070</td>
</tr>
<tr>
<td></td>
<td>35.99 (45)</td>
<td>38.80 (93)</td>
<td>2.81</td>
<td>0.005</td>
</tr>
</tbody>
</table>

Note: values in parentheses are sample sizes; $H_0: \mu_c = \mu_w$, $H_a: \mu_c > \mu_w$, and $\alpha = 0.05$

In both of the study locations, $V_2$, speed between the stop bar and 100 feet upstream of the stop bar, was higher than $V_1$, speed between 100 feet and 200 feet upstream of the stop bar. These differences are highly significant ($P < 0.001$) in all ranges of timings on the pedestrian signal head including the pedestrian WALK signal. The speeds, $V_1$ and $V_2$, at two locations with different pedestrian signs on the pedestrian signals head, the difference of means, and P-values are shown in Table 32 and Table 33. The results suggest that motorists do not speed up only when the countdown timer is displayed on the pedestrian signal head but they also speed up when they approach the intersection. The mean speeds of vehicles with pedestrian WALK signal was displayed on the pedestrian signal head and with the countdown timer displayed on the pedestrian signal head are also shown in Figure 16 and Figure 17 at Green Valley / Warm Springs and Sunset Road / Marks Street, respectively. The error range of 5 percent of the mean is also shown in Figure 16 and Figure 17.
Figure 16. Mean speeds of vehicles with different pedestrian signals at Green Valley / Warm Springs.

Table 32 Speeds at Green Valley Parkway / Warm Springs Road with Different Signs on the Pedestrian Countdown Signal Head

<table>
<thead>
<tr>
<th>Signs on pedestrian signal head</th>
<th>Sample size (n)</th>
<th>Mean speed (mph)</th>
<th>μ₀ Difference in mean (V₂ - V₁), mph</th>
<th>P-value</th>
<th>Null hypothesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedestrian WALK signal</td>
<td>126</td>
<td>30.71</td>
<td>47.36</td>
<td>16.65</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Countdown time (&gt;15 sec)</td>
<td>141</td>
<td>31.33</td>
<td>52.84</td>
<td>21.51</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Countdown time (15 - 10 sec)</td>
<td>66</td>
<td>34.46</td>
<td>52.43</td>
<td>17.97</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Countdown time (10 - 5 sec)</td>
<td>61</td>
<td>33.14</td>
<td>50.89</td>
<td>17.75</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Countdown time (&lt; 5 sec)</td>
<td>75</td>
<td>34.05</td>
<td>52.27</td>
<td>18.22</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Note: H₀: μ₁ = 0, H₁: μ₁ > 0, and α = 0.05
Figure 17. Mean speeds of vehicles with different pedestrian signals at Sunset Road / Marks Street.

### Table 33 Speeds at Sunset Road / Marks Street with Different Signs on the Pedestrian Countdown Signal Head

<table>
<thead>
<tr>
<th>Signs on pedestrian signal head</th>
<th>Sample size (n)</th>
<th>Mean speed (mph) 200 ft before stop bar ($V_1$)</th>
<th>Mean speed (mph) 100 ft before stop bar ($V_2$)</th>
<th>$\mu_D$ Difference in mean ($V_2 - V_1$), mph</th>
<th>$P$-value</th>
<th>Null hypothesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedestrian WALK signal</td>
<td>76</td>
<td>33.07</td>
<td>44.51</td>
<td>11.44</td>
<td>&lt;0.001</td>
<td>Reject</td>
</tr>
<tr>
<td>Countdown time (&gt;15 sec)</td>
<td>31</td>
<td>32.77</td>
<td>51.80</td>
<td>19.03</td>
<td>&lt;0.001</td>
<td>Reject</td>
</tr>
<tr>
<td>Countdown time (15 - 10 sec)</td>
<td>61</td>
<td>34.40</td>
<td>47.16</td>
<td>12.76</td>
<td>&lt;0.001</td>
<td>Reject</td>
</tr>
<tr>
<td>Countdown time (10 - 5 sec)</td>
<td>64</td>
<td>36.18</td>
<td>46.64</td>
<td>10.46</td>
<td>&lt;0.001</td>
<td>Reject</td>
</tr>
<tr>
<td>Countdown time (&lt; 5 sec)</td>
<td>77</td>
<td>34.18</td>
<td>49.37</td>
<td>15.19</td>
<td>&lt;0.001</td>
<td>Reject</td>
</tr>
</tbody>
</table>

Note: $H_0: \mu_1 = 0$, $H_1: \mu_1 > 0$, and $\alpha = 0.05$
6.4 Turning Traffic Must Yield to Pedestrians

The "Turning traffic must yield to pedestrians" sign was placed at two locations: Harmon Avenue / Paradise Road and Lake Mead Boulevard / Pecos Road. The findings of the installation at these locations are discussed next.

6.4.1 Harmon Avenue / Paradise Road

The before-and-after study results show that the installation of the "Turning traffic must yield to pedestrians" sign has increased the percentage of motorists yielding at RTOR from 61.3 percent to 73.3 percent (P = 0.156). Similarly, the percentage of motorists yielding at right turn on green increased from 73.5 percent to 76.7 percent (P = 0.615) during the after-study period. The installation of the sign, "Turning traffic must yield to pedestrians," shows an increase in motorists yielding while turning either on red or green even though these differences were not statistically significant at the 95 percent confidence level.

