



---

# *An Evaluation of a Crosswalk Warning System Utilizing In-Pavement Flashing Lights*



Funding by  
**State of California**  
**Office of Traffic Safety**  
and  
**Federal Highway Administration**  
**University of North Carolina Highway Safety Research Center**

April 1998



---

*An Evaluation of a  
Crosswalk Warning System  
Utilizing In-Pavement Flashing Lights*

*Primary Funding Provided By*  
**State of California Office of Traffic Safety**

*Additional Funding Provided By*  
**Federal Highway Administration**  
through the  
**University of North Carolina Highway Safety Research Center**

April 10, 1998

---

## Table of Contents

	Page
Executive Summary .....	1
Crosswalk Warning System Description and Operation.....	4
Data Collection Procedures.....	9
Description of Test Sites .....	12
Results of Data Analysis.....	28
Evaluation of System Performance.....	46
Findings and Recommendations .....	49
Study Participants and References.....	52
Endnotes.....	53
Tables	
1 Comparison of Type H Marker and the Experimental Device .....	4
2 Site Characteristics Which Affect Pedestrian Crosswalk Conditions.....	13/14
3 Driver Interview Summary .....	45
Figures	
1. Experimental System .....	5
2. Staged Pedestrian Actions.....	10
3. Main Street/Laurel Street in Fort Bragg .....	17
4. Mt. Diablo Blvd./Lafayette Park Hotel in Lafayette.....	18
5. Pleasant Hill Road/Condit Road in Lafayette .....	19
6. Petaluma Boulevard/Putnam Plaza in Petaluma .....	20
7. Main Street/Hazel Street in Willits .....	21
8. Sunset Boulevard/Sunset Plaza in West Hollywood .....	22
9. Sunset Boulevard/Wetherly in West Hollywood.....	23
10. Sunset Boulevard/Alta Loma in West Hollywood.....	24
11. Altarinda Drive/JFK University in Orinda .....	25
12. Central Way/3rd Avenue in Kirkland.....	26
13. Northeast 124th Street/Community Center in Kirkland .....	27
14. Data Comparison - Main Street/Laurel Street in Fort Bragg .....	33
15. Data Comparison - Mt. Diablo Blvd./Lafayette Park Hotel in Lafayette .....	34
16. Data Comparison - Pleasant Hill Road/Condit Road in Lafayette.....	35
17. Data Comparison - Petaluma Boulevard/Putnam Plaza in Petaluma .....	36
18. Data Comparison - Main Street/Hazel Street in Willits .....	37
19. Data Comparison - Summerfield Road/Howarth Park in Santa Rosa.....	38
20. Existing Conditions - Sunset Boulevard/Sunset Plaza in West Hollywood .....	39
21. Existing Conditions - Sunset Boulevard/Wetherly in West Hollywood.....	40
22. Existing Conditions - Sunset Boulevard/Alta Loma in West Hollywood .....	41
23. Data Comparison - Altarinda Drive/JFK University in Orinda .....	42
24. Data Comparison - Central Way/3rd Avenue in Kirkland.....	43
25. Data Comparison - Northeast 124th Street/Community Center in Kirkland .....	44

## Executive Summary

---

### Introduction

In response to an unusually high incidence of pedestrian/vehicle collisions, the City of Santa Rosa, California, initiated a new concept in proactive pedestrian warning systems for uncontrolled crosswalks in 1993 after experiencing a significant number of pedestrian fatalities and injuries. A private citizen came forth to the City with an idea for a flashing device to be installed on the pavement surface along the crosswalk lines and facing traffic. The In-Pavement Flashing Lights Crosswalk Warning System's purpose was to warn the driving public of the presence of pedestrians in the crosswalk at uncontrolled intersections. The citizen is a pilot and the idea came to him when he thought that airport runway strobe lights used in landing his plane might be useful at crosswalks. The experimental system consists of a series of flashing light units which are embedded in the pavement adjacent to a marked crosswalk. The lights reflect toward the oncoming traffic to warn drivers of a pedestrian's presence.

The California Traffic Control Devices Committee allowed the City of Santa Rosa to test the experimental device at selected locations. The California Office of Traffic Safety also granted funds to the City to study the effectiveness of the device. The private citizen developed the In-Pavement Flashing Lights Crosswalk Warning System, while the City was responsible for the construction and installation requirements of the device and the analysis of the device through a consultant. The system was eventually installed at three locations in the City of Santa Rosa, two in 1994 and one in 1995. Those test sites were evaluated and the findings presented in a report, *Analysis of an Experimental Pedestrian Crosswalk Device*, W-Trans/TJKM, July 17, 1995.

In 1996, the California Traffic Control Devices Committee (CTCDC) endorsed the testing of the system in additional California cities in order to determine if the device should be sent on to the California State Department of Transportation for standardization. *Evaluation of an Experimental Crosswalk Warning System* dated July 1, 1997, presented an evaluation of the In-Pavement Flashing Lights Crosswalk Warning System based on the operation and experience in the Cities of Fort Bragg, Lafayette, Petaluma, Willits. Additional evaluation was conducted at one of the original Santa Rosa test sites two years following the initial installation of the device. Primary funding for that study was provided primarily by the California Office of Traffic Safety (OTS) through the Cities of Fort Bragg, Lafayette, West Hollywood and Willits.

This report presents an update to the *Evaluation of an Experimental Crosswalk Warning System* based on additional experience in the Cities of Orinda, California and Kirkland, Washington. Funding for this update was provided through the Federal Highway Administration's *Pedestrian Facilities Program* which is being conducted by the University of North Carolina Highway Research Center.

### Findings

- " The concept of flashing amber lights embedded in the pavement at uncontrolled crosswalks clearly has a positive effect in enhancing a driver's awareness of crosswalks and modifying driving habits to be more favorable to pedestrians.
- " The In-Pavement Flashing Lights Crosswalk Warning System has a much more significant effect in enhancing a driver's awareness of crosswalks during adverse weather conditions such as darkness, fog, and rain.
- " Over the long term, the affect of the crosswalk warning system will degrade slightly during daytime conditions from initial implementation of the system. However, the resulting long term conditions



still represent improved vehicle reaction characteristics compared with conditions before installation.

- " The In-Pavement Flashing Lights Crosswalk Warning System has the potential to be an effective traffic control device since it fulfills a need, commands attention, conveys a clear meaning, commands respect of road users, and gives adequate time for proper response.
- " An automatic detection system is more appropriate than a push button system and can result in less confusion for the pedestrian.
- " A recently demonstrated "bollard gateway system" which utilizes two parallel modulated visible red beams seems to be the most promising automatic activation technology.
- " The warning system seems to be particularly effective at locations where there is at least a moderate flow of pedestrians ( 100 pedestrian crossing per day ).
- " At speeds less than 35 mph, drivers seem to be able to respond properly if at least 400 feet of sight distance is provided to the warning system.
- " At speed greater than 40 mph, drivers seem to have difficulty stopping safely if less than 600 feet of sight distance is available prior to the warning lights.
- " The presence of a lighting device at the outer edge of the travel lane may be a hazard to some bicyclists.
- " Each successive prototype of the lighting devices which has been tested has been superior in terms of their physical durability. Further improvements to its durability are still warranted. However, the desires of the market will dictate further physical evolution of the device.

## **Recommendations**

- " Since the concept of flashing amber lights embedded in the pavement at uncontrolled crosswalks clearly has merit in modifying driving habits to be more favorable to pedestrians, further use of this concept should be pursued at appropriate locations.
- " The current installation pattern should be maintained as a standard. However, the outermost device should be placed to avoid the path of bicyclists to the extent possible.
- " The device should be no higher than 3/4-inch which is the maximum height of a standard lane delineator button.
- " Amber flashing lights seem to be the most appropriate color based on vehicle laws and considering a person's visual capabilities.
- " In the long run, an automatic pedestrian activation system seems to be more appropriate than a pedestrian push button. This allows the pedestrian to cross with caution and at their own discretion. The most promising technology to date has been a "bollard gateway system."
- " Appropriate street lighting should be considered at crosswalks where the system is applied. Street lighting will allow the pedestrian to be more visible at night and wash out the glow of the lighting devices so they do not distract the pedestrian.

- " Federal standardization through the Manual on Uniform Traffic Control Devices (MUTCD) and consistency with crosswalk laws in states other than California should be investigated. An organization such as the Institute of Transportation Engineers would be an appropriate organization to pursue this course of action.
- " Based on the experience of the initial test sites, it is recommended that the following guidelines be met for installation of the In-Pavement Flashing Lights Crosswalk Warning System. The development of guidelines will be important in focusing use of the device where it will be most effective and maintaining its effectiveness through limiting the number of locations where it is present.
- The Crosswalk Warning System should be used at uncontrolled crosswalks.
  - Main street average vehicular approach speeds should be 45 mph or less.
  - Main street traffic volumes should be between 5,000 and 30,000 vehicles per day. (It should be noted that the City of West Hollywood will be testing the device on Sunset Boulevard which has 55,000 vehicles per day.)
  - At speeds less than 35 mph, the approaching motorist should have visibility of the lighting devices at least 400 feet in advance of the crosswalk (measured from 3.5-foot eye height of the driver to 1-inch height at the edge of the crosswalk line). At speeds greater than 35 mph, appropriate additional sight distance to the warning lights should be provided.
  - There should be no other crosswalks or traffic control devices at least 250 feet in advance or following the crosswalk location.
  - A minimum pedestrian volume of 100 pedestrians per day is suggested for application of the system.
- " Agencies which install the system should ensure that the public is educated on the proper use of the device by both the driver and the pedestrian.

---

## Crosswalk Warning System Description and Operation

---

The experimental "Crosswalk Warning System," also known as the "LightGuard System" or the "Santa Rosa Lights," consists of warning lights housed in a unit which is installed on the pavement adjacent to a marked crosswalk. The lights reflect out toward the oncoming traffic to warn drivers of a pedestrian's presence.

### Device Design

The version of the lighting device which were evaluated at the majority of the test sites is similar in design to standard reflective pavement markers. Its appearance is similar to a standard California Type H One-Way Yellow Reflective Marker, but is larger and is constructed of a black rubberized material. A drawing of the current device design is shown in Figure 1. Following is a comparison of the Type H Marker dimensions with those of the experimental device.

**Table 1**  
**Comparison of Type H Marker and the Experimental Device**

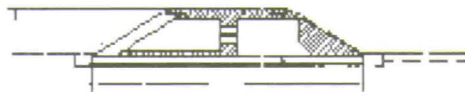
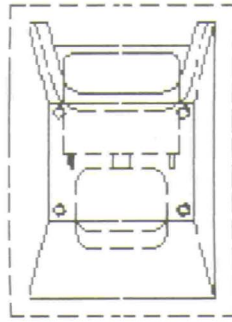
Dimensions	Type H 1-Way Yellow Reflective Marker	Experimental Device
Base	4 by 4 inches	8 <sup>3</sup> / <sub>4</sub> by 6 inches
Top	3 <sup>3</sup> / <sub>8</sub> by 1 <sup>7</sup> / <sub>8</sub> inches	4 <sup>1</sup> / <sub>2</sub> by 3 <sup>1</sup> / <sub>2</sub> inches
Height (from ground)	<sup>3</sup> / <sub>4</sub> inch	1 <sup>3</sup> / <sub>8</sub> inches

Similar to any other device operating in or around a roadway, the device has evolved primarily to address physical durability issues. The construction of the device has been modified over the last several years to increase its structural integrity and to increase the brightness of the lights. The device has been in operation for since 1994 in Santa Rosa with typical maintenance issues needing to be addressed.

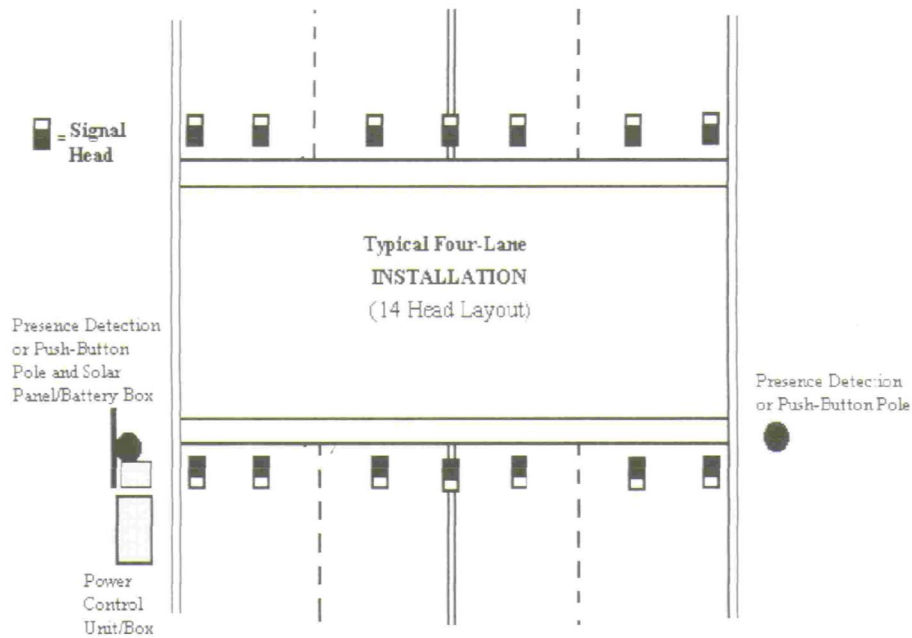
The most recent version of the device was designed to increase its durability and to withstand snowplows and street sweepers. Known as the "button type" design, it is more rounded in appearance similar to lane delineation markers, with a base diameter of 6 <sup>3</sup>/<sub>4</sub> inches and a height after installation of 1 <sup>1</sup>/<sub>4</sub> inches and constructed of a metal material. The light lens dimension is 3 inches by 1 inch, and is the same size lens as has been used at all of the test sites including the original installations in Santa Rosa. This version of the device was retrofitted at all of the existing test sites and was used and tested at the new sites.

### Installation Pattern

The typical installation of the devices has been to locate the lights on both outside edges of the crosswalk stripes with the lighting device facing away from the pedestrian crossing areas and toward the oncoming vehicular traffic. On a four-lane roadway, seven devices have been used per direction (one on the centerline, one in the center of each travel lane and one on the outside of the curb travel lane). On a two-lane roadway, five devices have been used per direction. An example of a typical installation for a four-lane roadway is shown in Figure 1. At midblock crosswalks or intersections with only one crosswalk on the main street, the devices have been installed on both sides of the crosswalk. At intersections where there are two crosswalks on the main street, the devices have been installed on the outside of each of the two crosswalks. The devices have only been installed where the traffic crossing the crosswalk path is uncontrolled. The devices have not been installed on side street crosswalks where traffic is controlled by a stop sign.



