REGION II
UNIVERSITY TRANSPORTATION RESEARCH CENTER

Pedestrian Crosswalk Safety: Evaluating In-Pavement, Flashing Warning Lights

FINAL REPORT

Prepared by the
Region 2, University Transportation Research Center

Peter Boyce, Ph.D. and John Van Derlofske, Ph.D.
Lighting Research Center
Rensselaer Polytechnic Institute

March 2002

In cooperation with

New Jersey
Department of Transportation
Bureau of Research
and
U.S. Department of Transportation

Y BUILDING   ROOM 220
THE CITY COLLEGE   NEW YORK NEW YORK 10031   212-650-8050   FAX 212-650-8374
WWW.UTRC2.ORG

DISCLAIMER STATEMENT

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-NJ-2002-015		

4. Title and Subtitle	
Pedestrian Crosswalk Safety: Evaluating In-Pavement, Flashing Warning Lights	5. Report Date March 2002 6. Performing Organization Code
7. Author(s) Peter Boyce, Ph.D. and John Van Derlofske, Ph.D	8. Performing Organization Report No. 75144-07-01
9. Performing Organization Name and Address Region 2, University Transportation Research Center City College of New York New York, NY 10031	10. Work Unit No. 11. Contract or Grant No. 75144-07-01
12. Sponsoring Agency Name and Address University Transportation Research Center, Region 2, (UTRC) City College of NY, NY 10031 Federal Highway Administration U.S. Department of Transportation Washington, D.C.	13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code FHWA-NJ-2002-015

15. Supplementary Notes

16. Abstract

This report describes work undertaken to determine the effect of an in-pavement flashing warning light system installed on a crosswalk on pedestrian safety, relative to striping.

The site for the work described was in Denville, New Jersey. This site was chosen for study for two reasons. First, the site forms part of a pedestrian route between a residential area and an extensive recreational area. Consequently, a significant proportion of the pedestrians are children. Second, vehicles can approach the site from several different directions, making it difficult for a pedestrian to know where to look, and the driver's view of the site is often obstructed by stationary, back-up traffic.

Evaluations were made shortly after the installation of this system, nine months later and one year later. Comparisons of the same crosswalk before and after striping and after installation of the in-pavement flashing warning lights enable the benefits of these actions to be determined.

Recommendations for the future use of in-pavement flashing warning light signals at crosswalks are given.

17. Key Words	18. Distribution Statement
Crosswalks, safety, lighting systems	No Restriction

19. Security Classif (of this report)	20. Security Classif. (of this page)	21. No of Pages	22. Price
Unclassified	Unclassified	41	NA

Form DOT F 1700.7 (8-69)

ACKNOWLEDGMENTS

This project could not have been completed without the contributions of many people. Notable contributions were made by Nancy Ciauffoli, the original NJDOT Research Project Manager, Alex Viale, who organized the experiment on the noticeability of the crosswalks, Xiangwei Fu, Jean Paul Freyssinier, and Chao Ling, who analyzed the video tapes; and Ujjaini Dasgupta and Ramesh Raghavan, who made some of the field observations.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SUMMARY

Accidents involving pedestrians on crosswalks are a common cause of road fatalities. In-pavement flashing warning lights have been proposed as a means of increasing the conspicuity of a crosswalk when a pedestrian is using it. Evaluations in California and Washington have demonstrated the effectiveness of such in-pavement flashing warning lights on moderating drivers' behavior when approaching a crosswalk. However, in-pavement flashing warning light systems are more expensive to install than striping, the conventional way of identifying crosswalks. This report describes work undertaken to determine the effect of an in-pavement flashing warning light system installed on a crosswalk on pedestrian safety, relative to striping.

The site for the work described was in Denville, New Jersey. This site was chosen for study for two reasons. First, the site forms part of a pedestrian route between a residential area and an extensive recreational area. Consequently, a significant proportion of the pedestrians are children. Second, vehicles can approach the site from several different directions, making it difficult for a pedestrian to know where to look, and the driver's view of the site is often obstructed by stationary, back-up traffic.

At the time of the first evaluation, in 1999, there was only one marked crosswalk, delineated by eroded minimal striping. In 2000, another crosswalk was added, both crosswalks were striped and ADA ramps were provided. The second evaluation was then made. In September 2000, the in-pavement warning light system and the associated pedestrian detectors were installed. Evaluations were made shortly after the installation of this system, nine months later and one year later. Comparisons of the same crosswalk before and after striping and after installation of the in-pavement flashing warning lights enable the benefits of these actions to be determined. From the data collected it is concluded that:

- Clear striping of a crosswalk enhances the noticeability of the crosswalk to drivers who are not familiar with the location.
- Clear striping of a crosswalk reduces conflicts between pedestrians and vehicles, a conflict being defined as an occasion when a driver moves over the crosswalk while a pedestrian is on the crosswalk.
- Clear striping of a crosswalk does not reduce the mean speed at which vehicles approach the crosswalk.
- Clear striping of a crosswalk does not reduce the mean number of vehicles passing over the crosswalk while a pedestrian is waiting to cross.
- Adding an in-pavement flashing warning light system to a crosswalk that is already clearly striped enhances the noticeability of the crosswalk to drivers who are not familiar with the location.

- Adding an in-pavement flashing warning light system to a crosswalk that is already clearly striped reduces the mean speed at which vehicles approach the crosswalk.

- Adding an in-pavement flashing warning light system to a crosswalk that is already clearly striped reduces the mean number of vehicles that pass over the crosswalk while a pedestrian is waiting.

- The impact of adding an in-pavement flashing warning light system to a crosswalk that is already clearly striped on the mean speed at which vehicles approach the crosswalk tends to diminish over time.

Recommendations for the future use of in-pavement flashing warning light signals at crosswalks are given.

