Developing and testing a LED system to improve pedestrian safety in Nevada

Research Report
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Executive Summary

The proposed LED pedestrian crossing system is an enhanced pedestrian crossing system that can automate the flashing of LED street light after the detecting the presence of pedestrian crossing streets. Comparing the existing pedestrian crossing, the proposed system has the warning by flashing the LED light. In addition, it can detect the pedestrian crossing and automatically trigger the LED. This feature can reduce the risk by pedestrian crossing without pressing the button.

Such a system was first developed in the lab at UNLV. Special LED light was designed that can cover a wide area where pedestrians cross streets. Pedestrian sensors are designed that can detect pedestrians in a wide range around the pedestrian crossing sign. A controller was developed that is attached to the LED sign overhead and was connected to the pedestrian sensors on the pedestrian crossing sign pole. To ensure that pedestrian used to press button, a pressing button was developed as well connecting to the controller.

The developed LED lighting system was installed at an intersection in the City of North Las Vegas. The installed system was not tested because of the vandalism concern. Even the test was not conducted, data on pedestrian behavior in the current crossing system were collected. A methodology on cost and benefit analysis was developed. It was concluded that the system worked in the field. The system could be more user-friendly if advanced technologies are developed for pedestrian detection. The successful system would improve pedestrian safety in Nevada.

Chapter 1 Introduction

Background

Pedestrian safety is the most important safety problem in Nevada, particularly in the Las Vegas metropolitan area. The most recent statistics indicates that between 2011 and 2015, a total of 316 fatal and 708 injury pedestrians' crashes have occurred in Nevada roadway network (*Strategic Highway Safety Plan*, 2016). The number of pedestrian's fatal crashes has been increasing yearly while there has been fluctuation in the number of the seriously injured pedestrians. The (*Strategic Highway Safety Plan*, 2016) report shows that, there were slight increase in the number of fatal crashes between 2014 and 2015 while the large magnitude of increase in number of fatal crashes (16) was observed between 2011 and 2012 (Figure 1).

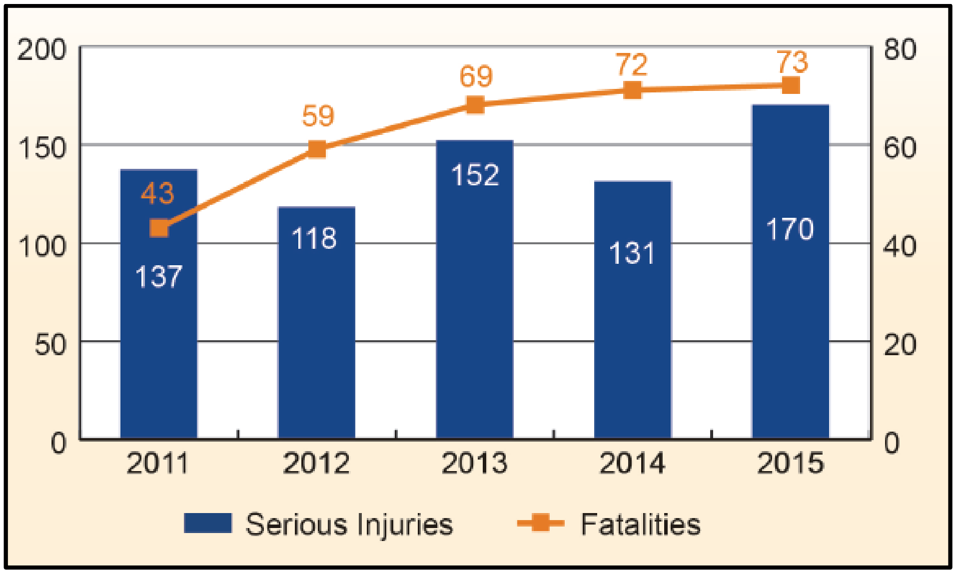

Figure 1 Pedestrians fatality and Injury trend in Nevada

Source (*Strategic Highway Safety Plan*, 2016)

Generally, male pedestrians were reported to more likely be involved in fatal crash than any other demographic. Location-wise, most of the crashes (50%) occurred in roadway while substantial number of crashes (29%) and (5%) occurred at the intersections with and without marked crosswalk respectively. Considering the pedestrian actions attributed to crash occurrences, the improper roadway crossing accounted for almost half (46%) of the crashes followed by darting (16%). Other factors included poor visibility (9%), failure to yield (10%) and failure to obey traffic signs (6%). Only 38% of the crashes occurred during daylight while 50% of crashes occurred during dark but lighted condition. The dark, dawn and dusk accounted for 11% of all crashes (*Strategic Highway Safety Plan*, 2016).

With the higher number of non-daylight crashes as well as some controllable pedestrians' and motorists' actions such as visibility, failure to yield right of way and improper crossing locations, NDOT formed several strategies to reduce pedestrian fatalities. One of the strategy being improving drivers ability to see pedestrians (*Strategic Highway Safety Plan*, 2016). Through this strategy, NDOT aims at providing the lighting at pedestrian crossing locations and applying NDOT process for evaluation of the existing and proposed uncontrolled crosswalk locations. The LED system in this project being part of the strategy.

The MUTCD (*Manual on Uniform Traffic Control Devices*, 2009) and the FHWA Lighting Handbook (Lutkevich, McLean, & Cheung, 2012) provide warrants for provision of the new crosswalk locations and/or lighting for pedestrian crossing. The traffic volume, presence of crosswalk, night time to day time crash ratio and the extent of raised median are the most important factors to be considered for provision of full lighting, partial lighting or delineation lighting at the intersection (Lutkevich et al., 2012). The installation of the new marked need to be accompanied with other speed reduction and motorists warning devices if the roadway has posted speed limit exceed 40mph. Other addition requirement are; either a four lanes without pedestrian refuge and 12,000 vehicle per day ADT or more, or a four lanes with pedestrian refuge and 15,000 vehicle per day ADT or more (*Manual on Uniform Traffic Control Devices*, 2009). The flashing lights in terms of pedestrian hybrid beacons can only be installed if there is a crosswalk. However, meeting the stated warrants doesn't necessitate the responsible agency to provide the crosswalk and or lighting. The consideration of where and when to install a pedestrian safety countermeasure as well as the decision on the type of the countermeasure to be installed has been varying substantially between jurisdictions. The variations are based on the engineering judgement and political and/or public pressure (Dougald, 2004). Engineering judgement which focus on the geometry, weather condition, crash rates, benefit cost analysis among other is the key ingredient to the countermeasure provision decision (Lutkevich et al., 2012).

The objective of this study is to develop and test a lighting system at pedestrian crossings that can provide rapid flashing light based on factors such as pedestrian location at a minimal cost. There have been various pedestrain safety products and countermeasures implemented in Nevada.

The notable ones include the Median Refuge Islands, Overhead Flashing Beacons (Standard and RRFB), Pedestrian Hybrid Beacon- High intensity Activated Crosswalk (HAWK), HAWK, flash+detection, Flashing LED Sign Systems and Lighting for Pedestrain Crossing. The product: Lighting for Pedestrain Crossing, is an example of enhanced street lighting. Our proposed system is indeed better than this system since we add sensors that detect pedestrians, with which the lighting can be triggered automatically. Flashing light and lighting trigger button can be added as special features.

In this study, literature on pedestrian crossing was reviewed. The proposed LED pedestrian crossing lighting system was developed in the lab first, and then installed at a location in the City of North Las Vegas. Data on the pedestrian behavior before the installation of the system were collected. It was intended to compare the pedestrian behavior before and after the installation of the system. The methodology for evaluating the benefit and cost of the system were developed. Conclusions were drawn on the performance of the system and the recommendations were developed on the application of the system.