Device Design



Experimental System Installation Pattern

Source: LightGuard Systems, Inc.



**Figure 1** Experimental System  
In-Pavement Flashing Lights Crosswalk Warning System Evaluation

Whitlock & Weinberger Transportation Inc.

## Lighting

Similar to the California Type H marker, which has an amber reflector on one “ramp,” the experimental device contains a lighting unit on one ramp. Originally, before any devices were installed, amber flashing lights were planned to be used with yellow painted school crosswalks and white lights were intended for use in conjunction with all white painted crosswalks. The use of an amber LED (Light Emitting Diode) lamp was selected for all locations over a white light because in addition to relaying a message of warning and caution, the amber LED lamp provides the following additional benefits.

- C Best visibility for motorists at a distance in bright sunlight and poor weather
- C Easy recognition by motorists who are red-green blind
- C Easily dimmed by pulse width modulation for nighttime viewing
- C Long term reliability and low maintenance
- C Easily designed to eliminate EMI that can cause noise in vehicle radios.

Specifically, the light source selected for use in the devices was a HLMA-CL00, AS AlInGaP, 590 nm amber, T-1¾, 7° nondiffused LED lamp.<sup>1</sup> The device also utilizes an optical lens in front of the amber LEDs which enhances the light beam. The current design includes twelve (12) LED lamps with three groups of four yolked together in a 0.80 inch by 3.30 inch area with the optical lens.

The following lighting specifications were used in the development of the experimental devices which have been tested as part of this study.

The effective luminous intensity should be a minimum of 100 candela at the center of the LED panel measured at 25 feet.<sup>2</sup> Luminous intensity could be increased for daytime use provided that a dimming feature reduces the intensity during darkness. A pulse pattern of one second at four to six pulses per second with a fifty percent duty cycle followed by one second of steady on is further recommended. This pulse rate and duty cycle maximize the temporal contrast that induces the visual sensation of flicker and is below the photoconvulsive response frequency indicated by the National Institute of Health Epilepsy Research Branch.<sup>3</sup>

Additional lighting details of the Experimental Warning Device is included in Appendix A.

## Operation

Upon approaching the crosswalk, the driver of a vehicle views a series of amber lights flashing in unison across their field of vision. Depending on the roadway alignment, the lights can be viewed from 1,000 to 1,500 feet away from the crosswalk. The optical lenses in the device concentrate the most intense beam within a limited horizontal and vertical angle of vision toward the oncoming vehicles. For the initial and current testing, the only supplemental signage provided to warn the motorist consisted of the standard pedestrian crossing sign.

## **System Activation**

The first installations in Santa Rosa were activated by a pedestrian push button. The initial study on the effectiveness of the system suggested that an automatic detection system be used in lieu of the push button activation. Pedestrians seemed to associate the push button with a traffic signal and generally were confused because of the absence of any indication to the pedestrian. The current test sites were installed with an ultrasonic automatic detection system. The City of Petaluma supplemented that system with a video imaging detection system.

At the initial testing sites in Santa Rosa, upon approaching the crosswalk from the sidewalk, a pedestrian is presented with a sign on the pedestrian push button which reads, "Push Button for Crosswalk Warning Device." The push button also includes a flashing amber light on the push button post. The pedestrian is not able to view the amber lights flashing toward the drivers. There is no pedestrian indication similar to the walking man or upright hand used at signalized intersections. For the initial testing, there was no additional signage provided to instruct the pedestrian of the required reaction other than the sign on the push button post. The push button activation system was also used in Orinda and Kirkland.

For the test sites in Fort Bragg, Lafayette, Petaluma and Willits, which have an automatic detection system, upon approaching the crosswalk from the sidewalk a pedestrian views the traffic flow and crosses at their own discretion similar to any other uncontrolled crosswalk. Upon entering the sidewalk zone immediately adjacent to the crosswalk, the warning lights are activated.

## **Cost**

The current cost for equipment has run approximately \$9,000 for a crossing of a two-lane street and \$15,000 for a crossing of a four-lane street. The total cost of installation including equipment, labor, solar power capabilities, and activation system, has averaged near \$20,000 for a crossing of a four-lane street. The developers of the system expect that the cost of the system should reduce by approximately 25 to 30 percent with mass production of the devices.

In comparison, the cost of an overhead flashing beacon at the crossing of a four-lane street generally runs between \$10,000 and \$30,000 depending on the type of overhead flashing device used and if a controller is used in activating the lights when a push button is present.

## **Maintenance**

The experimental crosswalk warning devices should require little maintenance in the course of everyday use. The window ramp on the prototype used in this evaluation is likely to become scratched over time and may need replacement. However, scratching does not noticeably reduce the visual effect of the device. The device can quickly be replaced by loosening the attachment bolts from the base plate and installing a new device. The acrylic material used for the current prototype ramps is not as durable or scratch resistant as the polycarbonate material (Lexin or equivalent) being used in the new button type design. The devices are not placed in the direct path of vehicle tires so that the occurrence of vehicle impact is minimized. The two to four units located in each oncoming vehicle travel lane may wear slightly more quickly than the other units.

When slurry seal or chip seal is necessary, the device can be unbolted, removed and re-bolted provided precautions are taken to cover the left-in-place base plates and wiring for ease of reconnecting after completion. Another option would be to simply cover the device with removable protection ( tape or covers) during the slurry seal work, than remove the protection after completion of the work.

Resurfacing or overlay may require additional considerations for retrofitting. If the overlay requires extensive excavation of the existing roadway surface, the in-roadway wiring and devices with base plates will likely have to be removed and reinstalled after completion of the overlay. The hand hole (G5 boxes ) could remain undisturbed with upward adjustments for the cover ring seats. New saw cuts for wiring and reinstallation of the base plates would be necessary. An overlay resurfacing without excavation of the existing roadway surface may permit the existing wiring and base plates to remain in place with upward adjustment of the base plates to allow for the proper height retrofit of the devices. Eventually, the production model design should address these long term issues with the marketplace dictating the best methods for retrofitting.

### **State Vehicle Code**

Within the State of California, the *California Vehicle Code* (CVC) establishes the pedestrian right of way at marked and unmarked crosswalks (unless signage indicates no pedestrian crossing) and at marked midblock crosswalks. However, the pedestrian shall not place the vehicle in jeopardy by their act of crossing within the crosswalk. Because the CVC provides the legal requirements for pedestrian crossings, the City of Santa Rosa considered the In-Pavement Flashing Lights Crosswalk Warning System a warning device instead of a traffic control device. It was believed the legal right of way requirements through the CVC provided adequate legal identification of who has the right of way. Also, the CVC indicates that, "Whenever an illuminated flashing red or yellow light is used in a traffic signal or with a traffic sign, it shall require obedience by drivers as follows: when a yellow lens is illuminated with rapid intermittent flashes, a driver may proceed through the intersection or past the signal only with caution."

---

## Data Collection Procedures

---

A “before and after” data collection and analysis process was employed as part of the evaluation. Data was collected under existing conditions before the installation of the experimental system. The data collection process was then repeated after installation of the system to determine the impacts and effectiveness of the system. The initial data collection in Santa Rosa was only conducted during the day and only while school children were present at the school crossing locations. The current tests have been conducted both during the day and at night. The intent has been to complete all daytime data collection under mostly sunny conditions. To ensure consistent data for both before and after the installation of the Crosswalk Warning System, the surveys have been conducted under similar weather and lighting conditions as much as practical.

In general, the data has been collected at each site for four to five hours during the day and two to three hours in the evening for both the before and after conditions. The after conditions have been surveyed approximately eight weeks following the installation of the device. At one of the original Santa Rosa locations, additional data was recently collected two years following installation.

The need to provide accident data was considered in this evaluation. Based on discussions with traffic engineering specialists in pedestrian safety<sup>4</sup>, it was evident that at least five to ten years of pedestrian accident data at any one location would be needed to determine if any measures have been effective in improving the safety of the intersection. Conflict/behavioral sampling techniques were suggested and there is evidence that suggests that there is good correlation between conflict/behavioral sampling data and resulting accident history. Therefore, because the analysis period for this study represents too short a time to analyze the change in accident history, all of the data focused on conflict/behavioral sampling data such as the change in driver and pedestrian reaction with the addition of the lights. The primary information which was collected consisted of driver speed and reaction surveys, driver interviews, pedestrian reaction surveys, and pedestrian interviews.

To ensure consistent data collection procedures and because the majority of the sites did not have a continuous pedestrian flow, all of the driver reaction surveys and interviews were conducted using a “staged” pedestrian as part of the data collection crew. Driver reaction was collected under conditions with the staged pedestrian “looking” to cross from the sidewalk and with the staged pedestrian “stepping” into the roadway.

During the study, the staged pedestrian never directly challenged the drivers by walking into their path. Examples of “looking” and “stepping” actions from the staged pedestrian are shown in Figure 2.

All driver reaction surveys were conducted on random vehicles which were generally the first vehicle in a platoon to ensure that there were no other conditions to react to other than the pedestrian.

### Driver Reaction Surveys

The reaction of the driver was measured under two conditions; (1) staged pedestrian looking at oncoming traffic, and (2) staged pedestrian stepping out into the travelway. The following information was collected:

- approach speed (from 500 to 300 feet in advance of the crosswalk)
- travel time and deceleration (from 500 to 100 feet in advance of the crosswalk)
- braking distance (distance away from the crosswalk that vehicles begin to brake)
- driver reaction (yielded to the pedestrian, reacted but did not yield, and did not yield to the pedestrian)





Looking



Stepping



Looking



Stepping



Figure 2

## Staged Pedestrian Actions

*In-Pavement Flashing Lights Crosswalk Warning System Evaluation*

Whitlock & Weinberger Transportation Inc.

All of these characteristics were recorded manually through use of stop watches and site view of street markers. The approach speed was calculated by using the measurement of the vehicle travel time from 500 to 300 feet in advance of the crosswalk and the 200 feet travel distance. The travel time and deceleration factor was simply the travel time between a marker 500 feet in advance of the crosswalk to a point 100 feet in advance of the crosswalk. It should be noted that due to upstream conflicts, collection point distances of less than 500 feet in advance of the crosswalk were used in both directions at the Petaluma site and in the northbound direction at the City of Fort Bragg study location.

### **Driver Interviews**

During a separate data collection process using the staged pedestrian, drivers were interviewed after they had driven through the subject crosswalk. The interview process required the cooperation of the local police department to assist in pulling over vehicles. Before the installation of the device, the questions included the following:

1. Did you notice the crosswalk which you passed within the last block? (yes/no)
2. Did you notice any pedestrians in or near that crosswalk? (yes/no)
3. If you did notice a pedestrian, where was the pedestrian? (in the crosswalk/stepping out from the curb/waiting on the sidewalk)

Following the installation of the device, the following questions were added.

4. Did you or have you previously noticed the flashing lights at the crosswalk? (yes/no)
5. Have the lights been effective in changing your driving habits at the crosswalk?(yes/no)
6. Do you rely on the lights to indicate that there is a pedestrian in the crosswalk?(yes/no)

### **Pedestrian Reaction Surveys**

At the study location in the City of Petaluma, which has the automatic activation and a fairly constant stream of pedestrians, the following pedestrian surveys were conducted.

- Pedestrian Profile Study - The actions of pedestrians were recorded including number of times they looked at the oncoming traffic and the action of drivers.
- Pedestrian Interviews - After crossing, pedestrians were asked the following questions.
  1. In terms of your level of safety, do you feel comfortable crossing at this location?
  2. Were you aware of the flashing lights in the pavement?
  3. (If yes) Do you rely upon the lights to cause the driver to stop and give you the right of way?
- Pedestrian Entry/Magnet Study - The number and location of pedestrians crossings in the crosswalk or within approximately 400 feet of the crosswalk were recorded.

At one of the test sites in Kirkland, which has the manual push-button activation, video recordings were taken to determine the extent of use of the push-buttons.

### **Long Term Impact Surveys**

In order to demonstrate the long term impact of the system, data was also collected at one of the original Santa Rosa test sites, two years after installation.

## Description of Test Sites

---

The initial test sites in Santa Rosa were typical suburban arterials with traffic volumes near 15,000 ADT (average daily traffic) and a posted speed limit of 35 mph. Two of the sites were school crossings while the third site provided access between a commercial district and a park. The current sites which represent a wide variety of functions, traffic volumes, pedestrian usage, prevailing speed, street geometrics and adjacent land use, consisted of the following locations.

- Main Street / Laurel Street in Fort Bragg, Mendocino County
- Mt. Diablo Boulevard / Lafayette Park Hotel in Lafayette, Contra Costa County
- Pleasant Hill Road / Condit Road in Lafayette
- Main Street / Hazel Street in Willits, Mendocino County
- Petaluma Boulevard South / Putnam Plaza in Petaluma, Sonoma County
- Summerfield Road / Howarth Park in Santa Rosa, Sonoma County
- Sunset Boulevard/Sunset Plaza in West Hollywood
- Sunset Boulevard/Wetherly in West Hollywood
- Sunset Boulevard/Alta Loma in West Hollywood
- Altarinda Drive at JFK University in Orinda, Contra Costa County
- Central Way/3rd Avenue in Kirkland, Washington
- Northeast 124th Street/Community Center in Kirkland, Washington

Besides vehicular speeds and traffic volume, pedestrian crossing conditions are affected by many other site characteristics. Table 2 lists the site characteristics which affect the pedestrian crosswalk conditions at each of the test sites.

Main Street/Laurel Street in the City of Fort Bragg, is a four-way intersection on State Highway 1. The setting is in the downtown area between the main shopping district and the Skunk Train Depot. There is a slight vertical curve on Main Street, south of Laurel Street, which impacts view of the crosswalk in the northbound direction. The approach speed averages near 25 mph. This study location is shown in Figure 3.

Mt. Diablo Boulevard/Lafayette Park Hotel in Lafayette (Lafayette #1), is a mid-block crosswalk which provides access between the Lafayette Park Hotel and street parking along the north side of Mt. Diablo Boulevard. The parking along the north side of the street is primarily used by employees of the hotel, restaurant patrons and special event guests. Besides the parking, there are not other pedestrian attractions on the north side of Mt. Diablo Boulevard as it is immediately adjacent to a freeway. There is a slight vertical curve east of the crosswalk which impacts view of the crosswalk in the westbound direction. The approach speed averages near 38 mph. Photos of the site are shown in Figure 4.