Before the installation of the sign, "Turning traffic must yield to pedestrians," about 11 percent of vehicles blocked the crosswalk before turning; after the sign was installed, the percentage of motorists blocking the crosswalk was reduced to zero (P < 0.001). The observed stopping behavior of motorists before RTOR indicates that about 74 percent of motorists were stopped completely before the sign was installed; this percentage increased to about 97 percent (P < 0.001) after the sign was installed. The values of MOEs during before and after study periods, their difference and statistical significance are shown in Table 34. The value of MOEs in percentage before and after study periods are depicted in Figure 18.
The average vehicle delay increased from 66.8 seconds/vehicle to 75.6 seconds/vehicle, before and after the installation of the sign respectively. The percentage of motorists yielding also increased so that more vehicles in the queue yield for pedestrians. Consequently, the vehicle delay also increases. Pedestrian delay increased from 44 seconds/pedestrian to 61 seconds/pedestrian, before and after the installation of the sign respectively. The motorists’ yielding was increased after the sign was installed so that pedestrian delay should have been decreased because more turning motorists yielded to pedestrians either on red or green. Even though the pedestrians’ arrival is considered as random, some pedestrians might have to wait longer and others might have to wait less. Some pedestrians arrive at the beginning of the WALK signal, i.e., no waiting time,
others arrive during the flashing DON'T WALK phase, and they have to wait for a cycle length typically 120 to 140 seconds. The weighted average of all pedestrians in that range might be a very rough estimate of delay. The field observations show that a vehicle interacts with pedestrians while turning either on red or on green. Motorists’ yielding percentage increased indicating that pedestrians do not have to wait longer for turning traffic. Therefore, pedestrian delay should have been reduced. The reason is not known why pedestrian delay has increased after the installation of the sign, “Turning traffic must yield to pedestrians.”

Table 34 MOEs during Before and After Study Periods and Their Statistical Significance at Harmon Avenue / Paradise Road Due to the Installation of “Turning Traffic Must Yield to Pedestrians” Sign

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Measures of Effectiveness</th>
<th>Before</th>
<th>After</th>
<th>(Before - After)</th>
<th>P-value</th>
<th>Null hypothesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Motorists' yielding at right turn on red (in the presence of pedestrian at turn or approach), %</td>
<td>31 61.29</td>
<td>30 73.33</td>
<td>-12.04</td>
<td>0.156</td>
<td>Do not reject</td>
</tr>
<tr>
<td>2</td>
<td>Motorists' yielding at right turn on green (in the presence of pedestrians), %</td>
<td>102 73.53</td>
<td>90 76.67</td>
<td>-3.14</td>
<td>0.615</td>
<td>Do not reject</td>
</tr>
<tr>
<td>3</td>
<td>Percentage vehicles blocking crosswalk</td>
<td>129 10.85</td>
<td>235 0.00</td>
<td>10.85</td>
<td>0.000</td>
<td>Reject</td>
</tr>
<tr>
<td>4</td>
<td>Percentage of drivers executing right turn on red coming to complete stop</td>
<td>129 74.42</td>
<td>235 97.45</td>
<td>-23.03</td>
<td>0.000</td>
<td>Reject</td>
</tr>
<tr>
<td>5</td>
<td>Pedestrian delay (sec/vehicle)</td>
<td>556 44.37</td>
<td>355 61.09</td>
<td>16.73</td>
<td>0.000</td>
<td>Reject</td>
</tr>
<tr>
<td>6</td>
<td>Vehicle delay at intersection (sec/veh)</td>
<td>1,356 66.83</td>
<td>1,275 75.64</td>
<td>-8.81</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>7</td>
<td>Percentage of pedestrians who looked at start of the WALK phase for turning vehicles</td>
<td>542 53.69</td>
<td>370 93.24</td>
<td>-39.55</td>
<td>0.000</td>
<td>Reject</td>
</tr>
<tr>
<td>8</td>
<td>Percentage of pedestrians who were in the crosswalk during the flashing DON'T WALK phase</td>
<td>639 45.07</td>
<td>390 43.33</td>
<td>1.74</td>
<td>0.586</td>
<td>Do not reject</td>
</tr>
<tr>
<td>9</td>
<td>Percentage of pedestrians who were in the crosswalk at the end of all-red</td>
<td>639 2.66</td>
<td>390 2.05</td>
<td>0.61</td>
<td>0.525</td>
<td>Do not reject</td>
</tr>
<tr>
<td>10</td>
<td>Percentage of pedestrians who were trapped in the middle of crossing</td>
<td>618 5.50</td>
<td>373 3.75</td>
<td>1.75</td>
<td>0.194</td>
<td>Do not reject</td>
</tr>
<tr>
<td>11</td>
<td>Percentage of pedestrian/vehicle evasive actions, change course/slow to avoid motorists</td>
<td>609 0.82</td>
<td>349 7.74</td>
<td>-6.92</td>
<td>1.000</td>
<td>Do not reject</td>
</tr>
</tbody>
</table>

Note: α = 0.05
The sign, “Turning traffic must yield to pedestrians,” is intended for motorists. However, the before-and-after study result indicates some positive influence on pedestrians’ crossing behavior. The percentage of pedestrians looking for turning vehicles at the beginning of the WALK signal increased from 53.7 percent to 93.2 percent (P < 0.001) before and after the installation of the sign respectively. As the motorists’ yielding increases, motorists might stop upstream of the crosswalk. Therefore, more pedestrians watch for turning vehicles before crossing. Marginal differences were observed in the percentage of pedestrians who were in the crosswalk during the flashing DON’T WALK phase and during the all red phase before and after the installation of the sign. The percentages of pedestrians who were in the crosswalk during the flashing DON’T WALK phase and at the all-red time were decreased by 1.7 percent (P = 0.586) and 0.6 percent (P = 0.525) respectively after the installation of the sign.