The first chaper below present the literauture review. The second chapter describes the development of the systems in the lab. In the third chapter, the field test of the system is presented, which is followed by the description of the data collection before the field test. The fifth chapter present the methodology of the cost and benfit evaluation of the system. The last chapter presents the conclusions of the study and the recommendations.

Chapter 2 Literature Review

The inadequate visibility has been pronounced to increase the risk of driving or walking on, or across the road. Low lighting level can be directly associated to the risk due to its effect on the time spent by drivers to respond with braking or other corrective actions. A study by (Chu, 2006) found that, the probability of pedestrian involvement in fatal injury was 24% and 5% lower under dark conditions with street without street lighting respectively. The impact of the lighting condition on pedestrian safety differs with the crossing locations as concluded by (Chu, 2006) that under daylight conditions, the probability of pedestrian involvement in fatal injury at the intersection is 49% lower than at the midblock locations, parallel to that, a pedestrian is 6 times more at risk of dying when stuck by a vehicle in midblock during darkness than under the presence of daylight. In general, studies have shown a reduction in nighttime crashes of up to 65%, 30% and 15% for fatal, injury crashes up to and property damage respectively with the use of roadway lighting (Elvik, 1995). In particular, the street light decreases the likelihoods of pedestrian fatal crash by 42% and 54% at midblock and intersections locations respectively (Chu, 2006).

In a process of warning the oncoming traffic of the presence of the pedestrian within or nearby the crossing location, numerous methods have been applied. Most of the applied methods involve one or several forms of motorists' visual attention catching facilities. The roadway illumination has been playing a great role in motorists' attention catching with the application of either overhead road lights, in-roadway lights, or rapid flashing beacons.

Overhead road lighting

Making pedestrians located within or near the crosswalk visible to drivers at a range that exceeds the distance at which vehicle headlights extent is equally important as warning the oncoming motorists of the presence of the pedestrians within or near the crosswalk (Bullough & Skinner, 2015). The combination of overhead road lighting installed at the crosswalks (Figure 4) and car headlights generally provides greater visibility extent than headlamps alone (Gibbons et al., 2008; Saraiji & Oommen, 2015). However, the level of effectiveness of overhead lighting in increasing visibility extent is affected by several factors including weather condition, pavement surface condition, glare, crosswalk paint type, color of the light source, intensity of the emitted light, location as well as alignment of the luminaire among the other (Gibbons, 2006; Gibbons et al., 2008).

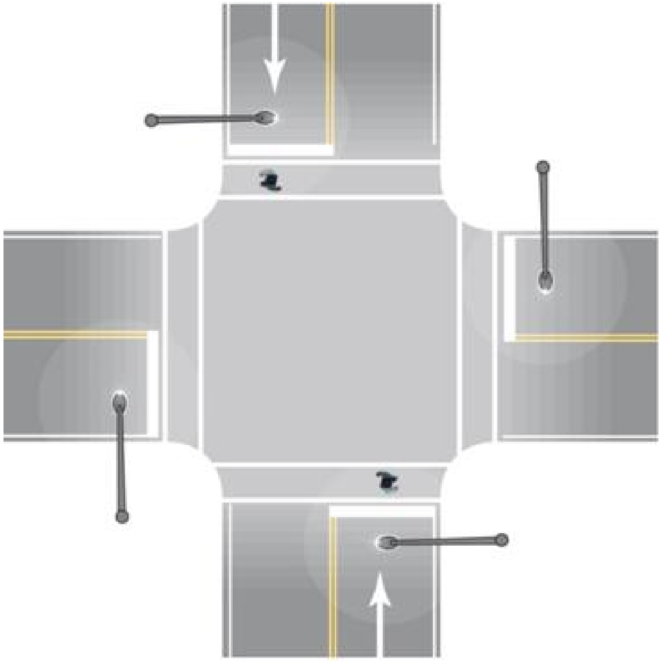

Figure 2 Overhead crosswalk lighting layout

Source (Gibbons, Edwards, Williams, & Andersen, 2008)

The study by (Gibbons et al., 2008) revealed for pedestrian to be visible at a sufficient distance, at least 3 m (10 ft.) from the crosswalk should be considered for the luminaire placement. This locational distance would enable the provision of 20 vertical lux at the crosswalk which would be sufficient depending on the target contrast. The target contrast is considered as the crucial aspect for target visibility (Saraiji & Oommen, 2015). Additionally, the background light density and pattern, and the size of the target play important roles on the object visibility and detection distance (Brémond, Bodard, Dumont, & Nouailles-Mayeur, 2013; Davoudian, 2016).

With the advancement in science and technology, the High Pressure Sodium (HPS), induction lamp and ceramic Metal Halide (MH) lighting were replaced by the Light Emitting Diode (LED) for the roadway lighting. Light emitting diode (LED) is not a longstanding technology; it became popular in the lighting world in late 2000’s.

BEFORE (HPS)

AFTER (LED)

Figure 3 Before and after photos of the Street LED lighting

Source (Henderson, 2009)

Several studies have been published on comparison of the LED and other light source for roadway lighting systems. Basically, roadway luminaire photometric performance (lighting level and uniformity) and energy efficiency were the decisive criteria to whether the LED was the appropriate technology for most of the studies. In terms of the energy saving, the LEDs has outperformed the other laminae types, however, the energy savings rates varies widely (Henderson, 2009; Juntunen et al., 2015; Kostic, Kremic, Djokic, & Kostic, 2013). On average, the energy savings when LED replaces high-pressure sodium (HPS) and Metal Halide (MH) luminaires range from 19–26% (Kostic et al., 2013), 42% (Henderson, 2009) to 40–60% (Juntunen et al., 2015) when the smart control was applied. In addition to the energy savings, the LEDs were found to have higher lighting uniformity (Figure 5) but less overall light levels (Juntunen et al., 2015). Regardless of the benefits described above, studies suggested further research to be done considering the financial aspect of the LED lighting solution since the cost for LED solution was found to be higher than the comparable HPS lighting solutions (Kostic et al., 2013).

In-roadway lights and rapid flashing beacons

In-roadway lights constitutes of a successions of amber lights entrenched in the roadway (*Manual on Uniform Traffic Control Devices*, 2009) which when activated warn oncoming drivers that they might be required to slow down and/or come to a stop. They can be activated by either traditional push button or an automatic pedestrian detection system that prompts the lights (Miller, Rousseau, & Do, 2004). The before-and-after study by (Polus & Katz, 1978) was among the early works focused on the impact of the in-roadway lighting performance for crash reduction. A substantial reduction in pedestrian crashes was reported for nighttime hours as compared to the daytime. The impact of in-roadway lighting on the approach speed reduction was the focus for numerous researchers (Huang Herman, Hughes Ronald, & Zegeer Charles, 1999), (Derlofske, Boyce, & Gilson, n.d.) and (Prevedouros, 2001). On average, 1.9 mph and 0.8 mph speed reduction with and without pedestrians respectively was observed after the installation of the flashing crosswalk (Huang Herman et al., 1999). (Derlofske et al., n.d.) reported higher magnitude (6.6 mph) of speed reduction in the presence of pedestrians in the crosswalk. On the other hand, without specifying the speeds in numerical values (Prevedouros, 2001) reported a 25.2% average decrease in speed for northbound and 27.2% for southbound direction. Among the major concern for this type of roadway lighting is visibility problems especially during daylight hours and a possibility that some pedestrians may feel too secured ,thus, cross without scanning the oncoming traffic (Prevedouros, 2001). In addition, the fact that in-roadway lights are embedded in pavement, they become not suitable for the locations with relatively high average daily traffic.