Pleasant Hill Road/Condit Road in Lafayette (Lafayette #2), is a T intersection which provides access between a residential neighborhood and a route to school and regional recreational trail. There are no fronting land uses or sidewalks along this section of Pleasant Hill Road, and the street has significant landscaping along both sides. The intersection is approximately 2,000 feet south of an interchange. Average speeds on Pleasant Hill Road typically exceed 45 mph. There is no street lighting near the intersection. The site is shown in Figure 5.

Petaluma Boulevard South/Putnam Plaza in Petaluma, is a midblock crosswalk in the heart of the historic Petaluma downtown. The crosswalk provides access between riverfront parking, a small plaza and pedestrian access to a parallel street. There are signalized intersections at either side of the block in which the crosswalk is located and parking is allowed along both sides of the street. The midblock crosswalk also features curb extensions on both sides of the crosswalk and advance limit lines with "Stop Here for Ped" signs. Average

**Table 2A**  
**Site Geometric and Operational Characteristics which Affect Pedestrian Crossings**

Site Characteristics	Fort Bragg		Lafayette #1		Lafayette #2		Petaluma		Willits	
	NB	SB	EB	WB	NB	SB	NB	SB	NB	SB
Intersection Type	4-leg		mid-block		tee		mid-block		tee	
Lane Geometrics	2	1	2	2	2	2	2	2	2	2
Prevailing Vehicle Speeds	25	25	40	35	46	46	22	22	35	35
Main Street Daily Traffic Volume	25,000		17,000		19,000		16,000		22,000	
Type of Traffic	Local/Tourist		Local		Local/Regional		Local/Shopping		Local/Regional	
Median	No		No		Yes		No		No	
Pavement Type	Asphalt		Asphalt		Asphalt		Asphalt		Asphalt	
Vertical Curve	Yes	No	Yes	Yes	No	Yes	No	No	No	No
Horizontal Curve	No	No	No	No	No	No	No	No	No	Yes
Upstream/Downstream Impedance	Signal	None	No	No	No	Signal	Signal	Signal	No	Signal
Crosswalk Striping	Standard White		White/Zebra		White/Zebra		White/Zebra		Standard Yellow	
Additional Pedestrian Signage	None	None	None	None	None	None	Yes*	Yes*	None	None
Additional Pavement Markings	None	None	None	None	None	None	Yes*	Yes*	None	None
Street Lighting	Yes		Yes		No	Yes	Yes		Yes	
Parking Allowed	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	Yes
Curb Return Radius	5-10 feet		None		25-30 feet		None		10-15 feet	
Curb Extension	No	No	No	No	No	No	Yes	Yes	No	No
Sidewalks	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes
Shoulder Width	n/a	n/a	n/a	n/a	8 ft.	8ft.	n/a	n/a	n/a	n/a
Landscaping	None	None	Some	None	Significant		Trees	Trees	None	Significant
Adjacent Land Use	Com'l	Com'l	Hotel	None	None	None	Com'l	Com'l	Com'l	Hospital
Building Proximity	b/s	b/s	100 ft.	None	None	None	b/s	b/s	40 ft.	40 ft.
Daytime Pedestrian Activity	significant		minimal		minimal		significant		moderate	
Nighttime Pedestrian Activity	moderate		minimal		none		moderate		minimal	
Community Type/Population	rural/6,300		suburban/24,000		suburban/24,000		suburban/47,000		rural/5,000	

n/a = not applicable b/s = back of sidewalk

\* = advance limit line and "Stop Here for Ped" sign

**Table 2B - Site Geometric and Operational Characteristics which Affect Pedestrian Crossings**

Site Characteristics	W. Hollywood Sunset Plaza		W. Hollywood Wetherly		W. Hollywood Alta Loma		Orinda		Kirkland Central/3rd		Kirkland 124th	
	EB	WB	EB	WB	EB	WB	EB	WB	EB	WB	EB	WB
Intersection Type	midblock		tee		tee		mid-block		tee		midblock	
Lane Geometrics	2	2	2	2	2	2	1	1	2	2	2	2
Prevailing Vehicle Speeds	35	35	35	35	45	35	25	35	35	35	40	40
Main Street Daily Traffic Volume	55,000		55,000		55,000		8,000		20,000		21,000	
Type of Traffic	Local/Regional		Local/Regional		Local/Regional		Local/College		Local/Regional		Local/Regional	
Median	Yes		No		No		No		Yes		Yes	
Pavement Type	Concrete		Concrete		Concrete		Asphalt		Asphalt		Asphalt	
Vertical Curve	Yes	No	No	No	No	No	Yes	Yes	No	No	No	Yes
Horizontal Curve	Yes	No	No	No	No	No	No	Yes	No	No	No	No
Upstream/Downstream	Signal	Signal	Signal	Signal	No	Signal	No	No	Signal		No	No
Crosswalk Striping	White/Zebra		White/Zebra		White/Zebra		Standard White		White Ladder		White Ladder	
Additional Pedestrian Signage	None	None	None	None	None	None	None	None	Yes	Yes	Yes	Yes
Additional Pavement Markings	None	None	None	None	None	None	None	None	None	None	None	None
Street Lighting	Yes		Yes		Yes		Yes		Yes		Yes	
Parking Allowed	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No
Curb Return Radius	None		10-15 feet		10-15 feet		None		25-30 feet		None	
Curb Extension	No	No	No	No	No	No	No	No	No	No	No	No
Sidewalks	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Shoulder Width	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	6 ft.	n/a	6 ft.	6 ft.
Landscaping	None	None	None	None	None	None	Trees	Trees	Trees	None	Trees	Trees
Adjacent Land Use	Com'l	Com'l	Com'l	Com'l	Office	Com'l	School	Church	Park	Com'l	None	Park
Building Proximity	b/s	b/s	b/s	b/s	b/s	100 ft.	50 ft	b/s	None	50 ft.	None	None
Daytime Pedestrian Activity	significant		moderate		significant		minimal		moderate		moderate	
Nighttime Pedestrian Activity	significant		significant		minimal		moderate		minimal		minimal	
Community Type/Population	urban/LA Basin		urban/LA Basin		urban/LA Basin		suburban/30,000		suburban/44,000		suburban/44,000	

n/a = not applicable b/s = back of sidewalk \* = advance limit line and "Stop Here for Ped" sign

speeds were typically less than 25 mph. Site photos are included in Figure 6.

Main Street/Hazel Street in Willits, is a T intersection on U.S. 101, south of the intersection with State Route 20. The setting is strip highway commercial uses and the area hospital. There is a horizontal curve on U.S. 101/Main Street, north of Hazel Street, which slightly impacts view of the intersection in the southbound direction. Parking is allowed along both sides of the street, however, it is not frequently used. Average approach speeds were near 35mph. Site characteristics are shown in the photos in Figure 7.

Sunset Boulevard/Sunset Plaza in West Hollywood, is a mid-block crosswalk which provides access across Sunset Boulevard in shopping and restaurant district. Sunset Boulevard is four lanes with average speeds near 30 to 35 mph and an average daily volume of 55,000. There is parking on both sides of the street and a horizontal and vertical curve just west of the crosswalk which impacts view of the crosswalk in the eastbound direction. Photos of the site are shown in Figure 8.

Sunset Boulevard/Wetherly in West Hollywood, is a T intersection in a commercial district near a popular nightclub, Billboard Live. Sunset Boulevard is four lanes with average speeds near 30 to 35 mph and an average daily volume of 55,000. There is parking on both sides of the street and a traffic signal within 500 feet to the east. Photos of the site are shown in Figure 9.

Sunset Boulevard/Alta Loma in West Hollywood, is a T intersection is a mixed commercial/office district adjacent to a major employer. Sunset Boulevard is four lanes with average speeds near 30 to 35 mph and an average daily volume of 55,000. There is parking on both sides of the street and a loading zone on the south side of the street near the office building which often impacts the driver's view of pedestrians waiting to cross. Photos of the site are shown in Figure 10.

Summerfield Road/Howarth Park in Santa Rosa, was one of the original three test sites. This site was surveyed to demonstrate the long term effectiveness of the warning system. This location is a midblock crosswalk between strip commercial uses including a movie theater and a City Park with lighted baseball fields and lighted tennis courts.

Altarinda Drive at JFK University in Orinda is a midblock crosswalk on a two-lane collector street which serves JFK University and median to low density residential development. The crosswalk provides access between the small business college which caters to evening students, a parking area and a church. There are no stop signs or traffic signals within 1,000 feet or more of the crossing. There is a moderate vertical curve along the street which impacts view of the crosswalk in the eastbound direction. The approach speed averages about 25 mph in the eastbound (uphill) direction and 35 mph in the westbound (downhill) direction. Average daily traffic volumes on the street are near 8,000 vehicles per day. Photos of the site are shown in Figure 11.

Central Way/3rd Avenue in Kirkland is a T intersection east of the downtown Kirkland area. Central Way is a four-lane primary arterial providing access between I-405 and the Kirkland downtown and Lake Washington waterfront. The crosswalk provides access between a residential neighborhood and Peter Kirk Park, which includes tennis courts, baseball facilities and the library. The approach speeds averages about 35 mph. Photos of the site are shown in Figure 12.

Northeast 124th Street/Community Center in Kirkland is a midblock crosswalk on 124th in the north Kirkland area. Northeast 124th Street is a four-lane arterial which provides access between I-405 and 100 Avenue Northeast, a primary north-south arterial. The crosswalk provides access between a residential neighborhood and the North Kirkland Community Center. Average approach speeds were near 40 mph. Photos of the site are shown in Figure 13.

Considering the site characteristics, the Petaluma site is the most conducive to pedestrian crossing conditions

and has the most pedestrian activity. Because of its downtown setting, Fort Bragg has moderately acceptable pedestrian crossing conditions and does have moderate pedestrian traffic. The sites in Willits, Lafayette and Orinda tend to have site conditions which do not make pedestrian crossings desirable. In addition, these three sites have very infrequent pedestrian crossings. Kirkland is a very pedestrian conscience community with many sites which enhanced pedestrian signage. The three sites in West Hollywood have frequent pedestrian crossings, but drivers tend not to yield to the pedestrian even though many know that the pedestrian is there.

Each of the individual cities participating in the study have selected these sites for application of the In-Pavement Flashing Lights Crosswalk Warning System. All of the test locations have existing marked crosswalks. The city of Lafayette did add a new crosswalk at one site and moved a crosswalk at the other site prior to the initiation of this evaluation. With these changes in Lafayette, no before conditions data was collected until these modifications were in place for at least two months. This study did not evaluate whether or not these marked crosswalks were warranted or appropriate. That question was left to each of the cities. The focus of this analysis was to determine if the In-Pavement Flashing Lights Crosswalk Warning System was effective in enhancing the drivers' awareness of pedestrians at crosswalks under a variety of conditions.

The California Office of Traffic Safety funded the overall study and analysis of the study locations in Fort Bragg, Lafayette and Willits. The Federal Highway Administration funded the analysis of the sites in Petaluma, Orinda and Kirkland through the University of North Carolina Highway Safety Research Center



Looking North



Looking South



Figure 3

*In-Pavement Flashing Lights Crosswalk Warning System Evaluation*

Whitlock & Weinberger Transportation Inc.

Main Street/Laurel Street

City of Fort Bragg





Looking East



Looking West



Figure 4 Mt. Diablo Boulevard/Lafayette Park Hotel  
In-Pavement Flashing Lights Crosswalk Warning System Evaluation

Whitlock & Weinberger Transportation Inc.

City of Lafayette



Looking North



Looking South



Figure 5

Pleasant Hill Road/Condit Road

*In-Pavement Flashing Lights Crosswalk Warning System Evaluation*

Whitlock & Weinberger Transportation Inc.

City of Lafayette

XWKIPIC.DRW 4/98



Looking North



Looking South



Figure 6 Petaluma Boulevard South/Putnam Plaza  
In-Pavement Flashing Lights Crosswalk Warning System Evaluation

Whitlock & Weinberger Transportation Inc.

City of Petaluma

XWK1PIC.DRW 4/98





Looking North



Looking North



Figure 7

*In-Pavement Flashing Lights Crosswalk Warning System Evaluation*

Whitlock & Weinberger Transportation Inc.

Main Street/Hazel Street

City of Willits



Looking West



Looking East



**Figure 8** **Sunset Boulevard/Sunset Plaza**  
*In-Pavement Flashing Lights Crosswalk Warning System Evaluation*  
 Whitlock & Weinberger Transportation Inc. City of West Hollywood





Looking West



Looking East



Figure 9

*In-Pavement Flashing Lights Crosswalk Warning System Evaluation*

Whitlock & Weinberger Transportation Inc.

Sunset Boulevard/Wetherly

City of West Hollywood



Looking West (from crosswalk)



Looking East



Figure 10

Sunset Boulevard/Alta Loma

*In-Pavement Flashing Lights Crosswalk Warning System Evaluation*

Whitlock & Weinberger Transportation Inc.

City of West Hollywood





Looking East



Looking West



Figure 11

Altarinda Drive/JFK University  
In-Pavement Flashing Lights Crosswalk Warning System Evaluation

Whitlock & Weinberger Transportation Inc.

City of Orinda





Looking East



Looking West



Figure 12 Central Way/3rd Avenue  
In-Pavement Flashing Lights Crosswalk Warning System Evaluation

Whitlock & Weinberger Transportation Inc.

City of Kirkland

XWK2PIC.DRW 4/98



Looking East



Looking West



Figure 13 Northeast 124th Street/Community Center  
*In-Pavement Flashing Lights Crosswalk Warning System Evaluation*

Whitlock & Weinberger Transportation Inc.

City of Kirkland

## **Results of Data Analysis**

---

The most critical factors obtained in the behavioral/conflict sampling was the percentage of drivers that yielded to the pedestrian and the advance distance at which brakes were applied. These two factors seemed to be the most critical in terms of determining whether the experimental system enhances crossing conditions for the pedestrian. The results of these two factors under both before and after conditions for the twelve study locations are shown in Figures 14 through 25. The driver interviews provide results which are largely anecdotal, but are pertinent to the question of whether the system gains the driver's attention. A summary of the driver interviews is included in Table 3. Approach speeds (from 500 to 300 in advance of the crosswalk) and travel time (from 500 to 100 feet in advance of the crosswalk) which indicate vehicle deceleration, are also discussed below in the summary of each site. The raw data for before and after conditions is contained in Appendix B. The data results and tables comparing before and after conditions are contained in Appendix C.

### Main Street/Laurel Street in Fort Bragg

Existing pedestrian crossing conditions were initially less than desirable with less than 50 percent of the drivers during the day and less than 20 percent of the drivers during the evening yielding to the pedestrian at the four-way intersection on State Highway 1 in the City of Fort Bragg. As shown by Figure 14 and Table 3, the addition of the crosswalk warning system has consistently enhanced the driver's awareness of pedestrians and has modified driving habits to be more favorable for pedestrians. In both directions under both daytime and evening conditions, the distance at which brakes were applied has increased and the percentage of drivers that yielded to the pedestrian has increased to a level near 90 percent. The most dramatic changes occurred in the evening, with an increase of drivers yielding to the pedestrian from 20 percent to 90 percent and braking distance increasing from 90 feet to 250 feet from the crosswalk.