The percentage of pedestrians who were trapped in the middle of the road while crossing decreased during the after-study from 5.5 percent to 3.7 percent (P = 0.194). Pedestrians do not have to wait in the middle of the road if they have an acceptable gap for crossing. The motorists’ yielding behavior while turning improved. Therefore, motorists turning on permitted left-turn also yielded to pedestrians. As a result, the percentage of pedestrians trapped in the middle was reduced after installation of the sign.

The percentages of evasive actions were 0.8 percent and 7.7 percent before and after condition data collection period, respectively. The difference of the percentage of evasive action between before and after period was significantly different (P < 0.001) at the 95 percent confidence level but in an unexpected direction.
The before-and-after study results show that the installation of the “Turning traffic must yield to pedestrians” sign has increased the percentage of motorists yielding at RTOR from 51 percent to 92 percent ($P < 0.001$). On the contrary, the percentage of motorists yielding at right turn on green decreased marginally from 82 percent to 80 percent ($P = 0.566$) during the after-study period. However, this difference is not statistically different at the 95 percent confidence level. The installation of the sign “Turning traffic must yield to pedestrians” shows an increase in motorists yielding while turning on red. The values of MOEs during before and after study periods, their difference and statistical significance are shown in Table 35. The value of MOEs in percentage before and after study periods are also depicted in Figure 19.

Before the installation of the sign, “Turning traffic must yield to pedestrians,” 39 percent of vehicles blocked the crosswalk before turning; after the sign was installed, the percentage of motorists blocking the crosswalk increased to 82 percent ($P < 0.001$). The observed stopping behavior of motorists before RTOR indicates that about 75 percent of motorists were completely stopped before the sign was installed; this percentage decreased to 58 percent ($P < 0.001$) after the sign was installed.

The average vehicle delay increased marginally from 25.4 seconds/vehicle to 26.1 seconds/vehicle, before and after the installation of the sign, respectively. Similar trends were observed both morning and evening peak hours during both of the study periods. The percentage of motorists yielding also increases so that more vehicles yielded to pedestrians. Consequently, the vehicle delay also increases. Pedestrian delay increased
from 42 seconds/pedestrian to 45 seconds/pedestrian before and after the installation of
the sign respectively.

The percentage of pedestrians looking for turning vehicles at the beginning of the
WALK signal decreased from 88 percent to 58 percent (P < 0.001) before and after the
installation of the sign respectively. The percentages of pedestrians who were in the
crosswalk during the flashing DON'T WALK phase and at the end of all red time
decreased from 62 percent to 21 percent (P < 0.001) and 3.1 percent to 2.7 percent (P =
0.393) respectively during after study period.
Table 35 MOEs during Before and After Study Periods and Their Statistical Significance at Lake Mead Boulevard / Pecos Road Due to the Installation of “Turning Traffic Must Yield to Pedestrians” Sign

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Measures of Effectiveness</th>
<th>Before</th>
<th>After</th>
<th>(Before - After)</th>
<th>P-value</th>
<th>Null hypothesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Motorists’ yielding at right turn on red (in the presence of pedestrian at turn or approach), %</td>
<td>76</td>
<td>55</td>
<td>-39.59</td>
<td>&lt;0.001</td>
<td>Reject</td>
</tr>
<tr>
<td>2</td>
<td>Motorists’ yielding at right turn on green (in the presence of pedestrians), %</td>
<td>73</td>
<td>64</td>
<td>2.26</td>
<td>0.566</td>
<td>Do not reject</td>
</tr>
<tr>
<td>3</td>
<td>Percentage vehicles blocked the crosswalk, %</td>
<td>267</td>
<td>198</td>
<td>-43.00</td>
<td>1.000</td>
<td>Do not reject</td>
</tr>
<tr>
<td>4</td>
<td>Percentage of drivers executing right turn on red coming to complete stop, %</td>
<td>268</td>
<td>200</td>
<td>17.37</td>
<td>1.000</td>
<td>Do not reject</td>
</tr>
<tr>
<td>5</td>
<td>Pedestrian delay (sec/ped)</td>
<td>362</td>
<td>388</td>
<td>-3.23</td>
<td>0.914</td>
<td>Do not reject</td>
</tr>
<tr>
<td>6</td>
<td>Vehicle delay at intersection (sec/veh)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>AM</td>
<td>812</td>
<td>1,243</td>
<td>19.82</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>PM</td>
<td>1,642</td>
<td>1,384</td>
<td>31.78</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>2,454</td>
<td>2,627</td>
<td>26.12</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>7</td>
<td>Percentage of pedestrians who looked at start of the WALK phase for turning vehicles, %</td>
<td>331</td>
<td>412</td>
<td>29.36</td>
<td>1.000</td>
<td>Do not reject</td>
</tr>
<tr>
<td>8</td>
<td>Percentage of pedestrians who were in the crosswalk during the flashing DON'T WALK phase, %</td>
<td>354</td>
<td>432</td>
<td>41.26</td>
<td>&lt;0.001</td>
<td>Reject</td>
</tr>
<tr>
<td>9</td>
<td>Percentage of pedestrians who were in the crosswalk at the end of all-red, %</td>
<td>354</td>
<td>432</td>
<td>0.33</td>
<td>0.393</td>
<td>Do not reject</td>
</tr>
<tr>
<td>10</td>
<td>Percentage of pedestrians who were trapped in the middle of crossing, %</td>
<td>338</td>
<td>432</td>
<td>2.55</td>
<td>0.040</td>
<td>Reject</td>
</tr>
<tr>
<td>11</td>
<td>Percentage of pedestrian/vehicle evasive actions, change course/slow to avoid motorists, %</td>
<td>345</td>
<td>432</td>
<td>1.51</td>
<td>0.021</td>
<td>Reject</td>
</tr>
<tr>
<td>12</td>
<td>Vehicle speed (mph)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Eastbound</td>
<td>75</td>
<td>99</td>
<td>-2.46</td>
<td>0.963</td>
<td>Do not reject</td>
</tr>
<tr>
<td></td>
<td>Westbound</td>
<td>50</td>
<td>75</td>
<td>10.87</td>
<td>&lt;0.001</td>
<td>Reject</td>
</tr>
<tr>
<td></td>
<td>Northbound</td>
<td>50</td>
<td>60</td>
<td>10.75</td>
<td>&lt;0.001</td>
<td>Reject</td>
</tr>
<tr>
<td></td>
<td>Southbound</td>
<td>50</td>
<td>60</td>
<td>4.78</td>
<td>&lt;0.001</td>
<td>Reject</td>
</tr>
</tbody>
</table>