The Rapid Flashing Beacons (RFB) is among the most recent countermeasures to improve pedestrian safety at various crossing locations. Two types of flashing beacons exist; the Circular Rapid Flashing Beacons (CRFB) and Rectangular Rapid Flashing Beacons (RRFB) (see Figure 6). Regarding the effectiveness per shape of the flashing beacons (circular vs rectangular), a slightly but non-statistically significant difference in motorists yielding was found by the study involving twelve sites in the United States (Fitzpatrick, Potts, Brewer, & Avelar, 2015). A difference of 8% with Circular Rapid Flashing Beacons (CRFB) being highly rated (67%) was observed in daytime whereas during nighttime the Rectangular Rapid Flashing Beacons (RRFB) with 72% yielding rate outpaced the CRFB by 3%. However, the statistical evaluation revealed no statistical significant difference in effects on drivers' responses by shaped of the beacons (Fitzpatrick, Potts, et al., 2015).

Figure 4 Circular and Rectangular Rapid Flashing Beacons

Source ("Pedestrian Traffic Control Devices," n.d.)

The Rectangular Rapid Flashing Beacons (RRFB) is the commonly used one. It displays the alternating rapid flashes through the double rectangular LED lights (Figure 6). They can be positioned either above or below the pedestrian crossing sign, however, studies suggests that, locating the RRFB above the pedestrian crossing sign improves its general usefulness (Fitzpatrick et al., 2016)

Most of the studies evaluated the effectiveness of either RRFB or CRFB treatments applied the before-and-after field studies. After the installation, the overall motorists yielding behavior increased, whereas bicyclists and pedestrians yielded considerably less compared to motorists (Hunter, Srinivasan, & Martell, 2009; Shurbutt & Van Houten, 2010). A study by (Brewer, Fitzpatrick, & Avelar, 2015) for previously untreated twelve crosswalks in Texas revealed that the RRFB treatments resulted into 35% to 80% increase in motorists yielding tendency. At another location in Florida, the overall before and after motorist yielding rates were 2% and 35% respectively (Hunter et al., 2009). Meanwhile, in Canada, the reported motorists' compliance varied between 5% and 26% with an average of 15% yielding rate for the six crosswalk treated with RRFB (Domarad, Grisak, & Bolger, 2013). However, the activated beacon was found to be associated with the driver yielding tendency as much as three times (Fitzpatrick, Avelar, et al., 2015) and almost two times (Hunter et al., 2009) compared to when the it is not activated, beacon light intensity was the other factor for the increased yielding tendency while the average daily traffic had no correlation. While almost all pedestrians (94%) pushed the button to trigger the flashing lights (Brewer et al., 2015), more education was recommended to enable an increase of the number of pedestrian pressing the activation button (Hunter et al., 2009). In general, the flashing beacon treatments have not only increased the number of pedestrian using the crosswalk but also elevated the pedestrian searching behavior before crossings, by which more than 90% scanned at least one direction of traffic (Brewer et al., 2015). Therefore, it was concluded that the RRFB improved the safety of both pedestrian and bicyclists (Hunter et al., 2009).

Automatic pedestrian detection

Automatic pedestrian detections have been applied in numerous countermeasures designed to reduce pedestrian-motor vehicle crashes. They can be applied as standalone or as a supplement to the push button to activate the warning signs to motorists as well as facilitate in provision of the right of way for pedestrians to use a crosswalk (Hughes, Huang, Zegeer, & Cynecki, 2000). The technology used in the automatic pedestrian detection include the infrared, microwave, and video image processing, it is commonly used in grocery stores, shops, banks, and entrances to public buildings (Hughes et al., 2000; Nambisan et al., 2009). The advancement in technology has enabled the integration between the detection devices and the smart light, by which, when a pedestrian is detected, the signal triggers the increase of the lighting level to enable a clear visible of the pedestrian by the motorists (Nambisan et al., 2009). Generally, the automatic pedestrian detection has resulted into significant pedestrian safety improvements by reducing the vehicle to pedestrian conflict and increasing the pedestrian phase for slow walking pedestrians.

System benefit-cost analysis

The benefit cost analysis has been used as one of the means to justify the feasibility of the projects in question. The value of benefit cost ration greater than one is desirable to conclude that the project is feasible, however, other factors should be taken into consideration. For the pedestrian crossing location improvement, the typical costs include the purchase and installation cost of the entire system while the benefits include the reduction in all types of crashes.

Since most of cost benefit analysis are performed during design/implementation stages, various researchers have been applying various assumptions on the effect of the countermeasures on crash reduction. The early study by (Janoff & McCunney, 1979) provided the methodology for the benefit cost analysis of the roadway lighting. The benefit was computed as the difference between the crash costs at different levels of the illuminations. The crash costs were computed as the product of the average crash cost acquired from the National Highway Traffic Safety Administration and the crash rate which was the function of the area type, population density and fifteenth percentile visibility. This study did not consider different types of crash severities. (Polus & Katz, 1978) assumed that 36% crashes per year were reduced due to the presence of sign-lights, thus, the annual benefit was computed as the product of the pedestrian crash cost and the percentage of crashes saved per year per site. In the benefit cost analysis of the flashing light emitting diode (LED) stop sign and optical speed bars by (Arnold & Lantz, 2007) used the crash data from three similar sites to determine the benefits of the system. With different levels of crash severities, their study concluded that even with a single saving of any type of crash, the benefits were more than costs incurred.

Chapter 3 Developing the adaptive pedestrian lighting system

The LED system includes a sensor to detect the presence pedestrains, a controller to trigger the LED light, and the communications between the LED light and the sensor. Two type of sensors to detect pedestrians were employed, one is infrared and the other is the microwave. The infrared is for detecting pedestrian next to the light pole, while the microwave is to detect the pedestrian far from the light pole (10 feets). (see Figures 2).