There were no significant changes in approach speeds at the intersection. Before the device was installed, average speeds were near 25 mph for both daytime and nighttime conditions. After the warning system was installed, speeds were near 24 mph for both daytime and nighttime conditions. There were slight changes in travel time between 500 and 100 feet in advance of the crosswalk ( less distance for northbound ) which was measured as an indication of the deceleration changes of the approaching vehicles. Before the device was installed, travel time averaged 9.7 seconds for daytime and 8.2 seconds for nighttime conditions. After the warning system was installed, travel time increased to 11.3 seconds for both daytime and nighttime conditions. Both of these speed and deceleration factors indicate that the warning system has had a positive effect in gaining the attention of drivers.

### Mt. Diablo Boulevard/Lafayette Park Hotel in Lafayette

The midblock crosswalk of a four-lane arterial street in front of the Lafayette Park Hotel in the City of Lafayette started as a very poor pedestrian crossing location with almost no drivers yielding to the pedestrian. As shown by Figure 15 and Table 3, the addition of the crosswalk warning system has increased the drivers' awareness of the crosswalk and pedestrians and has modified driving habits to be more favorable to pedestrians. In both directions under both evening and daytime conditions, the percentage of drivers that yielded to the pedestrian has increased. However, with less than 30 percent of the drivers now yielding to the pedestrians during the day, this location continues to have very poor crossing conditions for the pedestrian even with the addition of the lights. This situation is generally caused by the speed of traffic, which exceeds the posted 35 mph limit and the presence of the freeway right of way on one side of the street, which leads to the driver not expecting a pedestrian crossing.

There were no significant changes in approach speeds at the intersection. Before the device was installed, average speeds were near 38 mph for daytime and 37 mph for nighttime conditions. After the warning system was installed, average speeds were virtually unchanged for both daytime and nighttime conditions. Travel

time between 500 and 100 feet in advance of the crosswalk also did not change significantly. Before the device was installed, travel time averaged 7.3 seconds for daytime and 7.5 seconds for nighttime conditions. After the warning system was installed, travel time averaged near 7.4 seconds for both daytime and nighttime conditions.

#### Pleasant Hill Road/Condit Road in Lafayette

As shown by Figure 16 and Table 3, for this crosswalk of a four-lane 45 mph suburban arterial at a T intersection in the City of Lafayette, the addition of the experimental system has increased the drivers' awareness of the crosswalk and pedestrians. In both directions under both daytime and evening conditions, the distance at which brakes were applied has increased and the percentage of drivers that yielded to the pedestrian has increased. Before the installation, almost no drivers yielded to the pedestrian. The percentage of drivers yielding to the pedestrians has generally increased to almost 40 percent, but this level is still not desirable for comfortable pedestrian crossing conditions. This situation is caused by the general inability of the driver to stop safely for the pedestrian due to high speeds and platooning of vehicles, the community's attitude toward pedestrians, and the general absence of pedestrians during most of the day and night. The inability of drivers to stop safely is particularly a problem in the southbound direction where there is a vertical curve which limits the distance at which the driver can see the crosswalk.

There was a slight decrease in nighttime approach speeds at the intersection. Before the device was installed, average speeds were near 44 mph for daytime and 48 mph for nighttime conditions. After the warning system was installed, average speeds were virtually unchanged for daytime conditions and decreased to approximately 44 mph for nighttime conditions. Travel time between 500 and 100 feet in advance of the crosswalk also did not change significantly. Before the device was installed, travel time averaged 6.4 seconds for daytime and 6.0 seconds for nighttime conditions. After the warning system was installed, travel time averaged near 6.5 seconds for daytime conditions and 6.9 for nighttime conditions.

#### Petaluma Blvd South/Putnam Plaza in Petaluma

This midblock crosswalk of a four-lane arterial street in the historic downtown setting in the City of Petaluma started with 60 to 70 percent of the drivers yielding to the pedestrian, which is a minimal desirable level. As shown by Figure 17 and Table 3, the addition of the crosswalk warning system has increased the drivers' awareness of the crosswalk and pedestrians. In both directions under both daytime and evening conditions, the distance at which brakes were applied has increased and the percentage of drivers that yielded to the pedestrian has increased to a level between 80 and 90 percent. This location seems to be a prototypical site for use of the experimental system. Drivers are traveling at a speed which allows them to stop safely and they expect the presence of pedestrians since this is a downtown setting.

There were no significant changes in approach speeds at the intersection. Before the device was installed, speeds averaged about 22 mph for both daytime and nighttime conditions. After the warning system was installed, speeds remained near 22 mph for both daytime and nighttime conditions. There were no significant changes in travel time between 250 and 50 feet in advance to the crosswalk. Before the device was installed, travel time averaged 7.2 seconds for daytime and nighttime conditions. After the warning system was installed, average travel time remained near 7.1 seconds for both daytime and nighttime conditions.

Pedestrian reaction surveys were also collected at the downtown Petaluma test location under before and after conditions. An analysis of the resulting data showed that:

- The number of pedestrians crossing in the crosswalk did not substantially change with the addition of the lights.
- The locations that the pedestrians entered the street did not substantially change with the addition of

the lights.

- The number of times that a pedestrian looked at oncoming traffic while crossing did not substantially change with the addition of the lights.
- Of those interviewed, 80 percent were aware of the flashing lights.
- Of the 80 percent who were aware of the lights, 23 percent said they relied on the lights to cause the driver to stop and give them the right of way.

#### Main Street/Hazel Street in Willits

Pedestrian crossing conditions were initially generally poor with less than 40 percent of the drivers yielding to the pedestrian at the four lane crossing at a T intersection on a State Highway in the City of Willits. As shown by Figure 18 and Table 3, the addition of the crosswalk warning system has consistently enhanced the awareness drivers have of pedestrians and has modified driving habits to be more favorable for pedestrian crossing conditions. In both directions under both daytime and evening conditions, the distance at which brakes were applied has increased and the percentage of drivers that yielded to the pedestrian has increased to a level near 65 percent, which is a minimal desirable level for the pedestrian. Even though the speed limit of 35 mph was the same as at Mt. Diablo Boulevard/Lafayette Park Hotel in Lafayette, this location seems to be a much more appropriate installation site due to the adjacent land use pattern which leads to drivers expecting pedestrian crossings and their ability to safely stop for the pedestrian.

There was a slight decrease in nighttime approach speeds at the intersection. Before the device was installed, average speeds were near 35 mph for daytime and 34 mph for nighttime conditions. After the warning system was installed, average speeds were virtually unchanged for daytime conditions and decreased slightly to approximately 32 mph for nighttime conditions. Travel time between 500 and 100 feet in advance of the crosswalk also did not change significantly. Before the device was installed, travel time averaged 8.1 seconds for daytime and nighttime conditions. After the warning system was installed, travel time averaged near 8.4 seconds for daytime conditions and 9.1 for nighttime conditions.

#### Summerfield Road at Howarth Park

This midblock crosswalk located on a four lane arterial was one of the first installations of the Experimental System in 1995. The device has been in operation for over two years. Recent data was collected and compared with earlier before and after data which was collected in 1995. Also, since no nighttime data was previously collected, new vehicle reaction data was collected at night under conditions both with and without the lights activated.

As shown in Figure 19, the daytime vehicle reaction characteristics have improved over conditions before the device was installed, but have degraded slightly from when the data was collected within one month of the device installation. This decrease in reaction characteristics may be attributed to the following issues:

- The brightness of the initial prototype units, which was of a different construction method than the current prototype, has degraded over the last two years.
- Drivers may have become more accustomed to the presence of the lights.
- The staged pedestrian's actions during the data collection process have been modified since the initial testing. In order to address the safety of the staged pedestrian, their actions are now less obtrusive on the approaching vehicle than in 1995.

The nighttime data shown in Figure 19 displays that the device is still extremely effective in enhancing the drivers' awareness of the presence of a pedestrian during evening hours. It should be noted that even though

the brightness of the initial prototype units has degraded, they are still very visible at night.

Between 1984 and 1994, in the segment of Summerfield Drive which includes the subject crosswalk, there was only one reported accident involving a pedestrian. For the two years since the installation of the device in 1995, there have not been any accidents involving a pedestrian on this section of Summerfield Road.

#### Sunset Boulevard/Sunset Plaza in West Hollywood

As shown by Figure 20, the midblock crosswalk of Sunset Boulevard at Sunset Plaza has very poor pedestrian crossing conditions. Approximately ten percent of the drivers yield to pedestrians during the day and almost no pedestrian yield at night. The system is expected to be installed during Summer 1998. Comparison with after conditions will follow on the next update of the report.

#### Sunset Boulevard/Wetherly

As shown by Figure 21, the T intersection at Sunset Boulevard/Wetherly has very poor pedestrian crossing conditions. Approximately ten to fifteen percent of the drivers yield to pedestrians during the day and almost no pedestrian yield at night. The system is expected to be installed during Summer 1998. Comparison with after conditions will follow on the next update of the report.

#### Sunset Boulevard/Alta Loma

As shown by Figure 22, the T intersection at Sunset Boulevard/Alta Loma has very poor pedestrian crossing conditions. Approximately ten to fifteen percent of the drivers yield to pedestrians during the day and almost no pedestrian yield at night. The system is expected to be installed during Summer 1998. Comparison with after conditions will follow on the next update of the report.

#### Altarinda Drive/JFK University in Orinda

Before the warning system was installed, approximately 15 to 20 percent of all drivers yielded to the pedestrian. This is a level that is generally not desirable for comfortable pedestrian crossing conditions. As shown in Figure 23, after the system was installed, during the day, the percentage of drivers yielding to the pedestrian increased from 16 to 38 percent in the eastbound direction (uphill) while the downhill westbound direction decreased from 19 to 7 percent. During dusk conditions, the percentage of drivers yielding to the pedestrian increased from 16 to 42 percent in the eastbound direction and 15 to 21 percent in the westbound direction. Braking distance increased slightly in the westbound direction under both day and dusk lighting conditions while decreasing slightly in the eastbound direction (uphill)

There was no substantial change to either the approach speed or travel time measurements. The results at this site were the least consistent of all the other sites. This may be due to the grade on the street which results in restricted sight distance of the crosswalk in the uphill eastbound direction and faster speeds not conducive to abrupt stops in the downhill westbound direction. Many drivers in the downhill direction who did not stop were observed acknowledging the presence of the staged pedestrian either through a nod, smile or wave of the hand. The volume of traffic is only about 8,000 vehicles per day, which allows for many acceptable gaps for the pedestrian, and may have resulted in an understanding that it's too difficult for downhill drivers to come to an abrupt stop.

#### Central Way/3rd Avenue in Kirkland

In the "before" analysis, approximately 60 percent of the drivers were yielding to the pedestrian during the day, which is a minimal desirable level. In the evenings, pedestrian crossing conditions were less than desirable with approximately 15 to 25 percent of the drivers yielding to the pedestrian. As shown by Figure

24, the addition of the crosswalk warning system has increased the drivers' awareness of the crosswalk and pedestrians. In both directions, under both daytime and evening conditions, the distance at which brakes were applied has increased and the percentage of drivers that yielded to the pedestrian has increased to a level over 90 percent. The most dramatic changes occurred in the evening, with an increase of drivers yielding to the pedestrian from 20 percent to 95 percent and braking distance increasing from 145 feet to 250 feet from the crosswalk.

There were no significant changes in daytime approach speeds at the intersection. Before the device was installed, average speeds averaged 35 mph. After the warning system was installed, approach speeds decreased to 32 mph. During nighttime conditions, there was an increase in approach speeds recorded from 31.5 mph, before the system was installed, to 37.1 mph, after installation. However, total travel time in the study zone remained about the same even with the increase in approach speeds. In general, both the speed and deceleration factors indicate that the warning system has had a positive effect in gaining the attention of drivers.

This study location has manual push-button activation only. Video recordings were taken to determine the extent of use of the push-buttons by pedestrians. An analysis of the resulting data showed that:

- Over a two day period, 200 crossings were recorded consisting of 291 pedestrians or 1.45 pedestrians per crossing.
- Of the 200 crossings recorded, 66 crossings or 33 percent of the crossings used the push button to activate the lights.

#### Northeast 124th Street/Community Center in Kirkland

Existing pedestrian crossing conditions were initially at a minimal desirable level with approximately 50 percent of the drivers during the day and 60 percent of the drivers during the evening yielding to the pedestrian at the midblock crosswalk near the community center. As shown by Figure 25, the addition of the crosswalk warning system enhanced the driver's awareness of pedestrians and has modified driving habits to be more favorable for pedestrians. In both directions under both daytime and evening conditions, the distance at which brakes were applied has increased and the percentage of drivers that yielded to the pedestrian has increased to a level near 90 percent. At other locations, the change during the evening has typically been more dramatic than during the day. However, at this location, the change was similar to the daytime conditions. This may be due to the fact that this pedestrian crossing area on Northeast 124th Street had better lighting conditions than any other site evaluated.

There were both increases and decreases in vehicle approach speeds recorded at the site following installation of the warning system. There were very slight increases in travel time between 500 and 100 feet in advance of the crosswalk, which was measured as an indication of the deceleration changes of the approaching vehicles. Both of these speed and deceleration factors do not necessarily indicate any particular change in driving habits with the addition of the warning system. However, the reactions and braking distance have indicated that the system has had a positive effect in gaining the attention of drivers.