Note: $\alpha = 0.05$

The percentage of pedestrians trapped in the middle of the road while crossing decreased during the after-condition from 5.3 percent to 2.8 percent ($P = 0.040$). The
motorists' yielding behavior while turning improved. As a result, the percentage of pedestrians trapped in the middle decreased after installation of the sign.

The percentages of evasive actions were 1.7 percent and 0.2 percent for the before and after study periods respectively. The difference of the percentage of evasive action between before and after period was significantly different ($P = 0.021$) at the 95 percent confidence level. The average vehicle speeds decreased ($P < 0.001$) significantly during the after study period in the northbound, southbound, and westbound directions. However, the average vehicle speeds increased in the eastbound direction.

6.5 Portable Speed Trailer

The mean of the observed speeds on both the eastbound and westbound direction, corresponding sample size, and statistical significance of difference of the means are shown in Table 36. The existing condition mean speed in the eastbound direction was approximately 25 mph. The after-condition mean speeds upstream and downstream of the speed trailer were approximately 20 mph and 24 mph respectively. The difference of the mean speeds between the existing condition and after condition upstream of the speed trailer was approximately 5 mph ($P < 0.001$). The mean speed was reduced by approximately 1 mph ($P < 0.015$) downstream of the portable speed trailer during the after condition. Similar trends were observed in the westbound direction. The observed mean speeds were approximately 25 mph, 21 mph, and 22 mph, during the existing condition, after condition upstream and downstream of the speed trailer respectively. The mean speeds were reduced by approximately 4 mph ($P < 0.001$) and 3 mph ($P < 0.001$), during the after condition upstream and downstream of the portable speed trailers.
respectively. Both of these differences were statistically significant at the 95 percent confidence level. The mean speeds in three scenarios, the existing condition and the after condition upstream and downstream of the portable speed trailers are shown in Figure 20.

![Figure 20. Before and after study speed comparison at Fremont Street between 6th and 7th Street after installation of portable speed trailers.](image)

Table 36 Speed Statistics Before and After Installation of Portable Speed Trailers at Fremont Street between 6th and 7th Street

<table>
<thead>
<tr>
<th>Travel directions</th>
<th>Before-condition speed, mph (A)</th>
<th>After-condition speed (upstream of the speed trailer), mph (B)</th>
<th>After-condition speed (downstream of the speed trailer), mph (C)</th>
<th>Difference (A-B)</th>
<th>Difference (A-C)</th>
<th>Speed, mph</th>
<th>P-value</th>
<th>Null hypothesis</th>
<th>Speed, mph</th>
<th>P-value</th>
<th>Null hypothesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastbound</td>
<td>24.84 (252)</td>
<td>20.20 (197)</td>
<td>23.69 (272)</td>
<td>4.64</td>
<td>3.15</td>
<td>1.15</td>
<td>&lt;0.001</td>
<td>Reject</td>
<td>1.15</td>
<td>0.015</td>
<td>Reject</td>
</tr>
<tr>
<td>Westbound</td>
<td>24.94 (274)</td>
<td>21.34 (162)</td>
<td>22.41 (143)</td>
<td>3.60</td>
<td>2.53</td>
<td>2.53</td>
<td>&lt;0.001</td>
<td>Reject</td>
<td>2.53</td>
<td>&lt;0.001</td>
<td>Reject</td>
</tr>
</tbody>
</table>

Note: values in parentheses are sample sizes; $H_0: \mu_A = \mu_B, H_0: \mu_A > \mu_B, H_0: \mu_A = \mu_C, H_0: \mu_A > \mu_C$, and $\alpha = 0.05$.

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6.6 In-roadway Knockdown Sign

"In-roadway knockdown signs" were installed in the Bonanza Road corridor. The findings due to this installation are discussed next.

6.6.1 Bonanza Road / D Street

An “In-roadway knockdown sign” was deployed on the eastbound approach of the intersection of Bonanza Road and D Street. The sign was installed approximately 200 feet upstream of the intersection. The comparison of the MOEs during before and after study periods is shown in Table 37. The before and after study analysis shows that the percentage of pedestrians trapped in the middle of the street increased from 5 percent to approximately 9 percent (P = 0.110). Crosswalks are located on three approaches: west, east, and north. Signal violation increased approximately by 10 percent during the after study (P = 0.059). The average pedestrian delay increased during the after study period by 10 seconds per pedestrian. People waited on the side of the street for hours. On some occasions, the same people crossed the street several times. Therefore, to record pedestrian delay at such locations was not an easy task. The proportion of pedestrians delayed decreased in the after study period but not significantly (P = 0.875). The average vehicle delay increased during the after study period for both the morning and evening peak hours. The average vehicle delay increased from 6 seconds / vehicle to approximately 20 seconds / vehicle during the after study period.