INTRODUCTION

Accidents involving pedestrians on crosswalks are a common cause of road fatalities[1]. A number of companies are now promoting systems for increasing the conspicuity of a crosswalk when a pedestrian is on it. These systems consist of a series of high-intensity luminaires buried in the pavement on both sides of the crosswalk that direct light along the road towards oncoming traffic [2, 3]. When activated, either by a pedestrian pressing a signal button or by some form of automatic pedestrian detection system, the lamps in the luminaire flash at a set rate for a fixed time. The bright flashing warning lights lining the crosswalk draw driver's attention to the crosswalk making it more likely that drivers will pay attention to what is happening there and act appropriately. Such systems can be integrated with other traffic signal lights if required. The 2000 Millennium edition of the Manual of Uniform Traffic Control Devices contains language that makes the use of in-pavement flashing warning lights at crosswalks acceptable and gives guidance for their application [4].

Previous evaluations of such in-road warning lights have been carried out in the states of California and Washington [5]. The evaluations are based on observations of driver and pedestrian behavior and the opinions of drivers and pedestrians. However, these studies were all before-and-after studies and did not systematically compare the relative effectiveness of the in-pavement warning lights to the conventional approach of striping. As striping is less expensive to install than in-pavement flashing warning light systems, the use of the latter will only be justifiable if it produces a marked improvement in drivers' behavior and fewer conflicts between pedestrians and vehicles than does striping alone.

The objective of this project is to determine the effect of an in-pavement flashing, warning light system installed on a crosswalk on pedestrian safety, relative to striping.

RESEARCH APPROACH

The research approach is a field evaluation of the impact of successive improvements to an existing crosswalk. The evaluation design consists of an escalating series of before-and-after comparisons. The starting point was the crosswalk as it existed in 1999, with only one marked crosswalk delineated by eroded minimal striping. The first evaluation was made in these conditions. In 2000, another crosswalk was added, both crosswalks were striped and ADA ramps were provided. The second evaluation was then made. In September 2000, the in-pavement flashing warning light system and the associated pedestrian detectors were installed. An evaluation was made shortly after the installation of this system. Two further evaluations were made nine months and one year after the installation. Comparison of the same crosswalk before and after the striping and after the installation of the in-pavement flashing warning lights enables the impact of these modifications to be examined.

The evaluation was based on measurements of the behavior of drivers and pedestrians using the crosswalk, opinions of the pedestrians using the crosswalk and the conspicuity of the crosswalk to unwarned drivers. In addition, details of the reliability of the in-road, flashing warning light system over a year of operation were collected.

Evaluation Site

The Department of Transportation of the State of New Jersey identified a site for the evaluation in Denville, New Jersey. Figure 1 shows a plan of the site. The site is adjacent to a major traffic-signal-controlled intersection between US Route 46, a four-lane, divided highway, and Franklin Road, a two-lane road. There are crosswalks across US Route 46 and across Franklin Road but these are linked to the traffic signals via pedestrian operated push-buttons. The actual site of the evaluation is the T-junction between Franklin Road and Savage Road. At this junction, Franklin Road, which forms the stem of the T, has a large median, there being three lanes for travel in a southwesterly direction and one lane for travel in a northeasterly direction. As for Savage Road, which forms the cross of the T, there are two lanes for travel in the northwesterly direction for the part to the southeast of Franklin Road, and one lane each for travel in the southeasterly and northwesterly directions on the part of the road to the northwest of Franklin Road. To the North of Savage Road is Gardner Field, an extensive recreational area containing baseball diamonds, tennis courts, soccer and football fields, and a children's playground. Access to the parking lot of Gardner Field is off Savage Road, just to the west of crosswalk 2. Egress from the parking lot is actually into the junction adjacent to crosswalk 1. To the South of Savage Road, the area between Savage Road and US 46 to the southeast of Franklin Road is open grassland. The area between Savage Road and US 46 to the northwest of Franklin Road is dense scrubland.

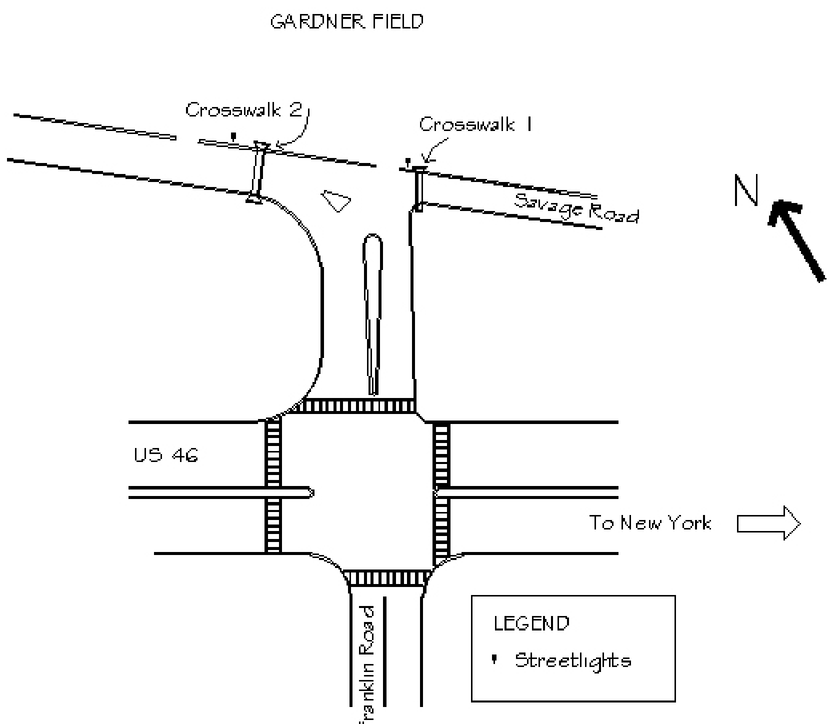

Figure 1. A plan of the evaluation site.

This complicated pattern of lanes means there are six possible routes for drivers to pass through the junction between Franklin Road and Savage Road. They are shown in

Figure 2. A triangular island is placed in the middle of the junction to guide drivers turning from Savage Road into Franklin Road. For pedestrians, the crosswalks being evaluated cross Savage Road from either side of Franklin Road. There is no crosswalk across Franklin Road until the intersection between Franklin Road and US Route 46.