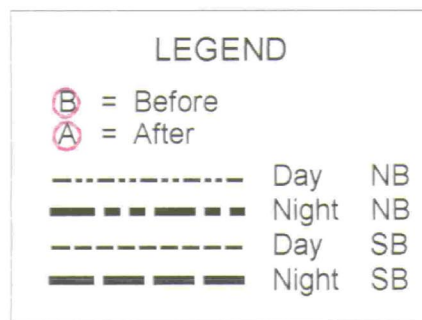
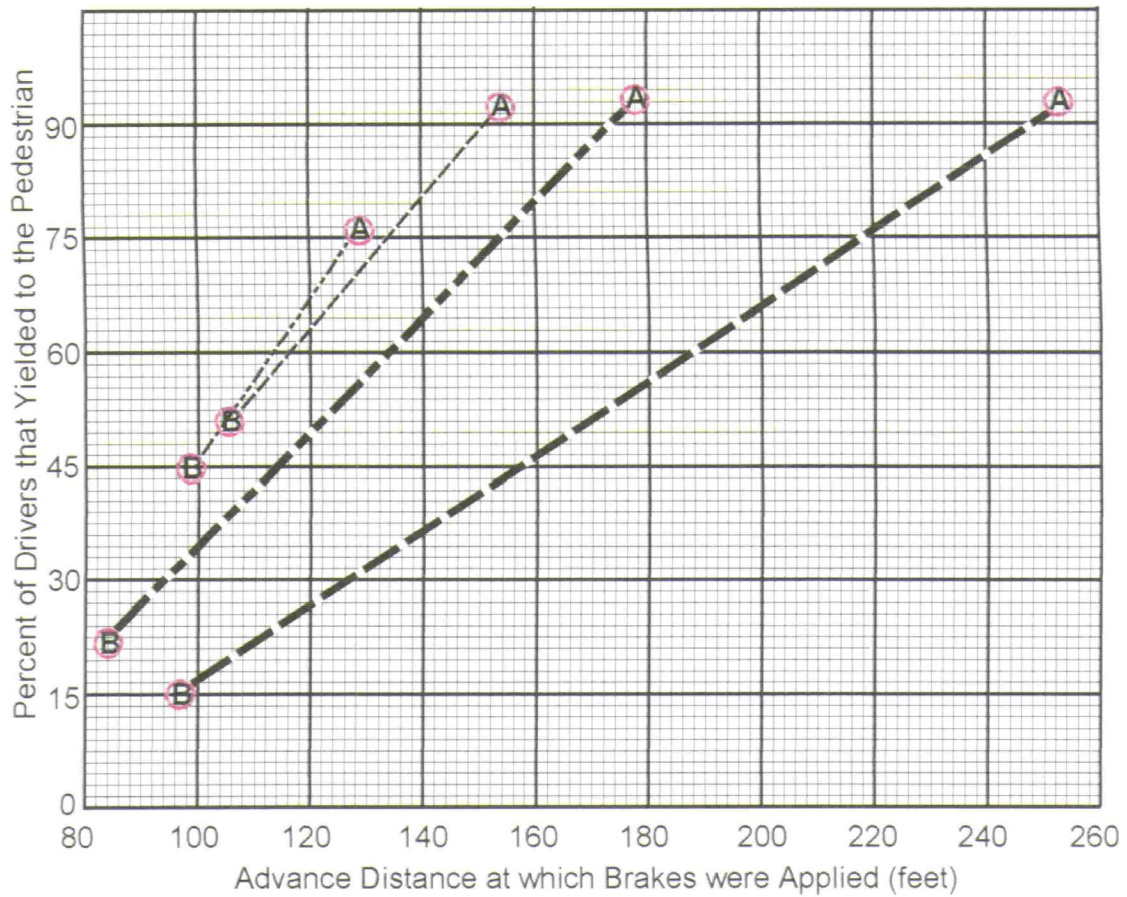
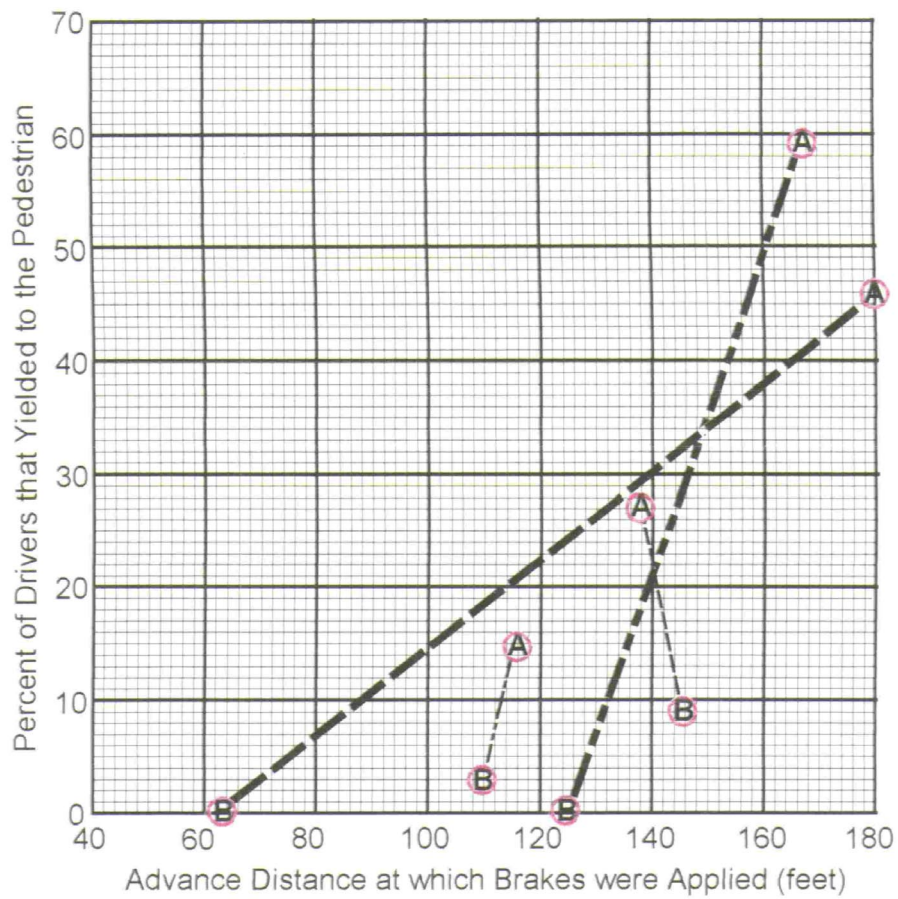


Figure 14 Data Comparison - Main Street/Laurel Street  
*In-Pavement Flashing Lights Crosswalk Warning System Evaluation*  
 Whitlock & Weinberger Transportation Inc. City of Fort Bragg





#### LEGEND

(B) = Before

(A) = After

-----	Day	EB
-----	Night	EB
-----	Day	WB
-----	Night	WB



Figure 15 Data Comparison - Mt. Diablo Blvd/Lafayette Park Hotel  
In-Pavement Flashing Lights Crosswalk Warning System Evaluation

Whitlock & Weinberger Transportation Inc.

City of Lafayette

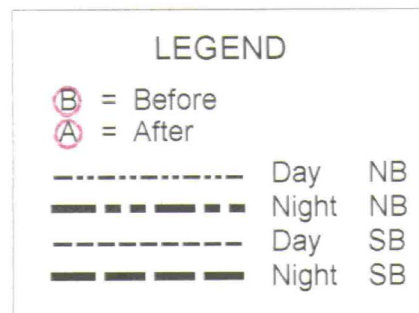
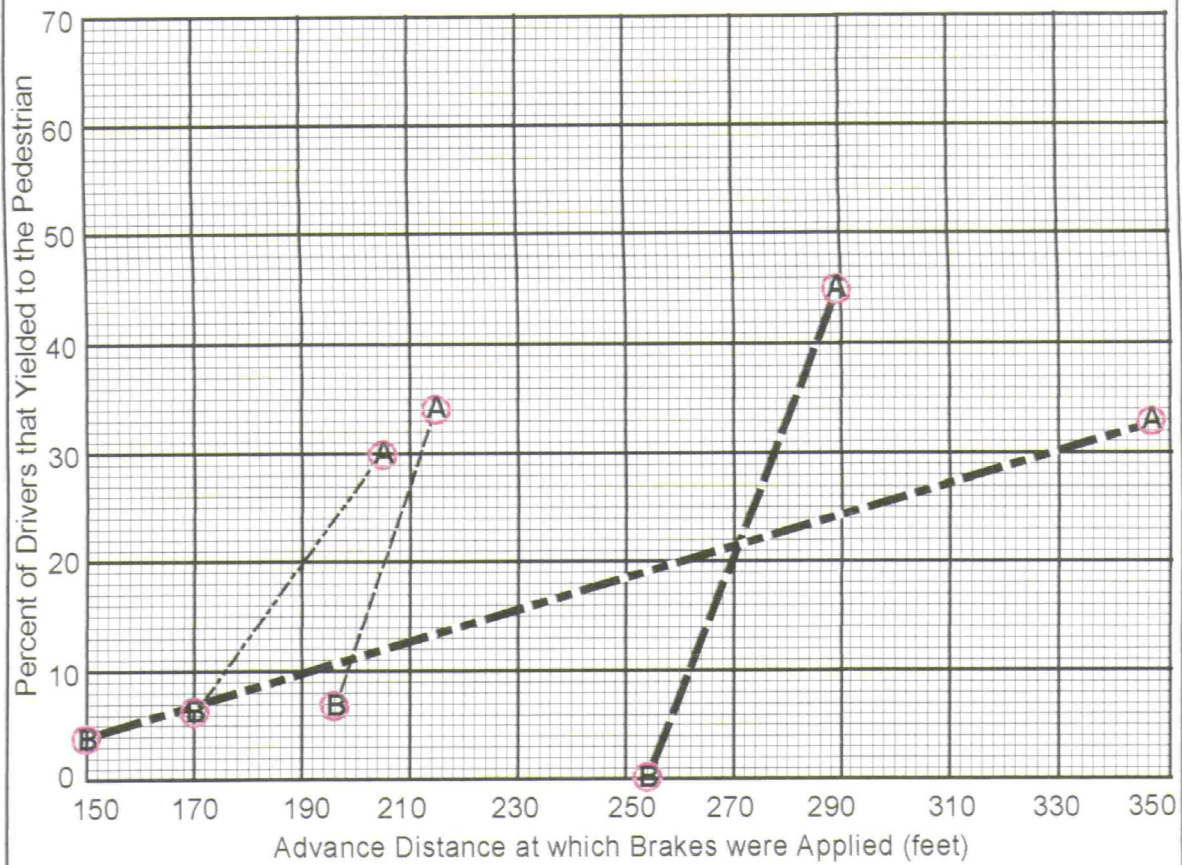


Figure 16 Data Comparison - Pleasant Hill Road/Condit Road  
In-Pavement Flashing Lights Crosswalk Warning System Evaluation  
Whitlock & Weinberger Transportation Inc. City of Lafayette

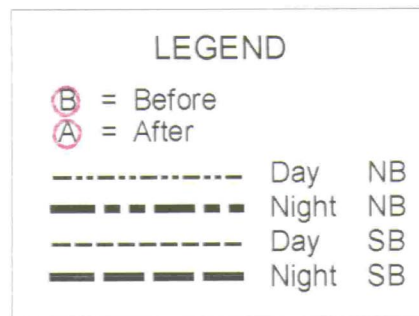
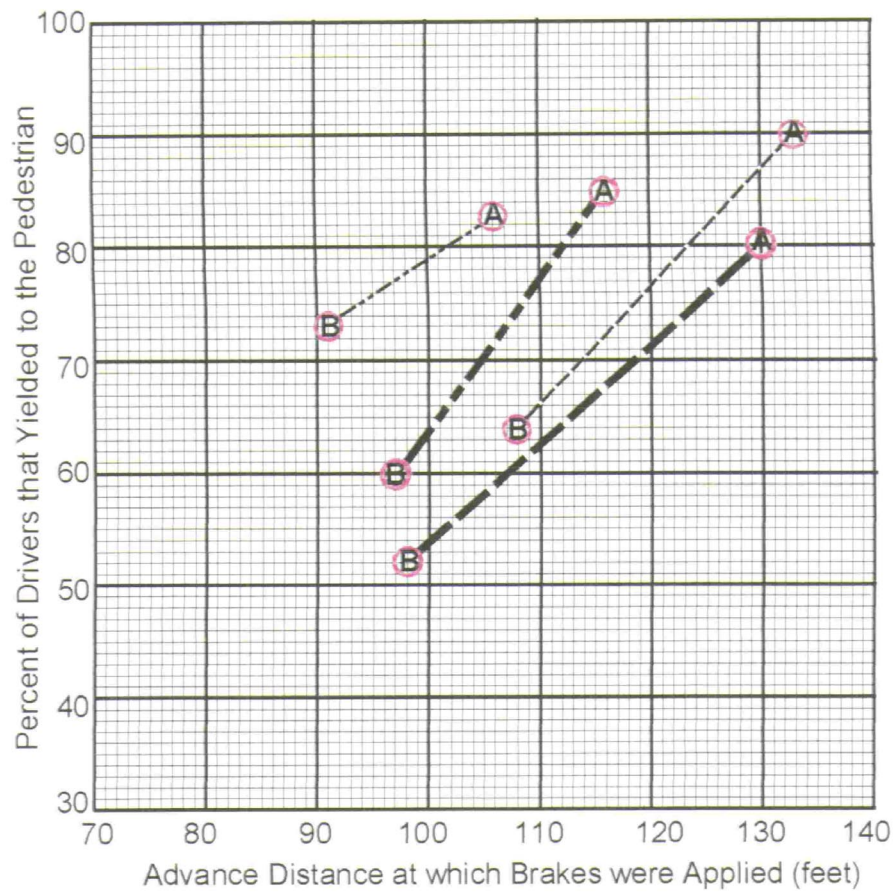


Figure 17 Data Comparison - Petaluma Blvd South/Putnam Plaza  
*In-Pavement Flashing Lights Crosswalk Warning System Evaluation*  
 Whitlock & Weinberger Transportation Inc. City of Petaluma



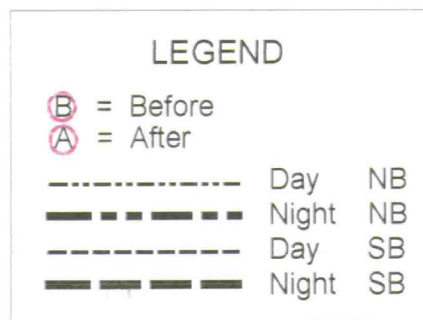
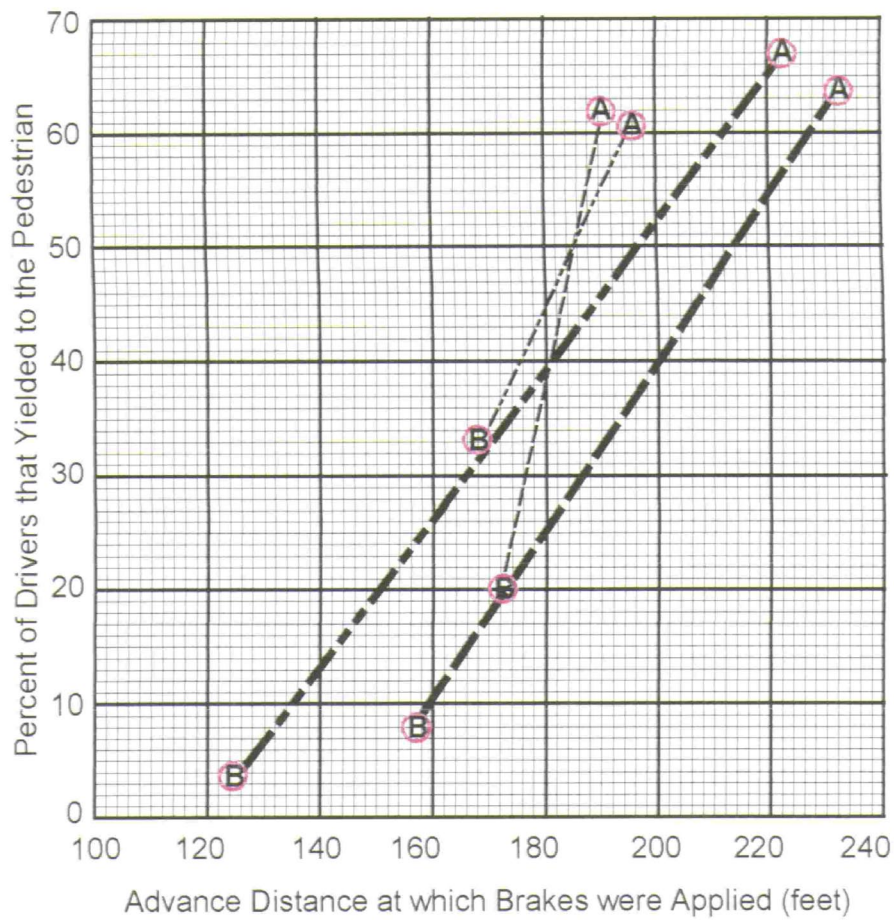


Figure 18 Data Comparison - Main Street/Hazel Street  
In-Pavement Flashing Lights Crosswalk Warning System Evaluation

Whitlock & Weinberger Transportation Inc.