Yielding distance of motorists while turning shows positive benefits due to the installation of “In-roadway knockdown sign.” The percentage of motorists yielding less than 10 feet upstream of the crosswalk decreased from 66 percent to 48 percent (P = 0.059). By the same token, the percentage of motorists yielding between 10 to 20 feet

134
Table 37 Comparison of the MOEs during Before and After Study at Bonanza Road and D Street Due to the Installation of “In-roadway Knockdown Sign”

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Measures of effectiveness</th>
<th>Unit</th>
<th>Before condition</th>
<th>After condition</th>
<th>Difference (before - after)</th>
<th>P-value</th>
<th>Null hypothesis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Value</td>
<td>Value</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sample size</td>
<td>Sample size</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Pedestrians who were trapped in the middle of the road</td>
<td>%</td>
<td>5.0</td>
<td>8.6</td>
<td>-3.6</td>
<td>0.110</td>
<td>Do not reject</td>
</tr>
<tr>
<td>2</td>
<td>Signal violation</td>
<td>%</td>
<td>49.5</td>
<td>59.0</td>
<td>-9.5</td>
<td>0.059</td>
<td>Do not reject</td>
</tr>
<tr>
<td>3</td>
<td>Pedestrians delay</td>
<td>sec/ped</td>
<td>5.9</td>
<td>15.4</td>
<td>-9.4</td>
<td>1.000</td>
<td>Do not reject</td>
</tr>
<tr>
<td>4</td>
<td>Proportion of pedestrians delayed</td>
<td>%</td>
<td>28.0</td>
<td>27.1</td>
<td>0.9</td>
<td>0.875</td>
<td>Do not reject</td>
</tr>
<tr>
<td>5</td>
<td>Vehicle delay</td>
<td>sec/veh</td>
<td>8.3</td>
<td>37.9</td>
<td>-29.6</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>AM peak</td>
<td></td>
<td>298</td>
<td>468</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PM peak</td>
<td></td>
<td>515</td>
<td>624</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total delay</td>
<td></td>
<td>6.1</td>
<td>19.8</td>
<td>-13.7</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>813</td>
<td>1092</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Yielding distance</td>
<td>%</td>
<td>66.0</td>
<td>48.3</td>
<td>17.8</td>
<td>0.059</td>
<td>Do not reject</td>
</tr>
<tr>
<td></td>
<td>&lt;10 ft</td>
<td></td>
<td>53</td>
<td>29</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10-20 ft</td>
<td></td>
<td>15.1</td>
<td>17.2</td>
<td>-2.1</td>
<td>0.401</td>
<td>Do not reject</td>
</tr>
<tr>
<td></td>
<td>&gt;20 ft</td>
<td></td>
<td>18.9</td>
<td>34.5</td>
<td>-15.6</td>
<td>0.065</td>
<td>Do not reject</td>
</tr>
<tr>
<td>7</td>
<td>Vehicles stop distance away from the crosswalk during red</td>
<td>%</td>
<td>91.1</td>
<td>35.4</td>
<td>55.7</td>
<td>&lt;0.001</td>
<td>Reject</td>
</tr>
<tr>
<td></td>
<td>&lt;10 ft</td>
<td></td>
<td>112</td>
<td>99</td>
<td>22.3</td>
<td>&lt;0.001</td>
<td>Reject</td>
</tr>
<tr>
<td></td>
<td>10-20 ft</td>
<td></td>
<td>8.0</td>
<td>99</td>
<td>0.7</td>
<td>&lt;0.001</td>
<td>Reject</td>
</tr>
<tr>
<td></td>
<td>&gt;20 ft</td>
<td></td>
<td>0.9</td>
<td>29.3</td>
<td>-28.4</td>
<td>&lt;0.001</td>
<td>Reject</td>
</tr>
<tr>
<td>8</td>
<td>Vehicle blocked the crosswalk</td>
<td>%</td>
<td>45.2</td>
<td>2.0</td>
<td>43.2</td>
<td>&lt;0.001</td>
<td>Reject</td>
</tr>
<tr>
<td>9</td>
<td>Evasive actions either by a pedestrian or a motorist</td>
<td>%</td>
<td>1.9</td>
<td>6.5</td>
<td>-4.6</td>
<td>0.204</td>
<td>Do not reject</td>
</tr>
<tr>
<td>10</td>
<td>Speed</td>
<td>mph</td>
<td>36.4</td>
<td>36.6</td>
<td>-0.1</td>
<td>0.556</td>
<td>Do not reject</td>
</tr>
<tr>
<td></td>
<td>Westbound</td>
<td></td>
<td>75</td>
<td>87</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Eastbound</td>
<td></td>
<td>37.4</td>
<td>34.4</td>
<td>3.0</td>
<td>&lt;0.001</td>
<td>Reject</td>
</tr>
</tbody>
</table>

Note: α = 0.05

upstream of the crosswalk and greater than 20 feet increased by 2 percent (P = 0.401) and 16 percent (P = 0.065), respectively during the after study. Thus, the proportion of the vehicles which stopped closer to the intersection decreased, and those stopped farther...
from the intersection increased due to the in-roadway knockdown signs. The percentage of vehicles, which stopped less than 10 feet decreased by approximately 56 percent ($P < 0.001$). On the other hand, the percentages of vehicles stopped in between 10 to 20 feet and greater than 20 feet increased by 27 percent ($P < 0.001$) and 28 percent ($P < 0.001$), respectively during the after study period.