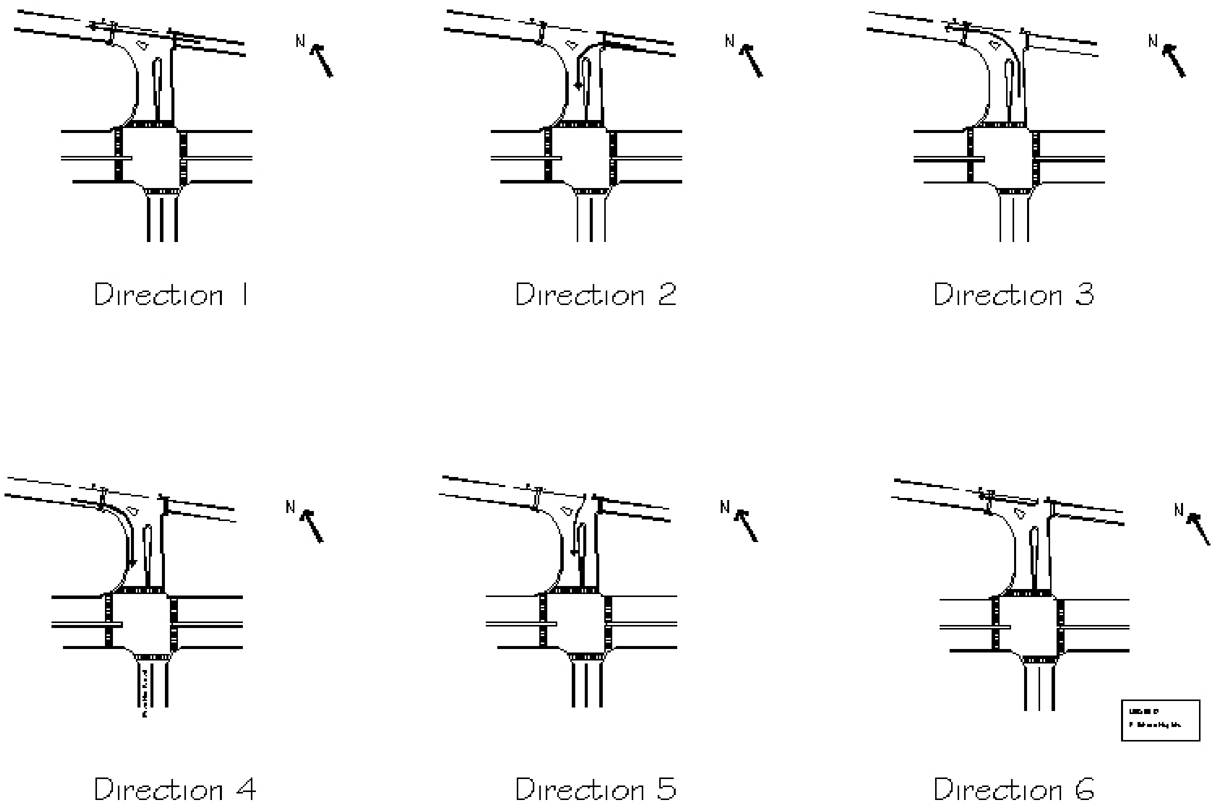

Figure 2. The six directions of traffic flow through the evaluation site.

Throughout the series of evaluations the lighting of the junction of Franklin Road and Savage Road has been provided by two drop-lens cobrahead luminaires, each one containing a 250 W high-pressure sodium discharge lamp (Figure 3). Each luminaire is mounted on an extension arm fixed to a wooden utility pole. The two poles are located close to the two crosswalks.

Figure 3. The cobrahead luminaires used to light the evaluation site at night.

Changes to the crosswalks

<u>Original state of the crosswalk</u>

The first evaluation was made on Saturday, 12th June 1999. At this time, there was only one marked crosswalk at the site, that being crosswalk 2 on the northwest side of the junction of Franklin Road and Savage Road. This crosswalk was linked to a sidewalk on the northwest side of Franklin Road. There was no sidewalk on the southeast side of Franklin Road so there was no marked crosswalk 1 at this point. Figure 4 shows the marking of crosswalk 2 from the sidewalk on Savage Road on the day of the evaluation. It is clear that the original marking of crosswalk 2 consisted of two parallel lines across the road, although by the time of the evaluation, the lines had been badly eroded by traffic.

Figure 4. Crosswalk 2 at the time of the first evaluation.

Striping

The second evaluation took place on Saturday, 13th May 2000. By this time, a sidewalk had been constructed on the southeastern side of Franklin Road and a new crosswalk across Savage Road (crosswalk 1), complete with ADA ramps, had been finished. Both crosswalks had been newly striped in a grating pattern. Specifically, the striping consisted of alternate 2-ft-wide bars of white paint and 2-ft-wide pieces of asphalt, arranged to form a grating pattern, the upper and lower boundaries of the grating being closed by a continuous white paint line of 9" thickness. The overall width of both crosswalks was 7 ft. Figure 5 shows a view of crosswalk 1 at this stage and Figure 6 does the same for crosswalk 2.

Figure 5. Crosswalk 1 at the time of the second evaluation.

Figure 6. Crosswalk 2 at the time of the second evaluation.

The in-pavement flashing warning light installation

The third evaluation took place on Saturday, September 23rd, 2000, one week after the completion of the installation of the in-pavement flashing warning lights. The in-pavement flashing warning lights (Model ZA230) were purchased from Traffic Safety Corporation of Sacramento, California and installed by the New Jersey Department of Transportation. Figure 7 shows a close-up of one of the in-pavement flashing warning light units as installed.

Figure 7. One of the in-pavement flashing warning lights, installed.