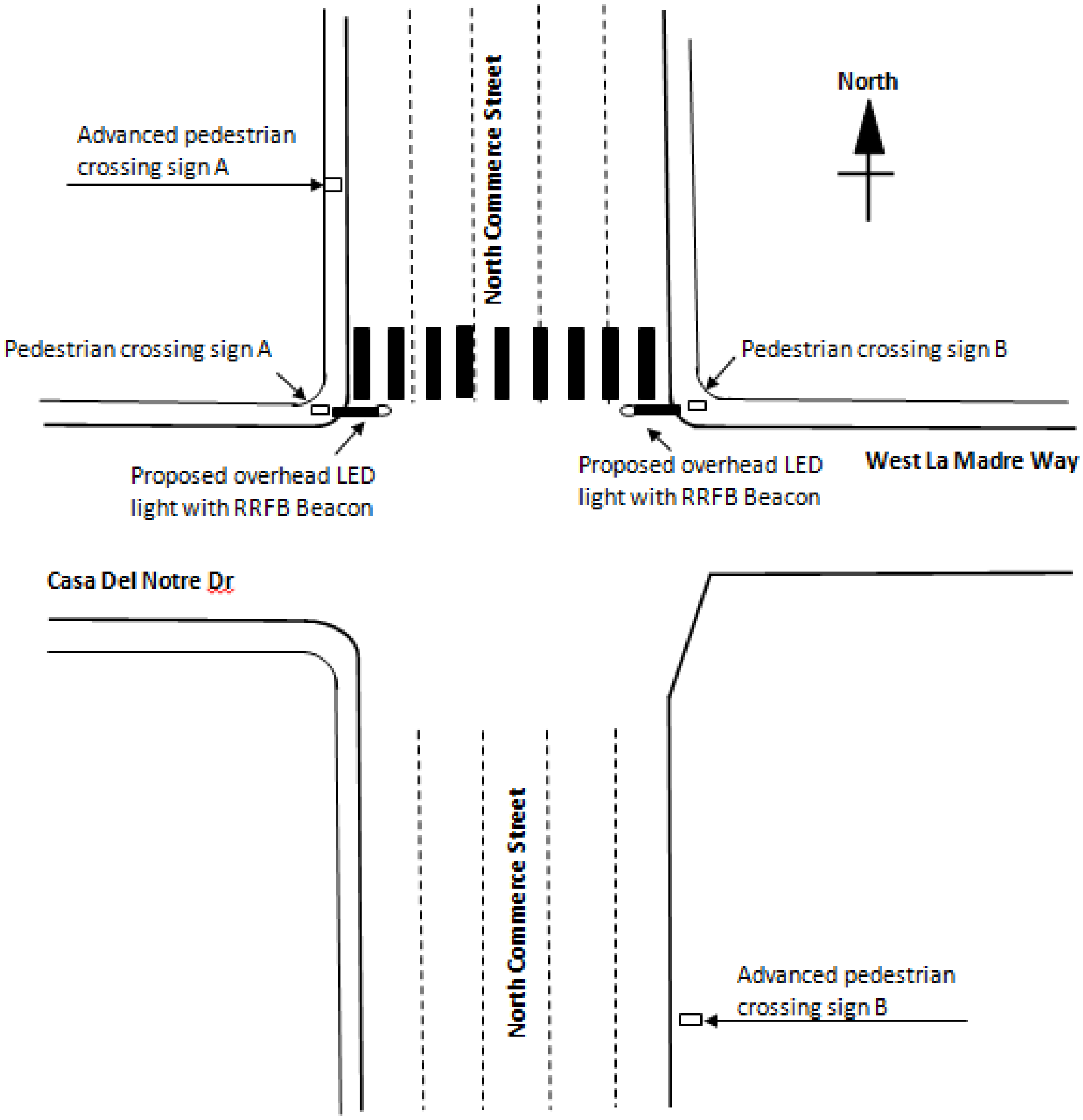

Figure 5 Setting of system components on a street light pole and coverage area

This system can save energy because additional lighting will be provided depending upon environement. During the day time, the LED will not be actvitied. In addition, this system will overcome human behavioral factors, such as when pedestrains choose not to press the button to activate the warning light. Indeed, pedestrians sometimes misperceive that vehicles will recognize them crossing a street without the warning lights. The proposed system in this study would be activated automatically when pedestrians are sensed, which is a volunteering system, having no pedestrain involved in triggering the LED for providing additional lighting. The enhanced lighting will alert vehicles in both directions to yield and stop. In addiiton, this system has the flexiblity to configurate to different system requirements. For example, the LED can be programmed to be flashing, which would enhance alerting to drivers at night. A button can be added to the system so that pedestrains who are used to using buttons can use the system in their ways.

Figure 6 LED light and light pole

Chapter 4 Testing the lighting system in the field

LED system and test site description

Several field test locations were evaluated for testing the LED system in this study. One site is at the Bruce Street on Charlston Ave. which was used in the previous study. The another site was at the Red Wood Dr on Sahara Avenue, the west side of Las Vegas, which was suggested by the NDOT. Both sites were note chosen for this study. The City of North Las Vegas suggested a location at the West La Madre Way on the Commerce Street.

The test site is the intesection of North commerce street which is a five lane arterial and Casa Del Notre Dr on west side which is three lane street and West la Madre Way on the East side which is two lane street. Generally, the intersection is located in a residential setup with resiedntial buildings and apartments (Figure 3), however, there are number of schools in the vicinity.

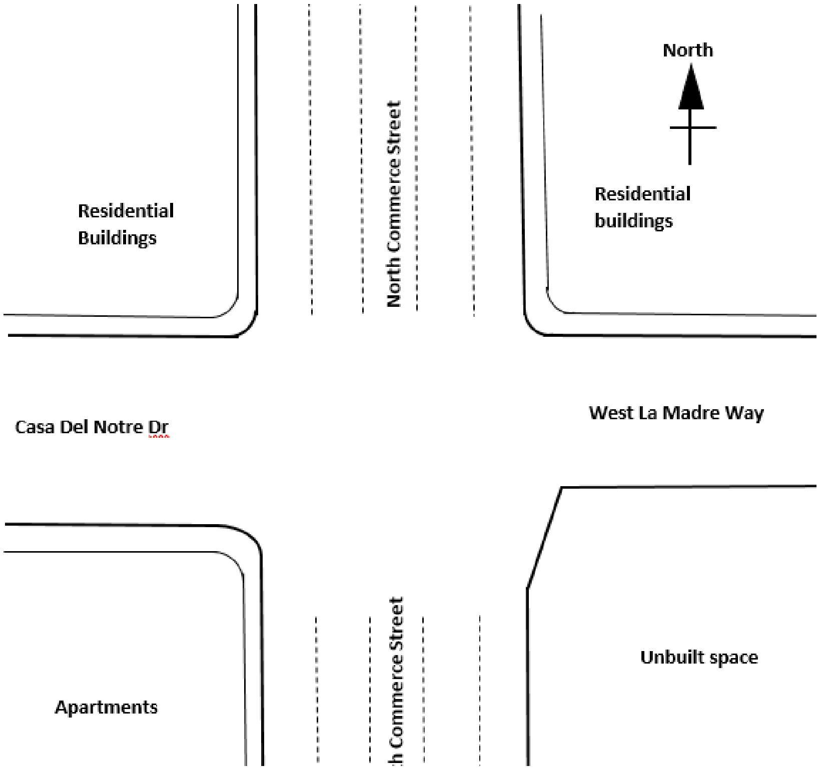

Figure 7 Test site location

There are no marked crosswalks on the intersection which is used by most of the pedestrian especially children when going to and coming from schools. In some cases, the parents or elder pedestrain assist the young ones to cross the North Commerce street. Only one corner (North-west corner) of the intersection is lighted by the street lighting while the nearest street lighting posts for other corners are about 40ft, 50ft and 100ft for South-west, North-east and South-east respectively. The nearest marked crosswalk are located about 1400 ft and 1000ft north and south of Casa Del Notre Dr/West La Madre Way. The intersection's crash history revealed that, one fatal crash involving a school kid occurred in November 2015. The crash occurred early morning when the kid was going to school. This site was extensively studied for which installation plan was developed. Pedestrian crossing data were also collected for four data in December 2016. The installation plan and the pedestrian crash data are listed in the Appendix.

This site was given up because a different safety improvement treatment was decided to be installed at this location. Thus, a new location close to the North Las Vegas City Hall was provided for the field test in this study. After a study, it was found that there was no pedestrain at that location, and thus the location at the West La Madre Way on the Commerce Street was given back for the field test.

On October 14, 2017, the system was installed at the intersection which can be seen from the pictures shown in Figure 8. The picture 8(d) shows that the LED light was operational. However it was found that the LEDs on the two sides of the street could not coordinate (see Figure 9).

(a) Working on the communication box

(b) Working on the LED light

(c) Working on the Infrared sensor (d) LED light is operational

Figure 8 Field Installation in October 2017

In three months a microwave sensor was developed for the communications between the LED lights at the two sides of the street. Before the start of the system operation, it was found that the infrared sensor (see Figure 10) on the light pole was vulnerable for vandalism. Then the system was not approved for operation, and then it was dismounted. The planned testing cannot be conducted for this event.