The percentage of vehicles blocking the crosswalk decreased by 43 percent during the after study period ($P < 0.001$). Evasive actions, either by a motorist or a pedestrian, were increased by approximately 5 percent ($P = 0.024$) during the after study period. The average vehicle speed was reduced in the eastbound direction by 3 mph ($P < 0.001$) during the after study period. In the westbound direction, the average vehicle speed increased slightly ($P = 0.556$) because the sign was not installed for this approach.

### 6.6.2 Bonanza Road / F Street

“In-roadway knockdown signs” were deployed in both the eastbound and westbound approaches of the intersection of Bonanza Road and F Street. These signs were installed approximately 200 feet upstream of the intersection on either side of Bonanza Road. The comparison of the MOEs during before and after study periods is shown in Table 38. The before and after study analysis shows that the percentage of pedestrians who were trapped in the middle of the street increased by approximately 7 percent ($P = 0.019$). Pedestrian delay decreased during the after study period by 2.5 seconds per pedestrian. The proportion of pedestrians delayed decreased in the after study period by 29 percent ($P < 0.001$). The average vehicle delay increased during the after study period at both morning and evening peak hours. The average vehicle delay increased from 6 seconds / vehicle to approximately 14 seconds / vehicle. An increase in vehicle delay might be due
to higher traffic volumes during the after study period. Traffic count during the vehicle delay observation is shown in Table 38. Turning vehicles might also have to wait longer to yield for pedestrians.

Table 38 Comparison of the MOEs during Before and After Study at Bonanza Road and F Street Due to the Installation of “In-roadway Knockdown Sign”

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Measures of effectiveness</th>
<th>Unit</th>
<th>Before condition</th>
<th>After condition</th>
<th>Difference (before - after)</th>
<th>P-value</th>
<th>Null hypothesis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Value</td>
<td>Sample size</td>
<td>Value</td>
<td>Sample size</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Pedestrians who were trapped in the middle of the road</td>
<td>%</td>
<td>4.1</td>
<td>97</td>
<td>11.4</td>
<td>123</td>
<td>-7.3</td>
</tr>
<tr>
<td>2</td>
<td>Pedestrians delay</td>
<td>sec/ped</td>
<td>10.2</td>
<td>97</td>
<td>7.7</td>
<td>123</td>
<td>2.5</td>
</tr>
<tr>
<td>3</td>
<td>Proportion of pedestrians delayed</td>
<td>%</td>
<td>58.8</td>
<td>97</td>
<td>29.8</td>
<td>123</td>
<td>28.9</td>
</tr>
<tr>
<td>4</td>
<td>Vehicle delay</td>
<td>sec/veh</td>
<td>AM peak</td>
<td>5.3</td>
<td>305</td>
<td>20.0</td>
<td>506</td>
</tr>
<tr>
<td></td>
<td>PM peak</td>
<td>sec/veh</td>
<td>6.7</td>
<td>424</td>
<td>9.86</td>
<td>767</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total delay</td>
<td>sec/veh</td>
<td>6.1</td>
<td>729</td>
<td>13.9</td>
<td>1273</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Yielding distance</td>
<td>%</td>
<td>84.6</td>
<td>13</td>
<td>28.6</td>
<td>21</td>
<td>56.0</td>
</tr>
<tr>
<td></td>
<td>&lt;10 ft</td>
<td>%</td>
<td>92.4</td>
<td>66</td>
<td>76.5</td>
<td>204</td>
<td>16.0</td>
</tr>
<tr>
<td></td>
<td>10-20 ft</td>
<td>%</td>
<td>7.6</td>
<td>66</td>
<td>23.0</td>
<td>204</td>
<td>-15.5</td>
</tr>
<tr>
<td></td>
<td>&gt;20 ft</td>
<td>%</td>
<td>-</td>
<td>13</td>
<td>28.6</td>
<td>21</td>
<td>-28.6</td>
</tr>
<tr>
<td>6</td>
<td>Vehicles stop distance away from the crosswalk during red</td>
<td>%</td>
<td>34.6</td>
<td>75</td>
<td>34.8</td>
<td>77</td>
<td>-0.2</td>
</tr>
<tr>
<td></td>
<td>Westbound</td>
<td>mph</td>
<td>34.6</td>
<td>75</td>
<td>34.8</td>
<td>77</td>
<td>-0.2</td>
</tr>
<tr>
<td></td>
<td>Eastbound</td>
<td>mph</td>
<td>37.1</td>
<td>50</td>
<td>36.5</td>
<td>100</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Note: $\alpha = 0.05$
Yielding distance of motorists while turning shows positive benefit due to this installation. The percentage of motorists yielding less than 10 feet was decreased from 85 percent to 29 percent (P < 0.001). On the contrary, the percentages of motorists yielding between 10 to 20 feet and greater than 20 feet were increased by 28 percent (P = 0.031) and 29 percent (P = 0.002), respectively during the after study. The proportion of the vehicles stopped closer to the intersection decreased and stopped far from the intersection increased during the after study. The percentage of vehicles stopped less than 10 feet was decreased by 16 percent (P < 0.001). On the other hand, the percentages of vehicles stopped in between 10 to 20 feet and greater than 20 feet were increased by 16 percent (P < 0.001) and approximately 1 percent (P < 0.158), respectively during the after study period.

Evasive actions, either by a pedestrian or a motorist, were increased by approximately 3 percent (P = 0.040) during the after study period. Vehicle speed was reduced in the eastbound direction by approximately 1 mph (P = 0.281) during the after study period. In the westbound direction, vehicle speed was increased marginally (P = 0.579).