The unit was originally designed for use on airport runways. Consequently, it is of rugged construction and designed to be set low enough in the pavement (projecting less than 0.50 inches above grade) that it will not be damaged by snowploughs. The light source used in the unit is a 45 W tungsten halogen lamp. The light output of the unit is predominantly in two directions, through apertures set at 180° to each other. The unit is installed so that these directions are along the main axis of the road. In Denville, only the direction towards approaching traffic emits light (the other direction is sealed). The light distribution from the unit is determined by the clear lens in the aperture of the unit. The effect of the lens is to direct a high luminous intensity beam along the road in the direction of approaching drivers. The color of the flashing warning lights was white. Four ZA 230 units were installed on crosswalk 1 and six units on crosswalk 2, as shown in Figure 8. Figures 9 and 10 show the installations at crosswalks 1 and 2 respectively.

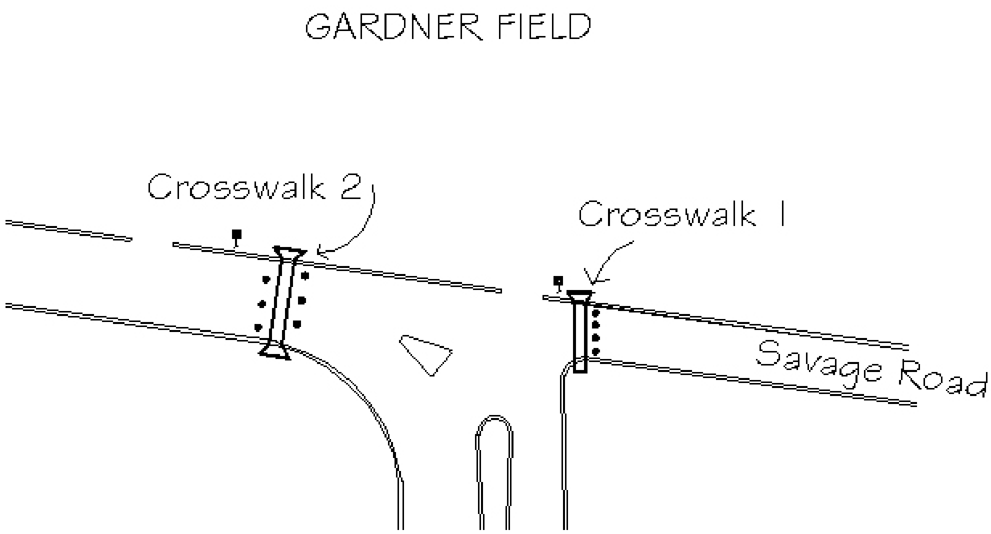

Figure 8. A plan showing the arrangement of the in-pavement flashing warning lights installed on the two crosswalks.

Figure 9. Crosswalk 1 with the in-pavement flashing warning lights installed and operating, at the time of the third evaluation.

Figure 10. Crosswalk 2 with the in-pavement flashing warning lights installed, at the time of the third evaluation.

The activation of the in-pavement flashing warning light units was by four microwave detectors (Model AD1400) also purchased from Traffic Safety Corporation. One of these detectors was mounted on a pole at either end of both crosswalks. Figure 11 shows the location of one of the AD1400 detectors relative to the pedestrian. These devices detect the presence of a pedestrian in the detection area. The pedestrian has to be in the detection area for a minimum time before the flashing warning lights are activated. This time delay from detection to activation is necessary so that pedestrians passing though the detection area but continuing along the sidewalk do not trigger the flashing warning lights. The sensitivity of the detector, the detection area and the delay time are all adjustable on site.

Figure 11. One of the four microwave detectors used to activate the in-pavement flashing warning lights. The detector is in the small box on the pole behind and above the pedestrian.

Evaluation timing

Evaluations were made at the site on five occasions, from approximately 11 a.m. to dusk. Table 1 lists the dates of the evaluations, the status of the crosswalks, and the prevailing weather conditions. With one exception, the evaluations were made on a Saturday. This day was chosen because it was assumed that number and nature of the pedestrians using the crosswalks would be similar on that day through the summer, whereas pedestrian use on other days of the week would vary depending on the school year (The use of Saturday as the evaluation day was abandoned for the last evaluation because experience at the site taught us that the number of genuine pedestrians using the crosswalks during each hour often was insufficient to get enough data to measure drivers' reactions reliably. Consequently, it was decided to use members of the evaluation team as faux pedestrians to increase the amount of data. This decision ensured that the nature of the pedestrians using the crosswalks would be similar any day of the week). All the evaluations were made during the summer or fall. No evaluations were made during the winter because activities at Gardner Field were very limited during those months and there were few pedestrians using the crosswalks at that time.

Table 1. Day, date, status of crosswalks and the weather conditions for each evaluation

Evaluation Number	Evaluation Day and Date	Status of Crosswalks	Weather Conditions
1	Saturday, 6/12/1999	Original	Dry and sunny
2	Saturday, 5/13/2000	Striped	Dry and sunny
3	Saturday, 10/23/2000	Striped and flashing	Initially dry and overcast, rain in late afternoon
4	Saturday, 6/12/2001	Striped and flashing	Dry and sunny
5	Thursday, 9/13/2001	Striped and flashing	Dry and sunny

Measurements
At each evaluation, the following information was collected:

- Traffic flow was counted in five directions, each direction being observed for ten minutes in every hour. The amount of traffic exiting Gardner Field was small so the totals for directions 5 and 6 were combined.

- After the striping of the crosswalks and after the installation of the in-pavement flashing warning lights, genuine pedestrians were interviewed about their opinions of the crosswalks

- Observations were made of the behavior of drivers and pedestrians and the operational characteristics of the in-pavement flashing warning lights.

In addition, a video record of the crosswalks throughout the evaluation period was made from a position on the North side of Savage Road. This video was subsequently analyzed to obtain the following information:

- Vehicle approach speeds from directions 1 and 2, in the absence of a pedestrian and when a pedestrian was waiting to cross or was actually crossing.

- How many vehicles passed across the crosswalk while the pedestrian or group of pedestrians was waiting to cross.