Figure 9 Communication problems between the LED lights on the two sides of road

Figure 10 Infrared sensor for pedestrian detection

Chapter 5 Data analysis

The performance of the system can be evaluated based on the observation data collected in the field. Before the field test, three days of data were collected. These data include number of bicycle, number of pedestrians, total pedestrian and bicycles, whether they cross street, whether they looked left, whether they looked right, their gender, whether pedestrian is trapped in the middle of road, whether pedestrian is delayed for crossing street, whether motorists yield to pedestrian, age of pedestrian, direction the pedestrian is walking, and the time when the pedestrian appears at the intersection. These data are listed in the table below.

The data at the intersection after the installation of the LED system were not available because the field test was not conducted. Thus a before- and after- study cannot be cinducted.

Table 1 Pedestrian data collection on December 13, 2016

S/N	Number of cyclist	Number of peds	Total peds & cyclists	Crossing location (N/S)	Looked left	Looked right	Gender	Ped trapped	Ped delay	Motorist yielded (Y/N)	Yielding distance	Age(adult, teen, kid)	Direction (EB/WB)	Time
1		1	1	Though			M					Adult	NB	
2		1	1	N	Yes	Yes	M	No	No	No		Adult	WB	11:30 - 12:30
3	2		2	N	Yes	Yes	M, M	No	No	No		Adult	WB	
4		1	1	Though			F					Teen	NB	
5	1		1	N	Yes	Yes	M	Yes	Yes	No		Adult	WB	13:30 - 15:30
6		1	1	Though			M					Adult	NB	
7		3	3	Though			F,F,F					Adult, Teen, Kid	NB	
8	1		1	Though			M					Teen	SB	
9	1		1	Though			M					Teen	SB	
10		1	1	Though			F					Teen	SB	
11		1	1	Though			F					Adult	SB	
12		1	1	Though			M					Teen	SB	
13		1	1	Though			M					Teen	NB	
14		2	2	S	Yes	Yes	M, F	No	Yes	No		Teens	EB	
15		1	1	Though			F					Adult	SB	
16	1		1	Though			M					Teen	SB	
17	2		2	Though			M,M					Adult	NB	
18		1	1	S	Yes	Yes	M	No	Yes	No		Adult	EB	
19	2		2	Though			M,M					Teen	SB	
20		1	1	Though			F,F					Teen	SB	
21		1	1	Though			M					Teen	SB	
22		2	2	Though			F,F					Teen	SB	
23		1	1	Though			M					Teen	SB	
24		1	1	Though			F					Teen	SB	
25		1	1	Though			F					Teen	SB	
26		1	1	Though			M					Adult	SB	
27		4	4	Though			4F					Adult, 2Teen, Kid	SB	
28		1	1	Though			F					Teen	SB	
29		1	1	Though			F					Adult	SB	
30		1	1	Though			F					Teen	SB	
31		1	1	Though			F					Teen	SB	
32		1	1	Though			M					Teen	SB	
33		1	1	N	Yes	Yes	F	No	No	No		Teen	EB	
34		1	1	Though			M, F					Teen	SB	
35		1	1	Though			M					Adult	NB	
36		1	1	Though			M					Teen	SB	
37	1		1	Though			M					Teen	SB	
38		1	1	Though			M					Teen	SB	
39		1	1	Though			M					Adult	SB	
40		1	1	Though			F					Teen	SB	
41	2		2	Though			M,M					Teen	SB	
42		1	1	Though			F					Adult	NB	
43		1	1	S	Yes	Yes	M	No	Yes	No		Teen	WB	
44		1	1	S	Yes	Yes	M	No	Yes	No		Teen	WB	
45		1	1	Though			M					Adult	SB	
46		1	1	Though			M					Adult	NB	
47		1	1	S	Yes	Yes	M	No	No	No		Teen	EB	17:00 - 18:00
48	1		1	N	Yes	Yes	M	No	No	No		Teen	WB	
49	1		1	Though			M					Adult	NB	
50	1		1	Though			M					Adult	SB	
51		1	1	S	Yes	Yes	M	No	No	No		Adult	WB	
52		1	1	S	Yes	Yes	M	No	Yes	No		Adult	WB	
53	1		1	Though			M					Teen	NB	
54		1	1	N	Yes	Yes	M	No	Yes	No		Adult	EB	
55	2		2	Though			M, M					Teen	NB	
56	1		1	S	Yes	Yes	M	No	Yes	No		Adult	EB	
57		1	1	Though			M					Teen	SB	
58			0	Though			M					Adult	SB	20:00 - 21:00
59			0	Though			M					Adult	SB	

Table 2 Pedestrian Data Collection on December 14, 2016

S/N	Number of cyclist	Number of peds	Total peds & cyclists	Crossing location (N/S)	Looked left	Looked right	Gender	Ped trapped	Ped delay	Motorist yielded (Y/N)	Yielding distance	Age(adult, teen, kid)	Direction (EB/WB)	Time
1	1		1	Through			M					Adult	SB	6:30 -8:30
2		2	2	Through			F,F					Teen	NB	
3	1		1	Through			M					Teen	NB	
4	1		1	Through			M					Teen	NB	
5		2	2	Through			F,F					Teen	NB	
6		1	1	Through			F					Teen	NB	
7		1	1	Through			F					Teen	NB	
8		1	1	Through			M					Teen	NB	
9		1	1	Through			M					Teen	NB	
10		1	1	S	Yes	Yes	M	No	Yes	No		Teen	EB	
11		2	2	S	Yes	Yes	M, M	No	No	No		Teen	EB	
12		1	1	S	Yes	Yes	M	No	No	No		Teen	EB	
13		2	2	Through			F,F					Teen	NB	
14		1	1	N	Yes	Yes	M	No	No	No		Teen	EB	8:30 - 11:30
15		2	2	N	Yes	Yes	M, F	No	Yes	No		Teen	EB	
16		1	1	Through			M					Teen	NB	
17		1	1	S	Yes	Yes	M	No	Yes	No		Teen	EB	
18		1	1	Through			M					Teen	SB	
19	1		1	Through			M					Adult	SB	
20		1	1	N	Yes	Yes	M	No	No	No		Teen	EB	
21		1	1	S	Yes	Yes	M	No	Yes	No		Teen	WB	
22		1	1	N	Yes	Yes	F	Yes	Yes	Yes	100ft	Adult	EB	
23		2	2	Through			M,F					Adult	SB	
24		1	1	N	Yes	Yes	F	No	Yes	No		Adult	WB	
25	1		1	Through			M					Adult	SB	
26	1		1	S	Yes	Yes	M	No	No	No		Adult	EB	
27		1	1	Through			M					Teen	SB	
28	2		2	Through			M,M					Teen	SB	
29		1	1	S	Yes	Yes	M	No	No	No		Teen	WB	11:30 - 12:30
30		1	1	Through			M					Adult	NB	
31		2	2	Through			F,F					Adult, Kid	NB	
32		1	1	Through			M					Teen	NB	
33		1	1	Through			M					Teen	SB	
34	1		1	N	Yes	Yes	M	No	No	No		Teen	WB	

Table 2 Pedestrian Data Collection on December 14, 2016 (cont.)