6.7 High Visibility Crosswalk, Warning Sign for Motorists, Regulatory Sign for Motorists, and Advance Yield Markings

A high visibility crosswalk, advance yield markings, regulatory sign for motorists, and warning signs for motorists were installed at Charleston Boulevard between 17th Street and Spencer Street. The comparison of MOEs during before and after study periods and their statistical significances are presented in Table 39. The percentage of pedestrians who trapped in the middle of the road was decreased by 7 percent during the
after study period \( (P = 0.726) \). Evasive actions, either by a motorist or a pedestrian, during the after study period also dropped by 7 percent \( (P = 0.758) \). Both of these MOEs show positive safety benefits even though these MOEs are not statistically significant at the 95 percent confidence level.

Table 39 Comparison of the MOEs during Before and After Study at Charleston Boulevard between 17th Street and Spencer Street Due to the Installation of High Visibility Crosswalk, Advance Yield Markings, Regulatory Sign for Motorists, and Warning Signs for Motorists

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Measures of Effectiveness</th>
<th>Unit</th>
<th>Before condition</th>
<th>After condition</th>
<th>Difference (before - after)</th>
<th>P-value</th>
<th>Null hypothesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pedestrians who were trapped in the middle of the road</td>
<td>%</td>
<td>37.5</td>
<td>24</td>
<td>30.2</td>
<td>43</td>
<td>7.3</td>
</tr>
<tr>
<td>2</td>
<td>Evasive actions</td>
<td>%</td>
<td>20.8</td>
<td>24</td>
<td>14.0</td>
<td>43</td>
<td>6.9</td>
</tr>
<tr>
<td>3</td>
<td>Motorists who yielded to pedestrians</td>
<td>%</td>
<td>6.0</td>
<td>50</td>
<td>22.0</td>
<td>91</td>
<td>-16.0</td>
</tr>
<tr>
<td>4</td>
<td>Average pedestrian delay</td>
<td>sec/pcd</td>
<td>15.4</td>
<td>24</td>
<td>7.7</td>
<td>43</td>
<td>7.7</td>
</tr>
<tr>
<td>5</td>
<td>Average vehicle speed (eastbound)</td>
<td>mph</td>
<td>32.2</td>
<td>266</td>
<td>27.2</td>
<td>100</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>Average vehicle speed (westbound)</td>
<td>mph</td>
<td>24.9</td>
<td>250</td>
<td>23.4</td>
<td>100</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Note: \( \alpha = 0.05 \)

The percentages of motorists who yielded to pedestrians were 6 percent and 22 percent during before and after study respectively. Motorists yielding increased by 16 percent \( (P = 0.002) \) during the after study period. The average pedestrian delay decreased from 15 seconds / pedestrian to 8 seconds / pedestrian \( (P = 0.259) \) during the after study. The average vehicle speeds in both eastbound and westbound direction were reduced during the after study period as compared to the before study period. The average vehicle speeds were reduced by 5 mph \( (P < 0.001) \) and 1.5 mph \( (P = 0.005) \), in the eastbound and westbound directions, respectively.
CHAPTER 7

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A summary of the research, conclusions, and recommendations is documented in this chapter.

7.1 Summary

An evaluation of several countermeasures intended to enhance pedestrian safety has been the focus of this dissertation. The measures of effectiveness used to evaluate countermeasures indicate improvements in both motorists’ and pedestrians’ behaviors. In most cases, these changed behaviors were beneficial and statistically significant. The after-study observations showed the following: fewer evasive actions, slower vehicle speeds, increased yielding and stopping distances, more motorists yielding, fewer signal violations, and fewer pedestrians trapped in the middle of the road. Therefore, these countermeasures seem to be effective in enhancing pedestrian safety. On the other hand, slower vehicle speeds were also observed. This poses questions regarding reduced mobility for the motorists. A detailed cost-benefit analysis of the trade-off of pedestrian safety and mobility is a topic for further research. Even though these deployed strategies and their influence on pedestrians’ and drivers’ behavior were effective in prevailing weather conditions and for the geographic location of the Las Vegas metropolitan area,
these findings are of value to other regions with similar traffic and pedestrian characteristics.

7.2 Conclusions

A summary of conclusions for each of the deployed countermeasure is discussed next.

7.2.1 In-pavement Flashing Light System, Warning Sign for Motorists, Regulatory Sign for Motorists, and Advance Yield Markings

The in-pavement lighting system appears to be an effective strategy to increase motorists’ yielding behavior in case of low traffic and pedestrian volumes. The speed of vehicles was also reduced after installation of the in-pavement lighting system while pedestrians were waiting to cross and while pedestrians were crossing. The yielding distance was consistent from the yielding markings for both approaches, i.e., on an average 10 feet upstream from the yield markings. The advance yield markings provide a guide for motorists to yield to pedestrians upstream of the crosswalk when pedestrians are present in the crosswalk. Marginal differences in conflicts were observed, although this was not statistically significant. Thus, the in-pavement lighting system evaluated was seen to be beneficial in improving pedestrian safety at a low traffic volume location.

7.2.2 Pedestrian Countdown Signal Based on Pedestrian Actions

The installation of the pedestrian countdown signal helps to improve pedestrians’ crossing behaviors. These behaviors might help to improve pedestrian safety by crossing safely in the crosswalk. The findings indicate the following: decrease in evasive actions,
fewer pedestrians crossing during the DON’T WALK, fewer pedestrians present in the crosswalk during the all-red phase, and fewer pedestrians present in the crosswalk during the flashing DON’T WALK. These improvements in pedestrians’ crossing behaviors are a reflection of safety improvement due to the installation of the pedestrian countdown signal. Therefore, the pedestrian countdown signal is effective in improving pedestrians’ crossing behavior from a safety perspective.