- The number of times a vehicle passed over the crosswalk while there was a pedestrian, or group of pedestrians, on the crosswalk, i.e., there was conflict between vehicle and pedestrian.

Finally, a video recording was made from the front passenger seat of a vehicle driving around Denville, during daytime when the roads were dry. This video was recorded as part of Evaluations 1, 2 and 4. This video was used in the measurement of the conspicuity of the crosswalks to drivers who were unfamiliar with Denville. Accident statistics were not collected as part of the evaluation because study of the accident data in the area of the crosswalk, from 1996 to 1998, indicated that the number of accidents occurring during the evaluation period was likely to be insufficient to reach a reliable conclusion.

RESULTS

Traffic flow

The number of vehicles per hour passing over the crosswalks in each direction was estimated by multiplying the number counted during a ten-minute interval by six. The mean number of vehicles per hour passing over the crosswalks in each direction between 12.00 and 18.00 hours, for each evaluation are given in Table 2. The number of vehicles passing over the crosswalks in each direction for each hour that measurements were made are recorded in Appendix A in Tables 11 to 15.

Table 2. Mean number of vehicles per hour in each direction, between the hours of 12.00 and 18.00 hours, for each evaluation

Evaluation Number	Direction 1	Direction 2	Direction 3	Direction 4	Directions 5 and 6
1	230	220	107	238	30
2	230	279	151	273	37
3	147	189	83	181	11
4	208	204	103	212	24
5	254	275	91	219	24

From Table 2 it can be seen that mean traffic flow is greatest for directions 1, 2 and 4, less for direction 3 and least for directions 5 and 6 combined. This pattern is stable over all five evaluations, although the amount of traffic is influenced by the weather. The least traffic flow for all five directions occurs on evaluation 3, when the weather started cloudy and the turned to rain in the late afternoon. It is concluded that there are no major changes in the traffic flow pattern over the five evaluations.

Driver behavior - approach speeds

The mean speed at which drivers approached the crosswalks was measured from the video record for direction 1 only. This direction requires the vehicle to travel in a straight line. All other directions require the vehicle to slow down to change direction. The approach speed for each vehicle was calculated from the time taken for the vehicle to travel a distance of 126 ft along Savage Road to the first edge of Crosswalk 1. These approach speeds were measured only for a single approaching vehicle, or for the vehicle at the front of a series of vehicles, i.e., only for vehicles whose speed was not influenced by that of vehicles immediately ahead. Approach speeds were measured without any pedestrian on or near the crosswalk, and when a pedestrian was obviously waiting to cross or was actually on the crosswalk. The mean approach speeds for direction 1, with and without a pedestrian present, between the hours of 12.00 to 18.00, for each evaluation are given in Table 3. The mean approach speeds for the hours that measurements were made at each evaluation are recorded in Appendix B in Tables 16 to 20.

From Table 3 it can be seen that the mean approach speed when a pedestrian was present is always slower than when a pedestrian was absent. The effect of the various crosswalk-marking systems can be seen by examining the changes between the different evaluations. Initially (Evaluation 1), the difference in mean approach speed for a pedestrian absent and present is 4.5 mi/h. After reconstructing one crosswalk, installing a new crosswalk, and striping both (Evaluation 2), the difference in mean

Table 3. Mean approach speed, in miles per hour, to crosswalk 1, from direction 1, with and without a pedestrian present, for the hours between 12.00 and 18.00, for every evaluation.

Evaluation Number	Mean approach speed without a pedestrian (mi/h)	Mean approach speed with a pedestrian present (mi/h)	Difference in mean approach speed
1	29.5	25.0	4.5
2	34.1	24.2	9.9
3	27.7	21.6	6.1
4	26.0	23.0	3.0
5	28.7	27.5	1.2

approach speed increases to 9.9 mi/h, mainly because of an increase in approach speed when no pedestrian is evident. Immediately after installing the in-pavement flashing warning lights (Evaluation 3) the difference in mean approach speeds decreases to 6.6 mi/h, but the mean approach speed when a pedestrian is present is a minimum for all the evaluations (21.6 mi/h). Over the next year (Evaluations 4 and 5) the difference in mean approach speeds decreases as the mean approach speed when a pedestrian is present increases until it is almost the same as when no pedestrian is present.

Driver behavior - crossing while pedestrians waiting
The number of vehicles that passed over the crosswalk while a pedestrian or group of pedestrians was waiting was counted from the video record. To be included in this total, a vehicle had to cross the crosswalk while a pedestrian was standing at the edge of the crosswalk, clearly waiting to cross. The number of crossing events measured and mean number of vehicles crossing per event, between the hours of 12.00 to 18.00, for each evaluation, are given in Table 4.

Table 4. Number of pedestrian crossing events and the associated mean number of vehicles passing over the crosswalk while a pedestrian was waiting, per event, for the hours between 12.00 and 18.00, for every evaluation.

Evaluation Number	Number of pedestrian crossing events	Mean number of vehicles passing over the crosswalk, per event
1	60	1.52
2	71	1.72
3	137	1.33
4	82	1.06
5	155	1.33

The number of crossing events measured and the number of vehicles crossing while a pedestrian was waiting, for the hours that measurements were made at each evaluation are recorded in Appendix C in Tables 21 to 25. From Table 4 it can be seen that the number of vehicles passing over the crosswalk while a pedestrian was waiting to cross, per crossing event, was less for evaluations 3 - 5 than for evaluations 1 - 2, i.e., after the installation of the in-pavement flashing warning lights.

Driver behavior - conflicts on the crosswalk

Another measure of driver behavior made from the video record was the number of times conflicts between pedestrians and drivers occurred over the use of the crosswalk. A conflict is defined as an occasion when a driver moves over the crosswalk while a pedestrian is on the crosswalk, the vehicle passing either in front or behind the pedestrian. The number of crossing events measured and mean number of conflicts per event, between the hours of 12.00 to 18.00, for each evaluation, are given in Table 5. The number of crossing events measured and the number of conflicts occurring, for the hours that measurements were made at each evaluation are recorded in Appendix C in Tables 26 to 30.