35		1	1	S	Yes	Yes	M	No	Yes	No		Adult	WB	13:30 - 15:30
36	1		1	Through			M					Teen	SB	
37		1	1	Through			M					Adult	SB	
38		1	1	Through			M					Adult	SB	
39		3	3	Through			M,M, F					Teen	SB	
40	1	2	3	Through			M, F,F					Teen	SB	
41		3	3	Through			F,F,F					Teen	SB	
42		1	1	Through			M					Teen	SB	
43		1	1	Through			F					Teen	SB	
44	1		1	S	Yes	Yes	M	No	Yes	No		Adult	EB	
45		4	4	N	Yes	Yes	4M	No	Yes	Yes	10ft	Teen	EB	
46		2	2	Through			M,M					Teen	SB	
47		1	1	N	Yes	Yes	M	No	Yes	No		Teen	EB	
48		1	1	Through			F					Teen	SB	
49		1	1	Through			F					Teen	SB	
50		1	1	Through			M					Teen	SB	
51		1	1	Through			F					Teen	SB	
52		2	2	N	Yes	Yes	M,M	No	No	No		Teen	EB	
53		1	1	S	Yes	Yes	M	No	No	No		Teen	WB	
54		3	3	S	Yes	Yes	M,F,F	No	No	No		Teen	WB	
55		1	1	S	Yes	Yes	F	Yes	Yes	Yes	10ft	Teen	WB	
56		2	2	N	Yes	Yes	M,F	No	No	No		Teen	WB	
57		1	1	S	Yes	Yes	M	No	No	No		Teen	WB	
58		3	3	Through			F,F,F					Teen	SB	15:30 - 17:00
59		2	2	Through			M,M					Teen	SB	
60		1	1	Through			M					Adult	NB	
61	1		1	N	Yes	Yes	M	No	Yes	No		Adult	WB	
62		1	1	N	Yes	Yes	M	No	Yes	No		Teen	EB	17:00 - 18:00
63		1	1	S	Yes	Yes	M	No	Yes	No		Adult	WB	
64		2	2	Through			M,F					Adult, Kid	SB	
65	1		1	S	Yes	Yes	M	No	Yes	No		Adult	EB	
66	1		1	N	Yes	Yes	M	No	No	No		Adult	WB	18:00 - 20:00
67	1		1	N	Yes	Yes	M	Yes	Yes	Yes	5ft	Teen	EB	
68		1	1	N	Yes	Yes	M	No	Yes	No		Teen	WB	
69		1	1	Through			M					Adult	NB	
70	1		1	S	Yes	Yes	M	No	Yes	No		Teen	WB	
71		1	1	Through			M					Adult	NB	
72	1		1	N	Yes	Yes	M	No	Yes	No		Teen	EB	
73		2	2	Through			M,F					Teen	SB	20:00 - 21:00
74		1	1	Through			M					Adult	SB	
75		1	1	S	Yes	Yes	M	No	Yes	No		Teen	WB	
76		2	2	Through			M,F					Adult	SB	

Table 3 Pedestrian Data Collection on December 15, 2016

S/N	Number of cyclist	Number of peds	Total peds & cyclists	Crossing location (N/S)	Looked left	Looked right	Gender	Ped trapped	Ped delay	Motorist yielded (Y/N)	Yielding distance	Age(adult, teen, kid)	Direction (EB/WB)	Time
1	1		1	Through			M					Teen	NB	7:10
2	1		1	Through			M					Teen	NB	7:12
3		1	1	Through			F					Teen	NB	7:13
4		2	2	Through			F,F					Teen	NB	7:15
5		1	1	Through			M					Teen	NB	7:16
6		2	2	Through			F,F					Teen	NB	7:18
7		1	1	Through			F					Teen	NB	7:19
8		1	1	Through			F					Teen	NB	7:23
9		1	1	Through			M					Teen	NB	7:30
10		1	1	Through			F					Teen	NB	7:35
11		1	1	Through			M					Teen	NB	7:40
12	1		1	Through			M					Teen	NB	7:42
13		1	1	S	Yes	Yes	M	No	Yes	No		Teen	EB	7:58
14		2	2	Through			F,F					Teen	NB	7:59
15		1	1	S	Yes	Yes	M	No	Yes	No		Teen	EB	8:00
16		1	1	S	Yes	Yes	M	No	Yes	No		Teen	EB	8:15
17	3		3	Through			M,M,M					Teen	NB	8:16
18		1	1	Through			F					Teen	SB	8:17
19		1	1	S	Yes	Yes	M	No	Yes	No		Teen	EB	8:18
20	1		1	Through			M					Teen	NB	8:18
21		2	2	S	Yes	Yes	M, F	No	No	No		Teen	EB	8:20
22		1	1	N	Yes	Yes	M	No	No	No		Teen	EB	8:26
23		4	4	S	Yes	Yes	2M, 2F	No	Yes	Yes	10ft	Adult + 3kids	EB	8:35
24	1		1	Through			M					Adult	NB	8:40
25		1	1	Through			M					Adult	SB	8:41
26	1		1	Through			M					Adult	SB	9:10
27	1		1	Through			M					Adult	NB	9:14
28		1	1	Through			M					Teen	SB	11:45
29		1	1	Through			M					Adult	NB	11:45
30		2	2	S	Yes	Yes	M, F	No	No	No		Adults	EB	12:29
31		1	1	Through			M					Adult	SB	12:30
32		1	1	Through			M					Teen	NB	12:30
33		1	1	Through			F					Teen	NB	13:45
34		1	1	Through			M					Adult	NB	13:50
35		1	1	Through			M					Teen	SB	14:00
36		1	1	Through			M					Teen	SB	14:04
37		1	1	Through			M					Adult	NB	14:07
38	1		1	N	Yes	Yes	M	No	No	No		Teen	EB	14:20
39	1		1	Through			M					Adult	SB	14:22
40		1	1	N	Yes	Yes	M	No	No	No		Teen	EB	14:25

Table 3 Pedestrian Data Collection on December 15, 2016 (cont.)

41	1		1	Through			M					Teen	SB	14:31
42		1	1	Through			M					Teen	SB	14:40
43		2	2	Through			M,F					Teen	SB	14:43
44		3	3	Through			F,F,F					Teen	SB	14:44
45		2	2	Through			M,M					Teen	NB	14:44
46		1	1	Through			F					Teen	SB	14:46
47		3	3	N	Yes	Yes	M,M,M	No	No	No		Teen	EB	14:48
48		2	2	Through			F,F					Teen	SB	14:49
49	1		1	S	Yes	Yes	M	No	No	No		Teen	EB	14:50
50		1	1	Through			M					Teen	SB	14:51
51		1	1	Through			M					Teen	SB	14:52
52		2	2	Through			M,M					Teen	SB	14:54
53		2	2	N	Yes	Yes	M,F	No	Yes	No		Teen	EB	14:55
54	1		1	S	Yes	Yes	M	No	Yes	No		Adult	EB	15:05
55		1	1	Through			F					Adult	SB	15:10
56		2	2	Through			M,M					Teen	SB	15:21
57		1	1	Through			M,M					Teen	SB	15:23
58		1	1	S	Yes	Yes	M	No	No	No		Teen	WB	15:24
59		1	1	Through			F					Teen	SB	15:27
60		1	1	Through			M,M					Teen	SB	15:29
61		1	1	N	Yes	Yes	F	No	Yes	No		Adult	EB	15:31
62		1	1	Through			F					Adult	SB	15:38
63		1	1	Through			M					Teen	SB	15:51
64		4	4	Through			3M,F					Teen , 3Kids	SB	15:56
65		1	1	Through			F					Teen	SB	16:02
66		1	1	Through			M					Teen	SB	16:04
67		1	1	N	Yes	Yes	M	No	Yes	Yes	5ft	Adult	WB	16:24
68		2	2	S	Yes	Yes	M, M	No	No	No		Teen	WB	16:31
69	4		4	Through			4M					Teen	SB	16:50
70	1		1	S	Yes	Yes	M	No	No	No		Teen	WB	17:10
71		1	1	S	Yes	Yes	M	No	Yes	No		Teen	EB	17:12
72		1	1	Through			F					Teen	SB	17:14
73		3	3	N	Yes	Yes	2F, M	No	Yes	No		Teen	WB	17:40
74		1	1	Through			M					Teen	SB	17:46
75		1	1	Through			F					Adult	SB	17:48
76		2	2	N	Yes	Yes	M, F	No	No	No		Teen	WB	18:27
77		1	1	Through			M					Adult	SB	18:36
78		1	1	Through			M					Adult	NB	18:40
79	1		1	N	Yes	Yes	M	No	Yes	No		Adult	WB	18:41
80		1	1	Through			M					Adult	SB	19:03
81		1	1	Through			M					Adult	NB	19:21
82		1	1	S	Yes	Yes	M	No	No	No		Teen	WB	19:37
83		2	2	N	Yes	Yes	M, M	No	No	No		Teen	EB	20:06
84	1		1	N	Yes	Yes	M	No	No	No		Teen	EB	20:14
85		1	1	Through			M					Adult	NB	20:21
86		1	1	Through			M					Adult	NB	20:23
87		1	1	Through			M					Adult	NB	20:28
88		1	1	Through			F					Adult	SB	20:41