City of Willits

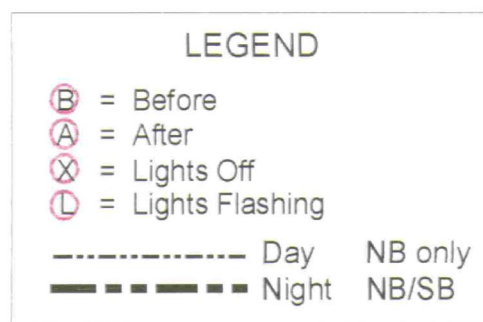
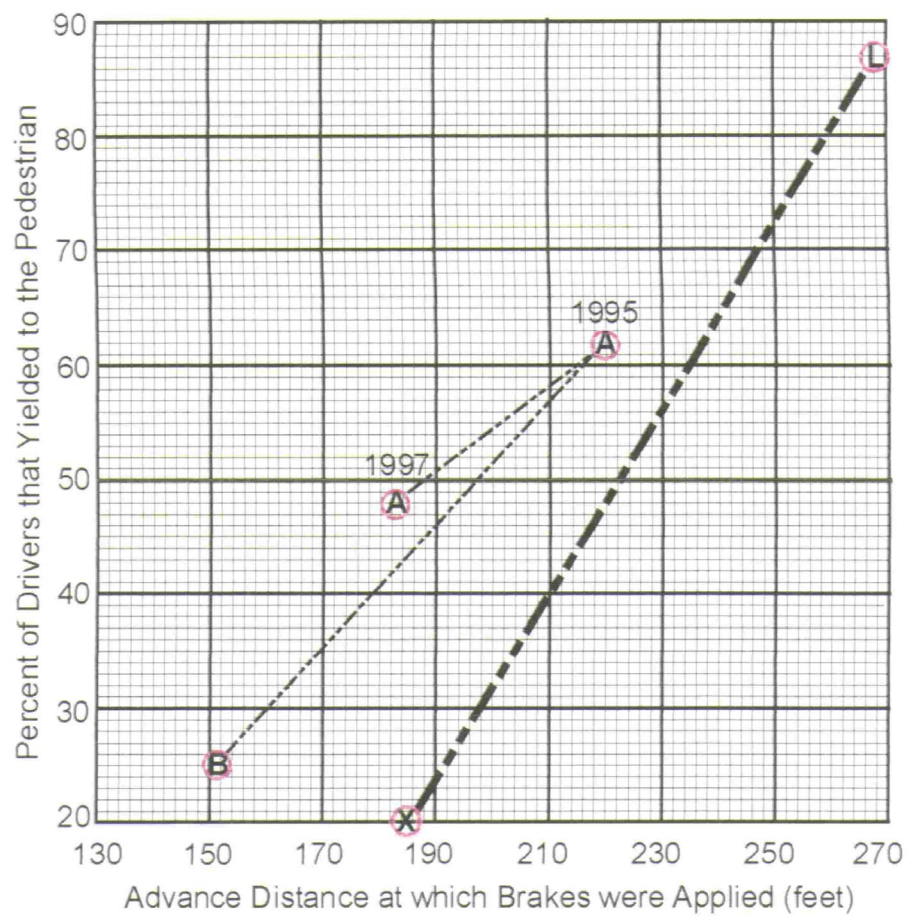


Figure 19 Data Comparison - Summerfield Road/Howarth Park  
In-Pavement Flashing Lights Crosswalk Warning System Evaluation

Whitlock & Weinberger Transportation Inc.

City of Santa Rosa

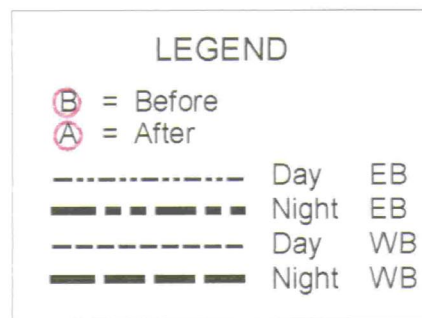
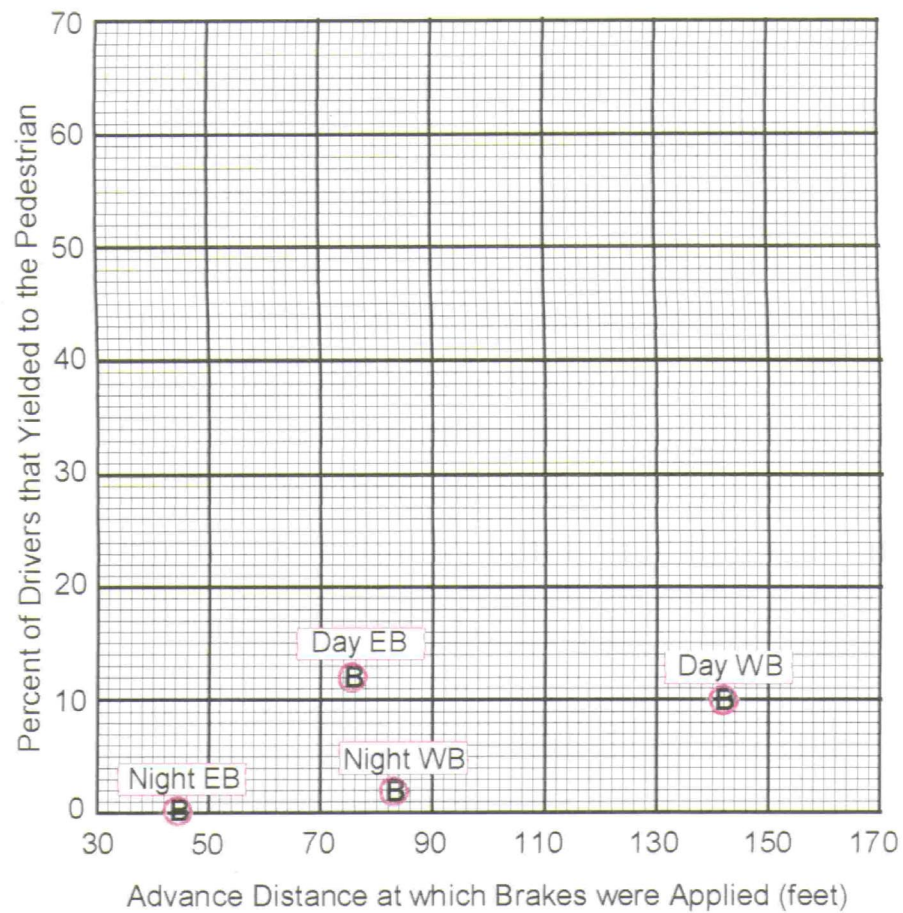
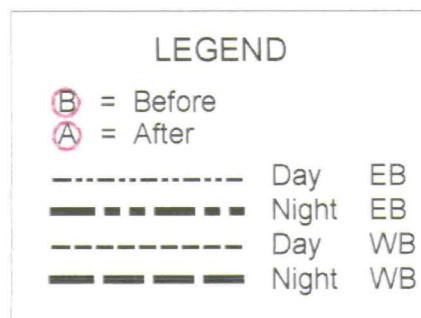
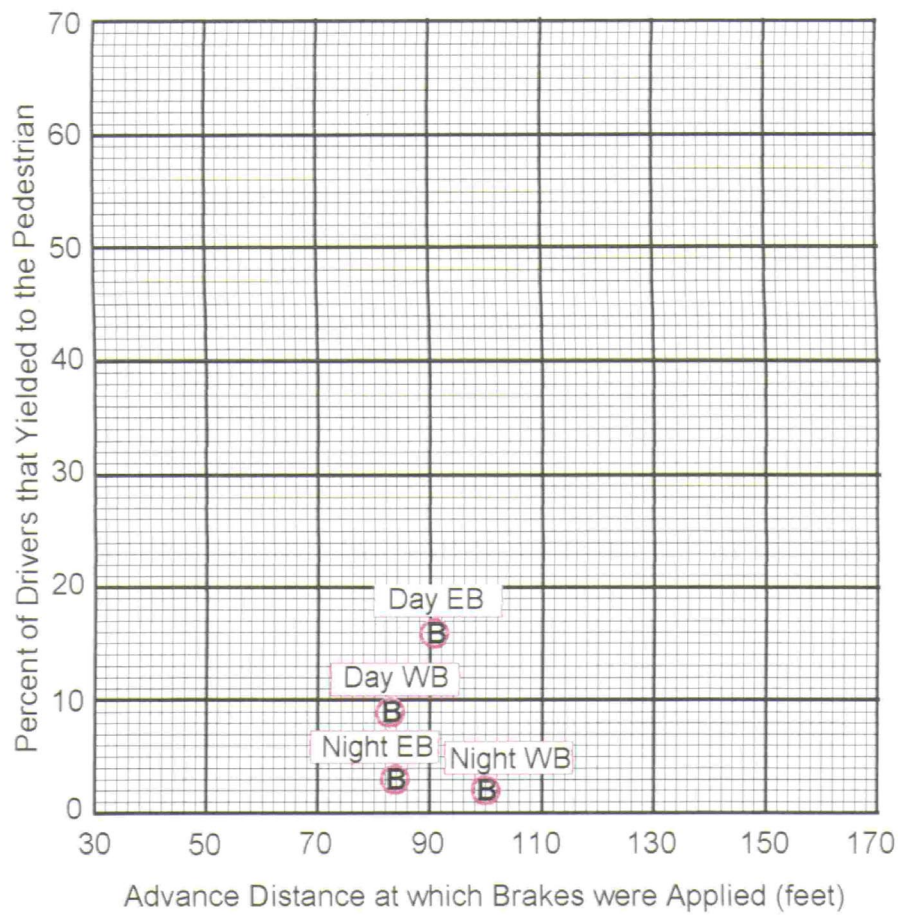


Figure 20 Existing Conditions - Sunset Boulevard/Sunset Plaza  
In-Pavement Flashing Lights Crosswalk Warning System Evaluation

Whitlock & Weinberger Transportation Inc.

City of West Hollywood





**Figure 21** Existing Conditions - Sunset Boulevard/Wetherly  
*In-Pavement Flashing Lights Crosswalk Warning System Evaluation*

Whitlock & Weinberger Transportation Inc.