Table 5. Number of pedestrian crossing events and the associated mean number of conflicts per event, for the hours between 12.00 and 18.00, for every evaluation.

Evaluation Number	Number of pedestrian crossing events	Mean number of conflicts per event
1	60	0.32
2	71	0.00
3	137	0.05
4	82	0.06
5	155	0.05

From Table 5 it can be seen that the mean number of conflicts per crossing event was dramatically reduced by striping the crosswalks so that they were clearly identified as crosswalks, a status that was doubtful at the time of the first evaluation. Specifically, before striping the probability that a vehicle would cross either behind or in front of you while you were on the crosswalk was 32%. Once the crosswalks were properly striped this probability was reduced to zero. Over time, the probability increased slightly to about 5%. Adding the in-pavement flashing warning lights did not change this probability.

Pedestrians' opinions
As part of the second evaluation, after the new striping of the crosswalks, and during the fourth evaluation, approximately nine months after the installation of the in-pavement flashing warning lights, a questionnaire about the perceived safety of the crosswalks was given to pedestrians using the crosswalks. The questionnaire used is given in Appendix D.

The characteristics of the pedestrians who answered the questionnaire on each occasion are given in Table 6. Table 6 gives a picture of the everyday use of the crosswalk. Clearly, the crosswalk is not heavily used; it took several hours to collect twenty interviews from genuine pedestrians. This pattern is also consistent with the frequency of use of the crosswalk reported by the interviewees. When the crosswalk is used, the people using it are almost equally divided between teenagers / young adults and mature adults. The unexpectedly high proportion of teenage users probably reflects their lack of access to a car and the presence of Gardner Field on one side of the crosswalk. The most interesting response in Table 6 is the high percentage of interviewees who claim that they had themselves been involved in an accident or near-miss or had seen an accident or near-miss at the crosswalk. Presumably, these claims refer mainly to near-misses, because police accident statistics do not show a high level of accidents reported.

Table 6. Demographic details of the pedestrians interviewed after the striping of the crosswalks (Evaluation 2) and after the installation of the in-pavement flashing warning lights (Evaluation 4). Data is given on the number of pedestrians interviewed, their gender and age, the average number of times they used the crosswalk per week, and whether they had had or had seen an accident or near-miss involving a pedestrian at the crosswalk.

Demographic data	Evaluation 2	Evaluation 4
Number interviewed	20	20
Gender - Male Gender - Female	12 8	12 8
Age - Teen Age - Young adult Age - Mature adult Age - Elderly adult	10 0 10 0	5 7 7 1
Mean number of times crosswalk used per week (and standard deviation)	6.5 (7.1)	4.4 (5.0)
Have you had or seen an accident or near miss involving a pedestrian here? - % yes	26%	45%

The mean (and standard deviation) of the ratings given by the interviewees in response to the questions about the safety of the crosswalk and the visibility of approaching traffic, for each evaluation, are given in Table 7. From Table 7 it can be seen that the pedestrians consider the crosswalk to be moderately safe, after striping (Evaluation 2) and after the installation of the in-pavement flashing warning lights (Evaluation 4). For both the evaluations, the mean ratings of safety are in the middle of the scale 1 = not safe at all, 5 = very safe. It is also worth noting that the installation of the in-pavement flashing warning lights does not change the perception of safety, the mean rating in Evaluation 4 being not statistically significantly different from Evaluation 2. As for how well the pedestrians can see approaching traffic, the mean ratings at Evaluations 2 and 4 are towards the top of the scale 1 = not at all well , 5 = very well. Again, it is worth noting that the installation of the in-pavement flashing warning lights does not change how well pedestrians can see approaching traffic, the mean rating in Evaluation 4 being not statistically significantly different from that obtained in Evaluation 2.

Table 7. Mean (and the associated standard deviation) of the ratings on a five-point scale in response to questions about the safety and the visibility of approaching traffic, when using the crosswalk.

Question	**Evaluation 2**	**Evaluation 4**
How safe do you consider this crosswalk to be? (1 = not safe at all; 5 = very safe)	2.9 (1.2)	2.7 (1.5)
When waiting to cross, how well can you usually see approaching traffic? (1 = not at all well, 5 = very well)	4.3 (0.9)	3.5 (1.6)

Finally, the interviewees where asked if they had any comments about the crosswalks. The comments made are listed in Table 8. There are a number of points made in these comments that are themselves worth commenting on. There are two points that are repeated in Evaluation 2. The first is the difficulty of seeing up Savage Road from one side of Crosswalk 2 because of the overhanging trees and shrubs on the adjacent land (Figure 12). The other is the difficulty produced by having to look out for vehicles coming from several different directions. This was emphasized by one pedestrian who, quite rationally, choose to always use Crosswalk 1 because then it was necessary to look out for traffic from only two lanes, both in the same direction. For Crosswalk 2, it is necessary to look out for vehicles in 4 lanes in four different directions (See Figure 2).

Figure 12. View up Savage Road to the northwest, from the Franklin Road side of Crosswalk 2, obscured by shrubs.

Table 8. Comments made by pedestrians interviewed after the striping of the crosswalks (Evaluation 2) and after the installation of the in-pavement flashing warning lights (Evaluation 4).

Evaluation 2	Evaluation 4
I always use crosswalk 1, so I only have to consider traffic from one direction.	Cars get confused about right of way. Have noticed the flashing but it seems to be a random event. Doesn't seem to be related to people being around.
Safety depends on the drivers.	Stop light suggested.
Needs a traffic light.	Something should be done to improve it.
When cars come from Gardner Field traffic backs up.	Works well.
Can't see past the trees when using Crosswalk 2. A traffic light would be nice on this crosswalk.	Will be safe at night.
Striping is a very good job.	It doesn't seem to work at all.
Sometimes drivers fly by.	Has gotten safer, but its not due to the flashing warning lights - people don't pay attention to those.
A lot of directions to look and a lot of traffic.	Flashing warning lights don't help.
There is a problem to see up the road at crosswalk 2 because of the trees	Safer since these lights - noticeable at night.
Dangerous - too much traffic.	Not really safe.
Traffic should go much more slowly. It is difficult to see on crosswalk 2 because of the trees.	The lights don't really deter the cars.
You need to look all around when crossing.	The lights help.
For the amount of traffic it handles it works well.	Crosswalk is fine.
Too much traffic travelling too fast, particularly between 5 and 7 p.m. on weekdays.	Should be a traffic light here.
Too much traffic, main road is wrong.	A bridge would be better.