Chapter 6 Cost and benefit analysis

Benefits of the LED pedestrian crossing system

To quantify the benefits of the automatic pedestrian detection at the mid-block, a better understanding of the difference in the probability of crash occurrence at the crosswalk equipped with traditional push button only and the one having push button with supplemented automatic pedestrian detection need to be explored. Consider a diagram below.

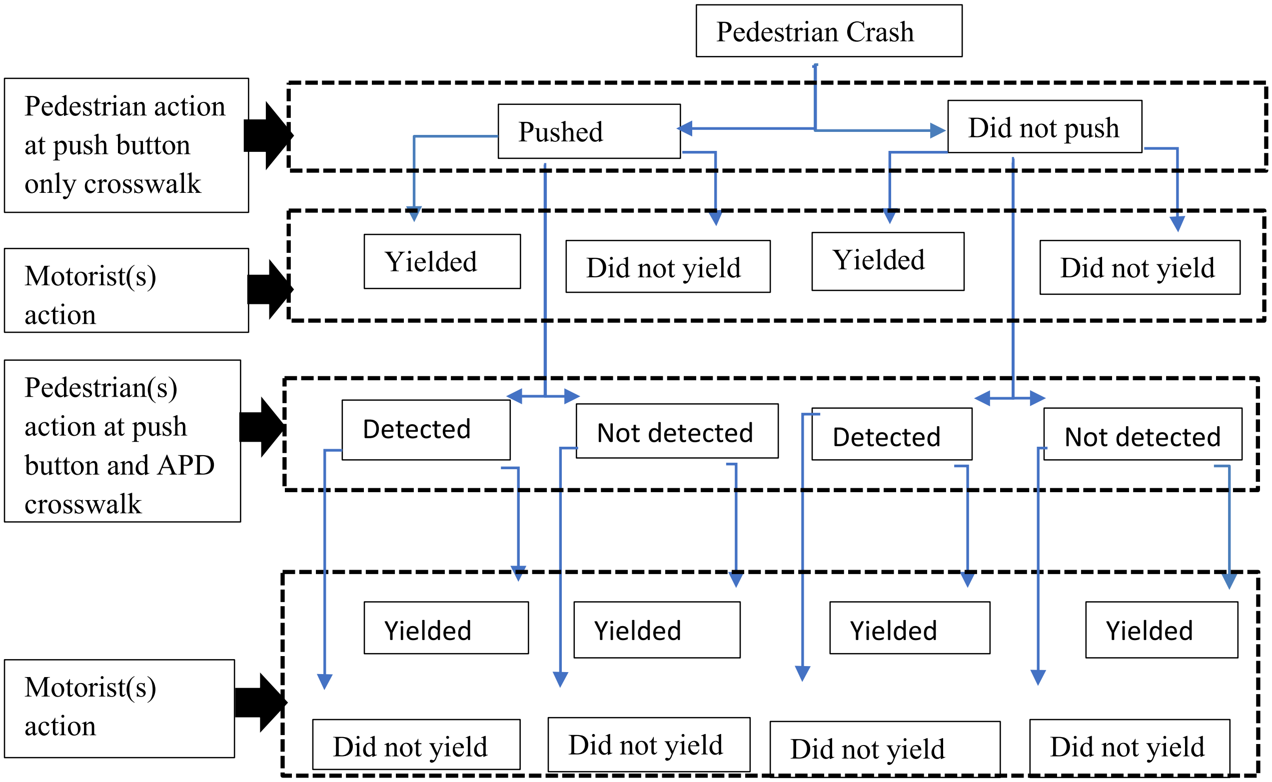

Figure 11 Pedestrian and motorists' actions in relation to crash occurrence

With the signalized crosswalk equipped with traditional push button only, the motorists can be alerted of the presence of the pedestrians and subsequently take appropriate actions if and only if the pedestrians intending to use the crosswalk pressed the push button. On the other hand, the signalized crosswalk having the push button with supplemented automatic pedestrian detection, even if the pedestrians don’t press the push button, the automatic pedestrian detection device still can detect the presence of the pedestrian and alert the motorists. However, the effectiveness of detection would depend on various factors including the distance from the device to where pedestrian crossed the roadway. The probability of pedestrian being involved in crash, for this case, is presumed to be high for the signalized crosswalk with push button only as compared to the one supplemented with the automatic pedestrian detection. However, under the automatic pedestrian detection case, the probability of pedestrian being involved in crash increases as the distance from the crosswalk to the crossing location increases. Therefore, the difference in the probabilities of crash occurrences for the two cases can be considered as the benefit of the automatic pedestrian detection. However, this difference in probabilities need to be quantified in monetary terms to clearly present the benefits.

By combining crash costs, crash data and the pedestrian crossing pattern and signal activation behaviors, the monetary benefits quantification can be performed. The crash costs provide the costs related to different types of crashed that occurred at the crosswalk locations, the crash data provide the number of crashes, the associated severity levels, and the locations where the crash occurred while the pedestrian crossing pattern and signal activation behaviors reveals the tendency of pedestrian to alert motorists of their presence and the location within the crosswalk effective area they use to cross the roadway.

Various assumptions stated and described below were made

1. The current pedestrians crossing pattern is the same as the one during crash occurrence. This is to say, the proportion of the pedestrians who effectively use the crosswalk at marked area to the ones cross outside the marked area during crash occurrence and during observation of pedestrian behavior has not changed.
2. The effective crosswalk area is bordered by the advanced pedestrian crossing signs for both side of the crosswalk. It implies that, the effective crosswalk area is from the crosswalk marking to the advanced pedestrian sign downstream and upstream of the traffic flow. Any crash, crossing activity within this area is assumed to be influenced by the presence of the crosswalk. The basis for this assumption is that, within this area, a driver is aware of the possibility of the presence of pedestrians, thus, he/she is in position to take appropriate cautions not to get involved in the crash. This assumption will facilitate the documentation of the crossing pattern and extraction of the appropriate crash data for this study.
3. Any activity (crossing or crash) that occurred within 3ft off the marked area of the crosswalk is considered to occur within marked area. The basis for this assumption is that it may happen that many people are using the crosswalk at the same moment thus cannot be within the marked area.
4. The effective pedestrian detection distance is 10 feet to and from the pedestrian crossing sign. In many cases, the pedestrian detection device is fixed at the pedestrian crossing sign. This device should not be able to detect pedestrian at long range since by doing that the system would have many false detections.

The diagram below summarizes the contents of the assumptions.