7.2.3 Pedestrian Countdown Signal Based on Vehicle Speed

The observed mean vehicles speeds were higher when the pedestrian countdown timer was displayed on the pedestrian signal head than that of the mean vehicles speeds with the pedestrian WALK signal. The observed speeds were higher when motorists were within 100 feet upstream of the intersection than when they were 100 to 200 feet upstream of the intersection. This may be because motorists tend to speed as they get closer to the intersection so as to clear the intersection, rather than have to wait through another signal cycle for that approach.

7.2.4 Turning Traffic Must Yield to Pedestrians

The installation of the sign “Turning traffic must yield to pedestrians” led to an increase in motorists’ yielding behavior while turning either on red or on green. Evasive actions increased at one site and decreased at the other site due to this installation.

Even though the sign, “Turning traffic must yield to pedestrians,” was intended for motorists, some improvements in pedestrians’ crossing behaviors were also observed. These behaviors include: decreases in the percentages of pedestrians in the crosswalk during the flashing DON’T WALK and at the all-red time, a decrease in the percentage of
pedestrians trapped in the middle of the road while crossing, and an increase in the percentage of the pedestrians looking for turning vehicles.

7.2.5 Portable Speed Trailer

A speed trailer seems to reduce speed immediately upstream of the deployed location. Motorists sped up downstream of the speed trailer as compared to the upstream speed. However, the speeds downstream of the speed trailer were statistically lower than the speeds at the same location prior to the installation of the speed trailer.

7.2.6 In-roadway Knockdown Signs

The higher proportion of motorists yielding and stopping further away from the crosswalk during the red phase are positive safety benefits of the installation of the “In-roadway knockdown sign.” Lower average vehicle speeds show positive safety impacts for pedestrians.

7.2.7 High Visibility Crosswalk, Warning Sign for Motorists, Regulatory Sign for Motorists, and Advance Yield Markings

Motorists’ yielding increased after the installation of devices so that fewer pedestrians were trapped in the middle of the road. Consequently, pedestrians also may have had to wait less time before crossing. A few evasive actions were taken either by a motorist or a pedestrian during the after study period. Average vehicle speeds were also reduced on the approaches. All of these improvements are positive safety impacts of the installation of a high visibility crosswalk, advance yield markings, and warning signs for motorists. Therefore, these devices are beneficial to improve pedestrian safety.
7.3  Recommendations

Further research to evaluate the effectiveness of each of countermeasure at different traffic scenarios will be discussed in this section. The summary of recommendations for each of the deployed countermeasure will be discussed next.

7.3.1  In-pavement Flashing Light System, Warning Sign for Motorists, Regulatory Sign for Motorists, and Advance Yield Markings

The installation of an in-pavement lighting system at locations with low traffic volume yields was seen to offer safety benefits for both pedestrians and motorists by reducing speed and increasing yielding behavior. The motorists’ yielding behavior also depends on pedestrian and traffic volumes. Locations with comparatively high pedestrian and traffic volumes might experience more vehicular delays after implementation of the in-pavement lighting system. The impacts of the lower vehicular speeds after the installation of the in-pavement lighting system on signal progression merit further analysis. Further research is recommended to quantify pedestrians and vehicular delay for different traffic and pedestrian volume combinations.

7.3.2  Pedestrian Countdown Signal Based on Pedestrian Actions

The pedestrian countdown signal is effective to improve pedestrians’ crossing behavior on arterial streets. Further research is recommended to evaluate pedestrians’ crossing behavior due to these installations on local streets. The speed of pedestrians before and after the installation of the pedestrian countdown signal during the flashing DON’T WALK is another subject for further research. Even though a higher percentage of pedestrians was observed in the crosswalk during the flashing DON’T WALK during
the before study, a lower percentage of pedestrians was present in the second half of the crossing. Pedestrians might have sped up to avoid the DON’T WALK signal. Further research is sought to identify whether pedestrians change their speed due to the installation of the pedestrian countdown signals during the flashing DON’T WALK while crossing the road.

7.3.3 Pedestrian Countdown Signal Based on Vehicle Speed

Further research on speeding behavior of motorists before and after installation of the pedestrian countdown signal is recommended. Speed observations with the conventional pedestrian signal head can be compared with the speed observations with the pedestrian countdown signal head. Therefore, a before-and-after study might be beneficial to evaluate motorists’ behavior to evaluate the pedestrian countdown signal.

7.3.4 Turning Traffic Must Yield to Pedestrians

The sign “Turning traffic must yield to pedestrians” is intended for both right and left turning traffic. However, on the wider arterial streets of the Las Vegas metropolitan area, traffic in the far left lanes might not be able to see the sign placed on the curb. Therefore, this sign should be visible for all turning traffic.

7.3.5 Portable Speed Trailer

The “Portable speed trailer” is an effective strategy to reduce speed upstream of the installed location. Therefore, the same speed trailer can be placed frequently at different locations along the high-risk corridor to reduce speed and to improve safety.
7.3.6 In-roadway Knockdown Signs

The study in this corridor mainly focused at intersections. This sign might have an effect on the corridor as a whole. Therefore, further evaluation of this sign is recommended at other locations within the Las Vegas metropolitan area such as nearby shopping complexes and residential area.

7.3.7 High Visibility Crosswalk, Warning Sign for Motorists, Regulatory Sign for Motorists, and Advance Yield Markings

The installed location of these devices had a low pedestrian volume. Most of the pedestrians were public transit users. Another crosswalk was also located approximately 200 feet west of the installed high visibility crosswalk. Motorists might have different behaviors if there is a high pedestrian volume. Therefore, such evaluation is recommended in a location with high pedestrian volume.
REFERENCES


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