Most of the comments made in Evaluation 4, have to do with the in-pavement flashing warning lights. Some pedestrians thought the in-pavement flashing warning lights had helped make the crosswalk safer, particularly at night, while others thought the lights had had no influence on drivers' behavior. During both evaluations, there were occasional mentions of alternative ways to make the crosswalk safer for pedestrians, by installing traffic signals or even constructing a pedestrian bridge.

Observations of drivers' behavior

While making the evaluations on site, the authors had an opportunity to observe drivers' behaviors. Two aspects of that behavior are of relevance here. The first is that traffic backing up from the traffic signals on US Route 46 sometimes produced partial blockages of different lanes between the two crosswalks. The most common blockages occurred for directions 2 and 3 because of vehicles coming from directions 2 and 4 (Figure 13). Occasionally, this situation was exacerbated by a vehicle coming out of Gardner Field and blocking direction 1. The importance of such blocking for the use of the crosswalks is that the vehicles obscure the drivers' view of the crosswalk and the pedestrians' view of the traffic. This means it is sometimes not possible for a driver traveling in direction 1 to see if a pedestrian is waiting to cross from one side of the two crosswalks, or even if a pedestrian has already started to cross, until the pedestrian emerges from behind a vehicle. Striping does not do anything to help in this situation but the in-pavement flashing warning lights would, if drivers were confident that their operation meant a pedestrian was using the crosswalk.

Figure 13. Blockage of some directions of travel in the area of the crosswalk by traffic backing up from the traffic signals at US Route 46 and Franklin Road.

Another observation was the evident uncertainty of drivers about what was the correct response to the in-pavement flashing warning lights. Evaluation 3 took place one week after the commissioning of the in-pavement flashing warning lights so many of the drivers observed were probably encountering the lights for the first time. When the lights flashed virtually all the drivers slowed down as they approached the crosswalk. Some then drove slowly over the crosswalk, even if a pedestrian was waiting to cross. Others stopped at the crosswalk and waited until the lights ceased flashing, even though there was no pedestrian present. Yet others stopped at the crosswalk, until the pedestrian had crossed. Some then continued to wait until the flashing stopped, while others drove over the crosswalk once the pedestrian had passed. Even a member of the Denville police department stopped and asked the evaluation team what the driver's correct response should be when the lights flashed.

Evaluation 5 took place approximately one year after the installation of the in-pavement flashing warning lights. During this evaluation, it became evident that drivers had by now become accustomed to the lights. They rarely reduced approach speed when the lights flashed, often ignoring them until they noticed a pedestrian waiting to cross. Certainly, no driver stopped when the lights were flashing but no pedestrian was evident and most drove over the crosswalk once the pedestrian had crossed.

Observations of pedestrians

While making the evaluations on site, the authors also had an opportunity to observe the pattern of pedestrian use of the crosswalks. The first things to say is that the number of pedestrians at the site was modest, typically about five per hour, the number depending on the weather and the level of activity on Gardner Field. However, about half of these pedestrians were children. Two aspects of the behavior of these pedestrians are of relevance here. The first is that some pedestrians did not use the crosswalks even after they had been striped and hence clearly identified as crosswalks. Instead, some pedestrians, mainly teenagers, used the central triangular island as a halfway point. The second is how long pedestrians waited before crossing. Observations suggest that this waiting time depends on traffic conditions. Obviously, when there was heavy traffic, the pedestrian had little choice but to wait until a driver conceded the right of way. However, when there was little or no traffic, pedestrians simply glanced in the appropriate directions and crossed without hesitation, i.e., did not wait at the kerbside. Such behavior makes it difficult for the pedestrian detection unit with a built-in time delay to activate the in-pavement flashing warning lights appropriately. Finally, it was noted that during daytime it was very difficult for a pedestrian waiting to use the crosswalk to tell whether the in-pavement lights were flashing because there is no light output in the direction of the pedestrian.

Operational history of the in-pavement flashing warning lights

The in-pavement flashing warning light system, as described earlier was commissioned during the week beginning September 10th, 2000. The operational history of the installation up to Evaluation 5, which was undertaken approximately one year later, has revealed three areas of concern. They are:

- The ability of the in-pavement unit to withstand high traffic flows

- The extent to which the in-pavement units require regular cleaning

- The reliability of the activating system

Each of these aspects is considered below

As originally installed, the in-pavement flashing warning light installation consisted of ten in-pavement light units. During the one year of operation New Jersey Department of Transportation has had to carry out maintenance on five of these units. Two of the units had to be replaced after suffering damage from a snowplow. Another three suffered electrical failure of some sort, probably a failure of the filament of the halogen lamp in the unit, caused by vibration produced by the high traffic flows over the units. This cause of failure has to be an assumption because the maintenance procedure is to extract the failed unit from the pavement, replace it with a spare unit, send the failed unit back to the manufacturer in California, who makes any necessary repair and returns the unit to NJDOT where it becomes a spare unit. Nonetheless, the fact that five out of the ten units initially installed have required maintenance during the first year suggests that the units are not suitable for use where they will be exposed to high traffic flows.

A close examination of the units after one year in the pavement showed a large reduction in light output from new. There were two reasons for this reduction. The first was the presence of small debris in the incline leading to the lens of each unit. The second, and more important, cause was the deposit of a black film, probably rubber, over a large part of the lens through which light is emitted in each unit. Both these causes of decline in light output were easily removed using a brush and glass cleaner respectively.