City of West Hollywood

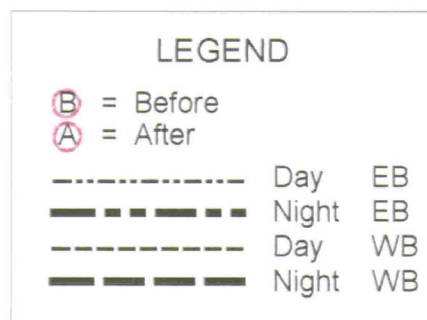
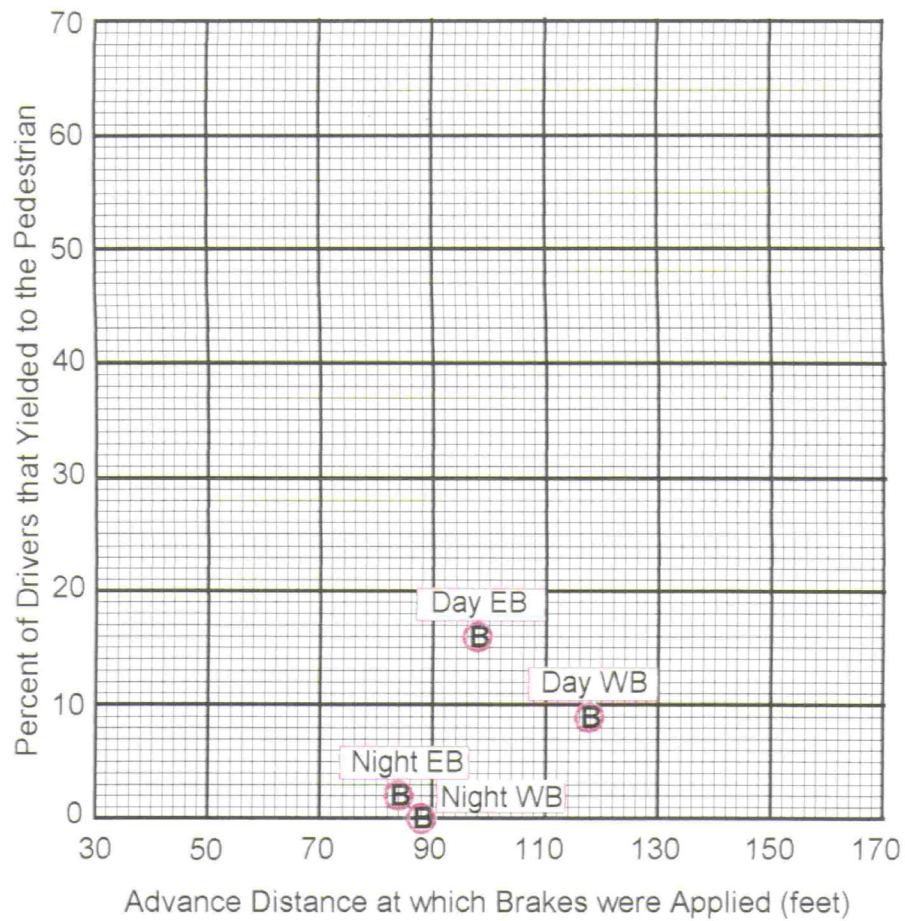
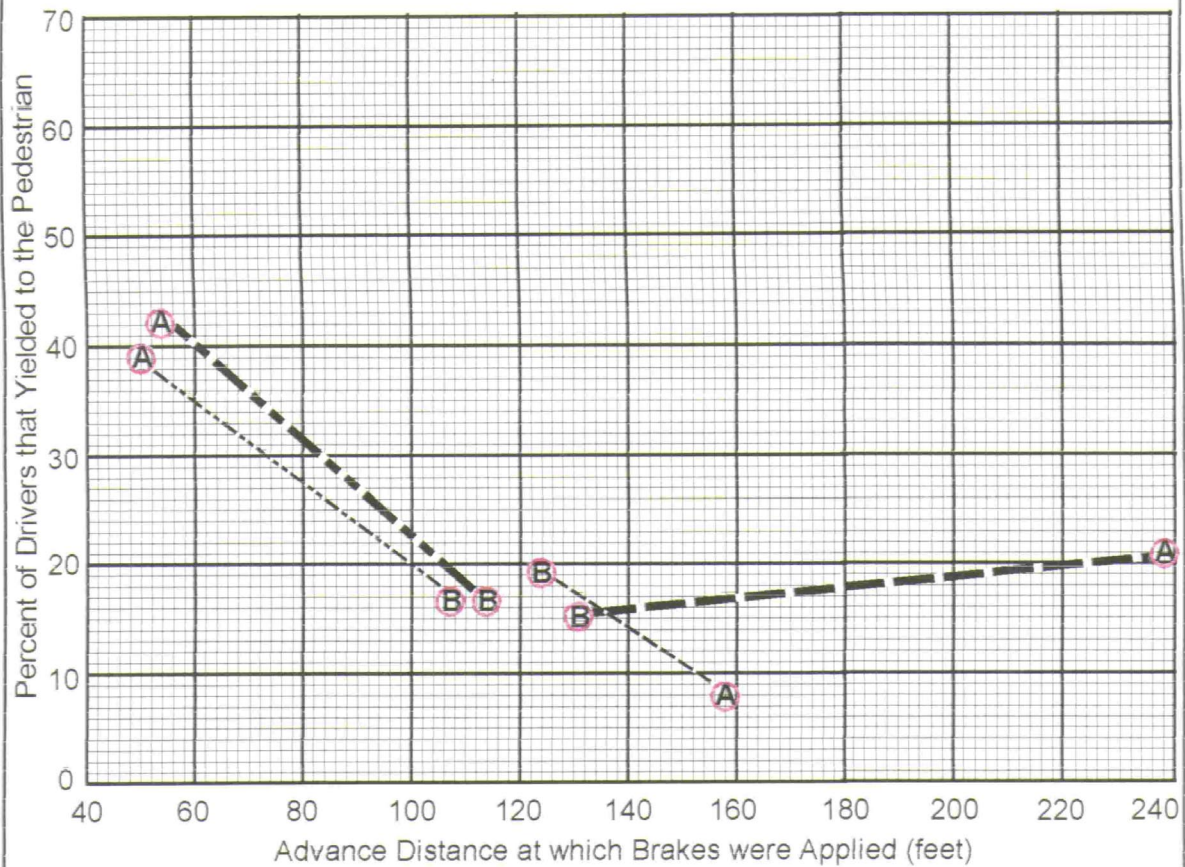


Figure 22 Existing Conditions - Sunset Boulevard/Alta Loma  
*In-Pavement Flashing Lights Crosswalk Warning System Evaluation*  
 Whitlock & Weinberger Transportation Inc. City of West Hollywood





#### LEGEND

(B) = Before

(A) = After

-----	Day	EB
-----	Dusk	EB
-----	Day	WB
-----	Dusk	WB



Figure 23 Data Comparison - Altarinda Drive/JFK University  
In-Pavement Flashing Lights Crosswalk Warning System Evaluation

Whitlock & Weinberger Transportation Inc.

City of Orinda

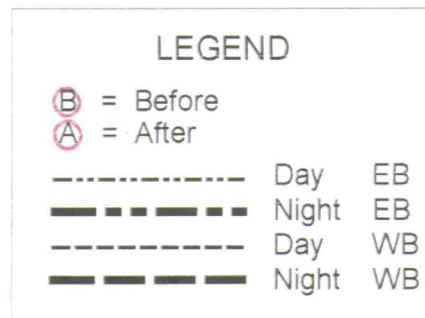
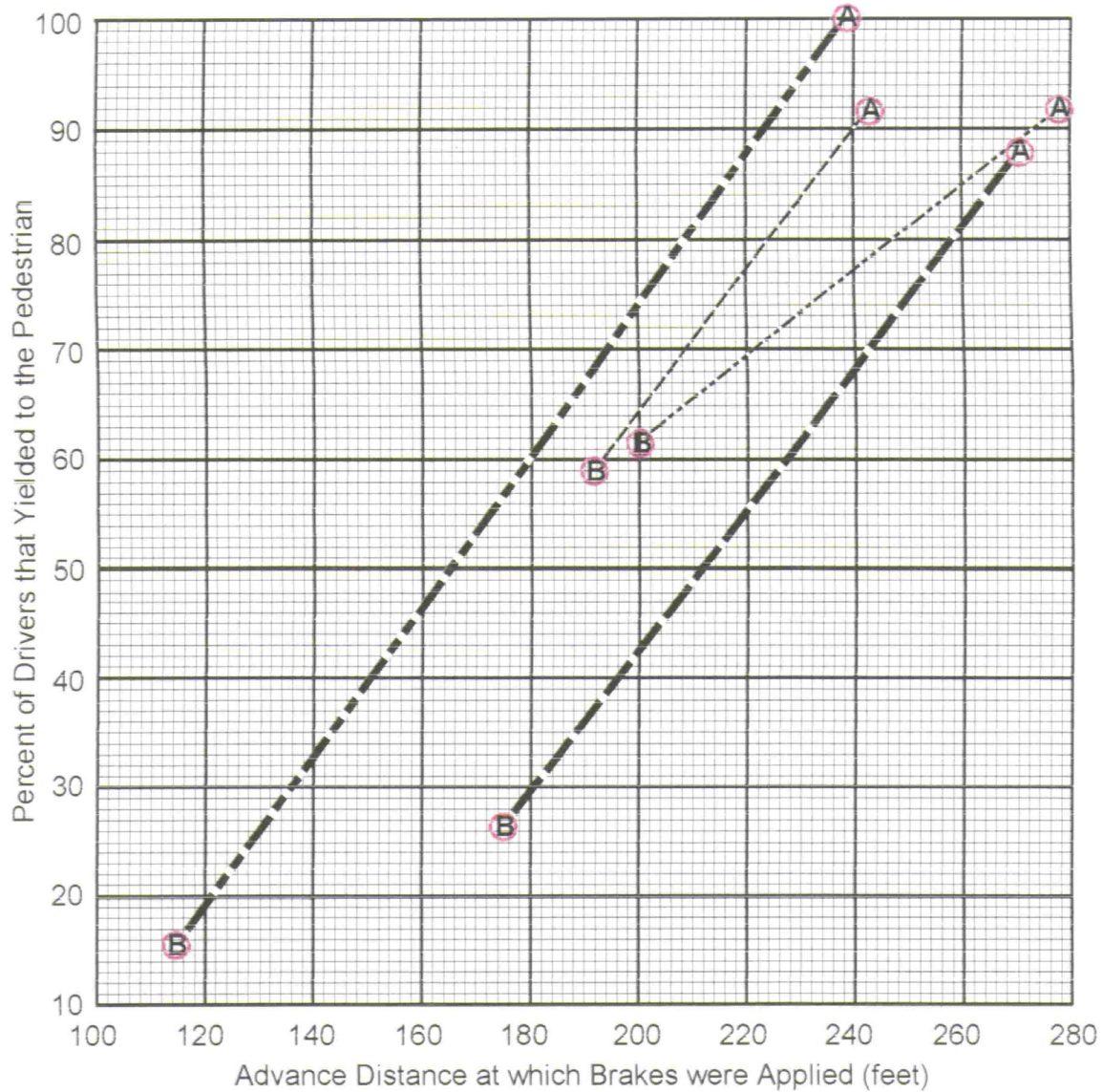


Figure 24 Data Comparison - Central Way/3rd Avenue  
*In-Pavement Flashing Lights Crosswalk Warning System Evaluation*  
 Whitlock & Weinberger Transportation Inc. City of Kirkland



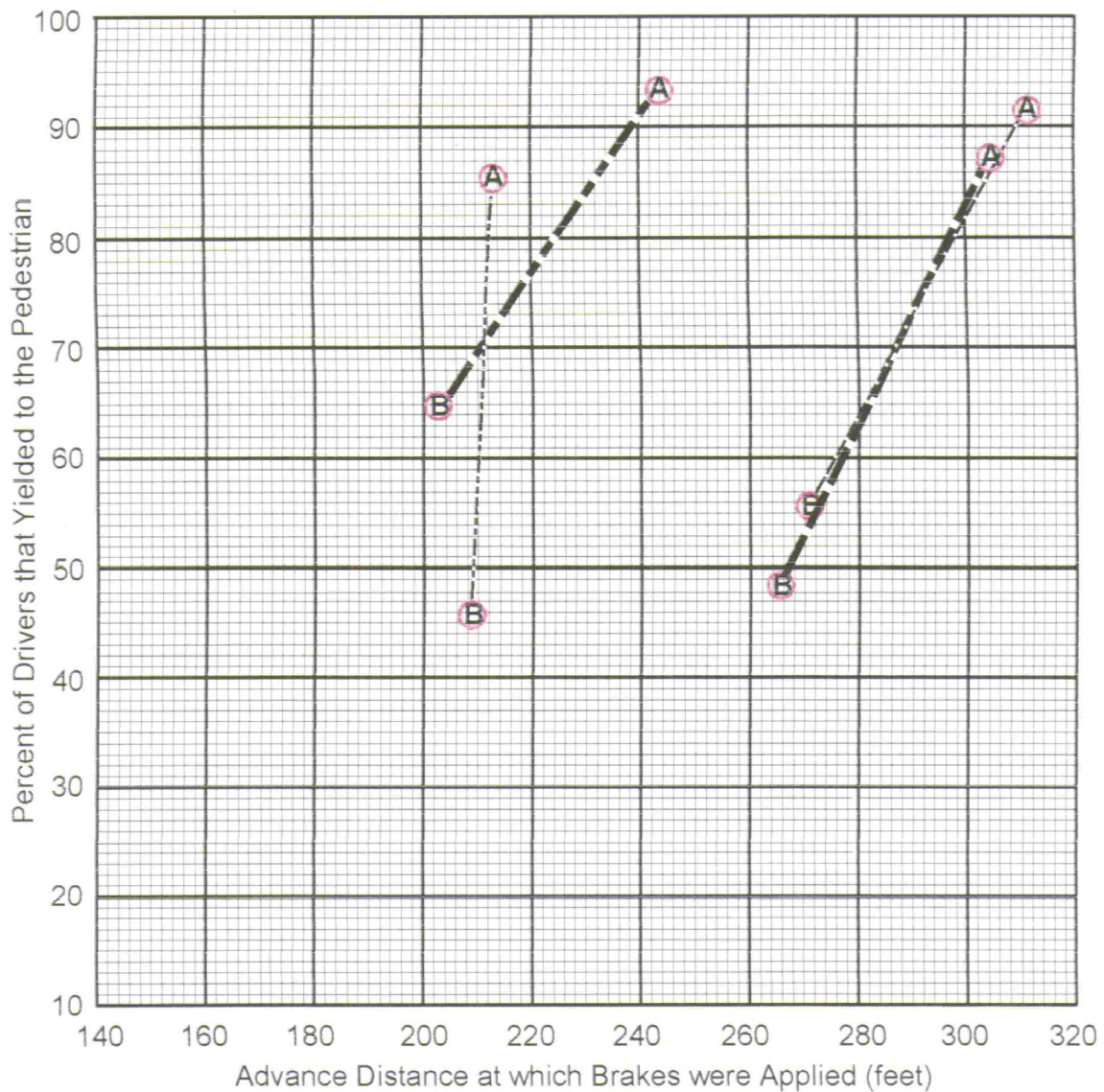


Figure 25 Data Comparison - Northeast 124th Street  
*In-Pavement Flashing Lights Crosswalk Warning System Evaluation*  
 Whitlock & Weinberger Transportation Inc. City of Kirkland

**Table 3**  
**Driver Interview Summary**

	Fort Bragg		Lafayette #1		Lafayette #2		Petaluma		Willits		Average	
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
Percent of drivers that saw crosswalk	93	96	76	89	82	94	88	91	87	94	85	93
Percent of drivers that saw pedestrian	70	94	70	81	71	82	60	70	84	91	71	84
Percent of drivers that stated the position of pedestrian accurately	54	59	38	64	29	51	72	86	56	71	50	66
Percent of drivers that saw lights	n/a	92	n/a	68	n/a	78	n/a	70	n/a	79	n/a	77
Percent of drivers that feel that the lights have changed their driving habits	n/a	56	n/a	81	n/a	72	n/a	50	n/a	52	n/a	62
Percent of drivers that rely on the lights to inform them when a pedestrian is present	n/a	9	n/a	16	n/a	4	n/a	0	n/a	3	n/a	6

Notes:

Before = Before the installation of the Experimental Crosswalk Warning System

After = After the installation of the Experimental Crosswalk Warning System

n/a = not available for this condition (question was not asked)

### Effectiveness

Based on these survey results, the In-Pavement Flashing Lights Crosswalk Warning System has clearly had a positive effect in enhancing a driver's awareness of crosswalks and modifying driving habits to be more favorable to pedestrians. The extent of the effectiveness of the device depends on the specific site and seems to be impacted by the following geometric and operational characteristics.

- weather and lighting conditions
- width of the street and associated number of light installations
- grade change and curvature of the street
- level of traffic enforcement
- community's attitude toward the pedestrian
- speed of the traffic
- amount of pedestrian activity

Based on observation of the device's operation during adverse lighting conditions, it should be noted that the In-Pavement Flashing Lights Crosswalk Warning System has a much more dramatic effect in increasing a driver's awareness of crosswalks during adverse weather conditions such as darkness, fog, and rain.