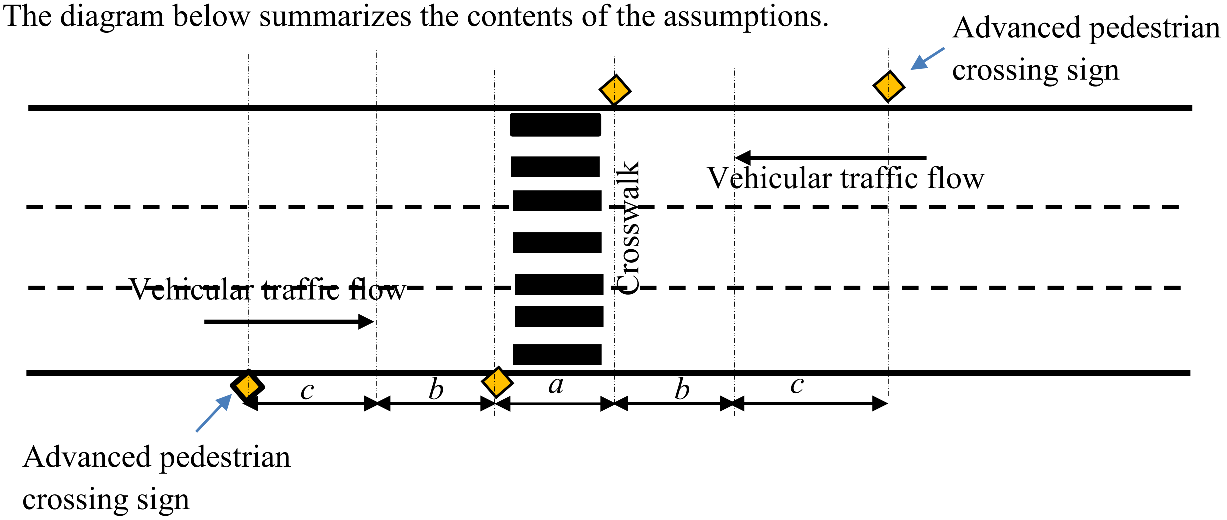

Figure 12 Pedestrian crossing zones

whereby,

a is the marked zone of the crosswalk
$a + b$ is the automatic pedestrian detection zone, and
$a + b + c$ is the effective crosswalk zone

Given that setup in Figure 2 and detailed motorists and pedestrians' actions in Figure 1, the total number of crashes at a given crosswalk is the sum of the crashes that occurred within zone a, zone b and zone c. The total number of pedestrian used the crosswalk is the sum of the pedestrians crossed through zone a, b and c. The following can be deduced on the total number of crashes occurring within crosswalk area ($Crash_{total}$) , the total number of pedestrian using the crosswalk ($Peds_{total}$) , the probability of a pedestrian pressing the push button (P_P), probability of motorists to yield (P_Y), , and the probability of pedestrian being detected by the automatic pedestrian device (P_D) if the device is to be provided.

$$Crash_{total} = Crash_{(zone\ a)} + Crash_{(zone\ b)} + Crash_{(zone\ c)}$$

$$Peds_{total} = Peds_{(zone\ a)} + Peds_{(zone\ b)} + Peds_{(zone\ c)}$$

$$P_{P\ (zone\ a)} > P_{P\ (zone\ b)} > P_{P\ (zone\ c)}$$

$$P_{D\ (zone\ a)} > P_{D\ (zone\ b)} > P_{D\ (zone\ c)}$$

$$P_{Y\ (pushed)} = P_{Y\ (pushed+detected)} = P_{Y\ (didn't\ push+detected)} > P_{Y\ (didn't\ push)}$$

$$P_{Y\ (didn't\ push)} = P_{Y\ (didn't\ push+didn't\ detected)}$$

The expected number of crashes for the crosswalk equipped with traditional push button only can be expressed as

$$
\begin{aligned}
&Number\ of\ crashes\\
&\quad = ((1-\ P_P) * \Big((1-\ P_{Y(pushed)}) + \big(1-\ P_{Y(didn't\ push)}\big)\Big)\, Crash)_{(\,zone\ a)}\\
&\quad +\ ((1-\ P_P)\Big((1-\ P_{Y(pushed)}) + \big(1-\ P_{Y(didn't\ push)}\big)\Big) * Crash)_{(\,zone\ b)}\\
&\quad +\ ((1-\ P_P)\Big((1-\ P_{Y(pushed)}) + \big(1-\ P_{Y(didn't\ push)}\big)\Big) * Crash)_{(\,zone\ c)}
\end{aligned}
$$

While the expected number of crashes for the crosswalk push button with supplemented automatic pedestrian detection can be expressed as

$$
\begin{aligned}
&Number\ of\ crashes\\
&\quad = \Bigg((1-\ P_P) * (1-\ P_D)\\
&\quad * \Big(((1-\ P_{Y(pushed+detected)}) + (1-\ P_{Y(pushed+not\ detected)})\Big)\\
&\quad * \Big(\big(1-\ P_{Y(didn't\ push+detected)}\big) + \big(1-\ P_{Y(didn't\ push+not\ detected)}\big)\Big)\Big)\\
&\quad * Crash\Bigg)_{(\,zone\ a)}\\
&\quad + \Bigg((1-\ P_P) * (1-\ P_D)\\
&\quad * \Big(((1-\ P_{Y(pushed+detected)}) + (1-\ P_{Y(pushed+not\ detected)})\Big)\\
&\quad * \Big(\big(1-\ P_{Y(didn't\ push+detected)}\big) + \big(1-\ P_{Y(didn't\ push+not\ detected)}\big)\Big)\Big)\\
&\quad * Crash\Bigg)_{(\,zone\ b)}\\
&\quad +\ ((1-\ P_P) * (1-\ P_D)\\
&\quad * \Big(((1-\ P_{Y(pushed+detected)}) + (1-\ P_{Y(pushed+not\ detected)})\Big)\\
&\quad * \Big(\big(1-\ P_{Y(didn't\ push+detected)}\big) + \big(1-\ P_{Y(didn't\ push+not\ detected)}\big)\Big)\Big)\\
&\quad * Crash)_{(\,zone\ c)}
\end{aligned}
$$

But, as the distance from the crosswalk increases, effectiveness of the automatic detection decreases. Thus, it is logical to assume that the probability of pedestrian being detected by the automatic pedestrian device (P_D) at zone c equals to zero. The equation for the difference in the expected number of crashes for crosswalk equipped with traditional push button only and the one having push button with supplemented automatic pedestrian detection becomes

Cost of the LED pedestrian system

The cost of the LED pedestrian system will be collected based on the expense in developing the system in this study. The expenses include all those for the system components: LED light, RRFL, light pole, pedestrian crossing sign, controller, press button.

The cost and benefit of the system can be calculated based on the methodology presented above. The needed data cannot be made available due to the termination of the field test.

Chapter 7 Conclusions and Recommendations

Conclusions

This project is not complete due to the technical problem in the system development. The entire system worked in the lab, but not in the field. The practical issues prevent this system to be implemented in the field: vandalism.

The methodology of evaluating the performance of the system is sound. The data collected in this study were used in evaluating the performance of other pedestrian crossing systems. A technical paper was generated from the study based on the data collected in this study.

The methodology of the cost and benefit study is very unique. It clearly quantifies the impact of relevant factors.

Recommendations:

This study can be continued by developing a use-friendly pedestrian detection system. It becomes aware that advanced image processing based infrared sensor can be developed that can detect pedestrian in far distance. Lidar can also be applied into detecting pedestrians which can be integrated into this system, making it success. The system would contribute to improving safety significantly in Nevada.

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