To be effective, as defined by the *Manual on Uniform Traffic Control Devices*, a traffic control device should meet five basic requirements, as follows.

1. Fulfill a need.
2. Command attention.
3. Convey a clear, simple meaning.
4. Command respect of road users.
5. Give adequate time for proper response.

The In-Pavement Flashing Lights Crosswalk Warning System has met these requirements in the following ways.

Fulfill a need: This warning system was developed due to a specific need in the City of Santa Rosa. The interest by other jurisdictions to be part of this second phase of testing indicates that the concern and associated need were not isolated. The exposure of this concept through the media and professional journals has helped it gain national attention and interest because communities do have need for a cost effective means of addressing pedestrian safety issues at unprotected crosswalks.

Command attention: The results of the data analysis has clearly shown that the use of lights in the pavement activated only when pedestrians are present gains the attention of the driver. The percentage of drivers which yield to the pedestrian has increased significantly at all of the study locations with the addition of the warning system.

Convey a clear, simple meaning: A flashing amber/yellow light used under various applications is intended to warn drivers to act with caution. With the experimental system, the intention is the same. The flashing amber lights placed on the roadway conveys the clear message of caution.

Command respect of road users: Previous studies have shown that continuously flashing beacons at urban crosswalks do not increase driver awareness since these passive applications eventually become part of the background scenery.<sup>5</sup> The experimental warning system commands respect of the road users since it is only activated when a pedestrian is crossing the street.

Give adequate time for proper response: Depending on the roadway alignment, the lights can be viewed from 1,000 to 1,500 feet away from the crosswalk. As long as the devices are being placed so that at least 300 to 400 feet of sight distance is available to the lead vehicle in a platoon, adequate time for driver response is available.

### **Driver Understanding of the Device**

Based upon some of the comments received from drivers, most drivers seem to understand that they should react with some caution by either reducing their speed or applying their brakes. Observation of drivers' reaction two years later at the original Santa Rosa installation revealed a consistent "sweeping" of the drivers head back and forth looking for pedestrians when the lights were activated. There is some confusion by a small percentage of drivers who are unsure of whether they are required to stop when the lights flash. Some other confusion has been caused by malfunctions of the automatic detection system.

### **Pedestrian Understanding of the Device**

The automatic detection system has seemed to result in less confusion for the pedestrian than the push button activation because it does not require them to act in any way other than crossing the street as they would at any other uncontrolled crossing. Based on field observations at the Petaluma test site which has the automatic activation, the pedestrians seem to be continuing to cross the street with the same level of caution as before.

Pedestrians seemed to be more confused with the push button activation system. Some pedestrians were observed to push the button and then look around for some visual indication. Based on field interviews, pedestrians who did not push the button were not aware of the crosswalk warning system.

### **Activation System**

The activation system for this type of warning system is one of the most important features contributing to its effectiveness. Considering the experience at all of the test sites which have included both manual activation (push button) and automatic activation (overhead ultrasonic and overhead video imaging), an automatic detection system seems to be more appropriate than a manual push button activation. This recommendation is based on the following considerations.

- Historically, the pedestrian push button has been used almost exclusively as part of a standard traffic signal installation which includes pedestrian signal heads. Pedestrians who encounter a pedestrian push button without the associated traffic signal equipment are unlikely to expect it and may not understand what it is for. Worse, they may interpret a push button as giving them the right-of-way.
- Since this application is considered a warning system to the driver, no visual indication should be given to the pedestrian.
- The public may perceive the act of pushing a button as a way to cause approaching vehicles to stop.

- Based on field observations of several push button operated overhead crosswalk warning systems in Santa Rosa, California, the frequency with which pedestrians used the push button varied with the volume of traffic. During off peak periods when traffic volumes were lower, approximately one-third of the pedestrians activated the system. During peak periods when traffic volumes required the crossing pedestrian to wait for a gap, the use of the push button increased up to approximately two-thirds of the time.
- An automatic detection system should be less confusing to pedestrians because it does not require them to act in any way other than crossing the street with caution and at their own discretion. It also makes the pedestrian more responsible for their actions and causes less confusion.

It should be noted that the ultrasonic detection system which has been used to date has not performed satisfactorily. In general, the lights have activated 60 to 70 percent of the time when a pedestrian uses the crosswalk. Periodically, a turning vehicle or swaying trees have activated the lights with no pedestrians present. The video imaging detection system which was installed by the City of Petaluma seems to be a superior system but still had occurrences of false and non-activations. A recently demonstrated "bollard gateway system" which utilizes two parallel modulated visible red beams seems to be the most promising technology. When pedestrians break the two beams in succession while walking into the street, the system activates 100 percent of the time. The system does not activate when a pedestrian breaks the beams in the reverse order leaving the street.

### **Physical Durability**

The devices used in the In-Pavement Flashing Lights Crosswalk Warning System for the current test sites, which are a third generation prototype, have been superior to the original prototype in terms of their durability. There have been several instances of devices being damaged due to a street sweeper in Petaluma and logging trucks in Willits. They were replaced. The newest button type design, which has been tested in the field for less than a year, has performed better in terms of durability than the previous design and is more resistant to damage by snowplows and street sweepers, however, there have been instances of damage which required replacement.

### **Comparison with Standard Devices**

An overhead flashing beacon is a standard device which can be used in the application of warning the driver of a pedestrian crosswalk. As indicated above, previous studies have shown that continuously flashing beacons at urban crosswalks do not increase driver awareness since these passive applications eventually become part of the background scenery. Currently, there are other studies underway on the east coast which are evaluating the effectiveness of pedestrian activated, overhead flashing pedestrian signs.

The only way to directly compare the effectiveness of the In-Pavement Flashing Lights Crosswalk Warning System versus an overhead flashing beacon would be to install each at the same location in succession to determine how each impacts driver attention. None of the participating agencies was willing to go to the expense of this endeavor. Therefore, this report focused directly on the potential effectiveness of this experimental system and its merits.

## Findings and Recommendations

---

Based on the experience of the test sites in Fort Bragg, Lafayette, Petaluma, Santa Rosa, Willits, Orinda and Kirkland, the following findings and recommendations are presented. These findings and recommendations may be modified based on future experiences of the system.

### Findings

1. The concept of flashing amber lights embedded in the pavement at uncontrolled crosswalks clearly has a positive effect in enhancing a driver's awareness of crosswalks and modifying driving habits to be more favorable to pedestrians.
2. The In-Pavement Flashing Lights Crosswalk Warning System has a much more significant effect in enhancing a driver's awareness of crosswalks during adverse weather conditions such as darkness, fog, and rain.
3. Over the long term, the affect of the crosswalk warning system will degrade slightly during daytime conditions from initial implementation of the system. However, the resulting long term conditions still represent improved vehicle reaction characteristics compared with conditions before installation.
4. The warning system is expected to be extremely effective over the long term in enhancing driver awareness of the presence of a pedestrian during the hours of darkness.
5. The In-Pavement Flashing Lights Crosswalk Warning System has the potential to be an effective traffic control device since it fulfills a need, commands attention, conveys a clear meaning, commands respect of road users, and gives adequate time for proper response.
6. An automatic detection system is more appropriate than a push button system and can result in less confusion for the pedestrian because it does not require them to act in any way other than crossing the street as they would at any other uncontrolled crossing.
7. The ultrasonic automatic pedestrian detection technology tested in this evaluation was not found to be completely reliable in activating the system. The video imaging technology was superior to the ultrasonic detection, but still had many instances of false and non-activations. A recently demonstrated "bollard gateway system" which utilizes two parallel modulated visible red beams seems to be the most promising technology.
8. It is estimated that pedestrians use a push button in the 30 to 60 percent range for this type of application depending on the volume of traffic. The absence of a pedestrian crossing indication does not generally prompt pedestrians to seek out the push button.
9. The warning system seems to be particularly effective at locations where there is at least a moderate flow of pedestrians ( 100 pedestrian crossing per day ). These locations tend to have site characteristics which lead the driver to expecting pedestrian crossings.
10. At speeds less than 35 mph, drivers seem to be able to respond properly if at least 400 feet of sight distance is provided to the warning system.
11. At speed greater than 40 mph, drivers seem to have difficulty stopping safely if less than 600 feet of sight distance is available prior to the warning lights.
12. The presence of a lighting device at the outer edge of the travel lane may be a hazard to some bicyclists.



13. Each successive prototype of the lighting devices which has been tested has been superior in terms of their physical durability. Further improvements to its durability are still warranted. However, the desires of the market will dictate further physical evolution of the device.

## **Recommendations**

1. Since the concept of flashing amber lights embedded in the pavement at uncontrolled crosswalks clearly has merit in modifying driving habits to be more favorable to pedestrians, further use of this concept should be pursued at appropriate locations.
2. There have been suggestions to have the devices only on the lane lines. This may not be desirable since the device in the center of the lane is the light most visible to drivers in that lane. The current installation pattern should be maintained as a standard. However, the outermost device should be placed to avoid the path of bicyclists to the extent possible.
3. The device should be no higher than 3/4-inch which is the maximum height of a standard lane delineator button.
4. Amber flashing lights seem to be the most appropriate color based on vehicle laws and considering a person's visual capabilities. Therefore the amber lights and size of the lens should be maintained as a standard.
5. In the long run, an automatic pedestrian activation system seems to be more appropriate than a pedestrian push button. This allows the pedestrian to cross with caution and at their own discretion. It also makes the pedestrian more responsible for their actions and causes less confusion. The most promising technology to date has been a "bollard gateway system" which utilizes two parallel modulated visible red beams.
6. If a pedestrian push button is used, the sign which accompanies the button should be yellow and read, "Push Button for Warning Flasher/Cross With Caution" or similar wording. The use of a standard walking man symbol such as is used in the pedestrian head at a traffic signal and which indicates a protected pedestrian crossing, should be avoided.
7. If a pedestrian push button is used with appropriate signage, in order to address ADA (American with Disabilities Act) issues, the installation could be supplemented with a voice box which says, "The warning flashers have been activated - cross with caution," or similar wording.
8. Appropriate street lighting should be considered at crosswalks where the system is applied. Street lighting will allow the pedestrian to be more visible at night and wash out the glow of the lighting devices so they do not distract the pedestrian.
10. Federal standardization through the Manual on Uniform Traffic Control Devices (MUTCD) and consistency with crosswalk laws in states other than California should be investigated. An organization such as the Institute of Transportation Engineers would be an appropriate organization to pursue this course of action.
11. Based on the experience of the initial test sites, it is recommended that the following guidelines be met for installation of the In-Pavement Flashing Lights Crosswalk Warning System. These guidelines may be modified based on future experiences of the system. The development of guidelines will be important in focusing use of the device where it will be most effective and maintaining its effectiveness through limiting the number of locations where it is present.

- The Crosswalk Warning System should be used at uncontrolled crosswalks.
  - Main street average vehicular approach speeds should be 45 mph or less.
  - Main street traffic volumes should be between 5,000 and 30,000 vehicles per day. (It should be noted that the City of West Hollywood will be testing the device on Sunset Boulevard which has 55,000 vehicles per day.)
  - At speeds less than 35 mph, the approaching motorist should have visibility of the lighting devices at least 400 feet in advance of the crosswalk (measured from 3.5-foot eye height of the driver to 1-inch height at the edge of the crosswalk line). At speeds greater than 35 mph, appropriate additional sight distance to the warning lights should be provided.
  - There should be no other crosswalks or traffic control devices at least 250 feet in advance or following the crosswalk location.
  - A minimum pedestrian volume of 100 pedestrians per day is suggested for application of the system.
12. Agencies which install the system should ensure that the public is educated on the proper use of the device by both the driver and the pedestrian.

### Study Participants

#### Whitlock & Weinberger Transportation, Inc.

Project Manager/Engineer:	Stephen J. Weinberger, P.E.
Field Surveys/Data Reduction:	Cheryl Whitlock-Griffin
Report Review:	Dalene J. Whitlock, P.E.
Field Pedestrian:	Christine Bethards

#### California Office of Traffic Safety

Mark Bertacchi, Program Coordinator

#### Public Agency Representatives

Dave Goble, City of Fort Bragg  
Dave Godfrey, City of Kirkland  
Ashley Nguyen, City of Lafayette  
Farzaneh Sanders, City of Lafayette  
Maria Robinson, City of Orinda  
Allan Tilton, City of Petaluma  
Lucy Dyke, City of West Hollywood  
Dave Madrigal, City of Willits

#### Federal Highway Administration's Pedestrian Facilities Program

Charles Zegeer, University of North Carolina Highway Safety Research Center  
Richard Knoblauch, Center for Applied Research

### References

1. *Manual on Uniform Traffic Control Devices*, Federal Highway Administration, 1988
2. *Traffic Manual*, California Department of Transportation
3. *California Vehicle Code*, State of California, 1996
4. *Highway Design Manual*, California Department of Transportation
5. *New Technology for Pedestrian Safety* ( Application #530 for the Innovations in American Government 1997 Awards Program), City of Santa Rosa.
6. *Analysis of an Experimental Pedestrian Crosswalk Device*, Eugene R. Benton, P.E. and Stephen J. Weinberger, P.E., 1995 ITE Conference Compendium of Technical Papers, ITE, 1995
7. *Analysis of an Experimental Pedestrian Crosswalk Device*, Whitlock & Weinberger Transportation, Inc. in association with TJKM, July 1995.
8. *School Zone Flashers- Do they Really Slow Traffic?*; ITE Journal, January 1990; Benjamin E. Burritt, Richard C. Buchanan, and Eric I. Kalivoda
9. *Pedestrian Warning Flashers in an Urban Environment: Do They Help?*; ITE Journal, January 1990; James W. Sparks and Michael J. Cynecki.

## Endnotes

---

- <sup>1</sup> Lighting benefits and specifications provided by David Evans, Hewlett Packard.
- <sup>2</sup> Calibration Report #0012 prepared by Precision Solar Controls which measured luminous intensity values of test devices.
- <sup>3</sup> Source: Dr. T.E. Cohn, School of Optometry, University of California, Berkeley, California.
- <sup>4</sup> Discussions with Charles Zegeer, UNC Highway Safety Research Center; Richard Knoblauch, Center for Applied Research; and Joy Van Houten, Research Associate at the Center for Education and Research in Safety.
- <sup>5</sup> *School Zone Flashers - Do they Really Slow Traffic?*; ITE Journal, January 1990; Benjamin E. Burritt, Richard C. Buchanan, and Eric I. Kalivoda  
*Pedestrian Warning Flashers in an Urban Environment: Do They Help?*; ITE Journal, January 1990; James W. Sparks and Michael J. Cynecki.