The pole-mounted activating system has adjustments of coverage area, sensitivity and time delay. These adjustments are used to ensure that the in-pavement flashing warning lights are only operated when a pedestrian is waiting to cross and are not activated by a pedestrian walking along the sidewalk past the crosswalk, nor by passing traffic. At the time of Evaluation 3, i.e., one week after commissioning, it was observed that the in-pavement units were sometimes activated when there was no pedestrian present. Examination of the activation of the in-pavement flashing warning lights for several hours during Evaluation 5 revealed the pattern of activation shown in Table 9.

Table 9. Hits, misses, false positives and true negatives for activation of the in-pavement flashing warning light units during Evaluation 5.

Situation	Crosswalk 1	Crosswalk 2
Hit = Lights flashing when pedestrian waiting to cross or crossing	48	45
Miss = Lights not flashing when pedestrian waiting to cross or crossing	21	33
False positives = Lights flashing when no pedestrian waiting to cross	9	4
True negative = Lights not flashing when pedestrian walks past crosswalk on sidewalk	31	11

From Table 9 it can be seen that the reliability of activation is poor for both crosswalks. Specifically, the number of incorrect activations (misses and false positives) as a percentage of the total number of activations is 27% for Crosswalk 1 and 40% for Crosswalk 2.

Laboratory experiment to assess noticeability

One aspect of the in-pavement flashing warning light system that might be expected to be of benefit to the safety of pedestrians using a sidewalk is the enhanced noticeability of the sidewalk when a pedestrian wishes to use it. How effective the in-pavement flashing warning light system is in making a crosswalk noticeable could not be determined from on-site observations because there was no access to drivers, and even if there had been, most of the drivers were familiar with the area and so knew there was a crosswalk in that location. To measure noticeability it is necessary to collect the reactions of drivers who have never been to Denville and so have no knowledge of the presence of a crosswalk. This was done by running an experiment in Troy, New York, with subjects resident in that area.

Video taken from the front passenger seat of a vehicle driving through Denville, during daytime when the roads were dry, was recorded as part of Evaluations 1, 2 and 4, i.e., for the original situation without any clear marking of the crosswalk on the pavement; after the construction of a second crosswalk and the striping of both crosswalks; and nine months after the installation of the in-pavement flashing warning light system. This footage was edited onto three separate videotapes; one tape with video of the crosswalk from Evaluation 1, one with video of the crosswalk from Evaluation 2, and a third tape with video of the crosswalk from Evaluation 4. The clips from Evaluation 4 all showed the in-pavement lights flashing. Each tape contained a total of 20 video clips; two clips of the crosswalk, and 9 miscellaneous clips taken from other areas of Denville that were repeated one time each. Each clip lasted ten seconds and showed a straight-line movement along a road

Thirty people took part in this study. All participants had normal or corrected vision, and were licensed drivers of at least one-year experience. None of the participants were familiar with Denville or the crosswalk of interest. Participants were instructed that they would watch three videotapes showing the view forward from a vehicle driving through an urban area. They were told that there were 20 ten-second clips on each tape, and they would be shown one clip at a time. Subjects were then given a checklist of 18 driving-related items such as stop signs, traffic signals, cars ahead braking, roadwork obstacles, lane markings, etc., and instructed to look for these items in each clip, as they would when driving. They were also told that at the end of each clip they would be asked to rate the noticeability of each existing item on a five-point scale (1 = hardly noticeable at all; 5 = extremely easy to notice). If the subject did not notice the item at all a score of zero was assigned. Before the experiment began, three practice clips were presented to each subject in which the experimenter pointed out what each item on the checklist looked like. To control for order effects, the presentation of the tapes was counterbalanced using a full Latin Square throughout the experiment. The mean ratings (and the associated standard deviations) of noticeability of the crosswalk, for the three crosswalk conditions are given in Table 10.

Table 10. Means and standard deviations of the sum of ratings of crosswalk noticeability

Crosswalk condition	Mean rating of sum of crosswalk noticeability ratings	Standard deviation of sum of crosswalk noticeability ratings
Original - Evaluation 1	0.30	0.92
Striped - Evaluation 2	4.07	3.34
Striped plus in-pavement flashing warning light unit - Evaluation 5	6.63	3.07

These mean ratings and standard deviations are based on the sum of the two responses each subject gave to the same condition. This means the range of possible scores for a subject are from zero to ten. A score of zero means the subject failed to notice the crosswalk on the two occasions it was present. A score of ten means the subject the subject rated the crosswalk as extremely easy to notice on both occasions it was presented.

A single-factor repeated-measures analysis of variance (ANOVA) revealed a statistically significant effect on noticeability of the way the crosswalk was marked ($F(2,58) = 48.624$, $p < .001$). Paired sample t-tests were then performed to find out under what conditions the statistically significant effect occurred. It was found that striping the cross walk produced a large, statistically significant increase in noticeability from the original virtually unmarked crosswalk condition ($t = 5.94$, $p<.001$) and that adding the in-pavement flashing warning light system produced a smaller but still statistically significant increase in noticeability ($t = 3.55$, $p<.005$). The mean rating of the combined striped and in-pavement flashing warning light system is 6.63, which implies that it is noticeable although not impossible to miss, a state which would have been characterized by a mean rating close to 10.0.

It can be concluded that the activation of the in-pavement flashing warning light units does indeed increase the noticeability of the crosswalk to drivers who were unaware of its existence, over that provided by striping alone.

DISCUSSION

This project was undertaken to determine the effect of an in-pavement flashing, warning light system installed on a crosswalk on pedestrian safety, relative to striping. The effect of striping on what was originally a very poorly marked crosswalk is evident in two areas. First, from the laboratory experiment, it is evident that clear striping increased the noticeability of the crosswalk to drivers who were not familiar with the location (Table 10). Second, from the field observations it was found that clear striping eliminated conflicts between pedestrians and vehicles, a conflict being defined as an occasion when a driver moved over the crosswalk while a pedestrian was on the crosswalk, the vehicle passing either in front or behind the pedestrian (Table 5). However, clear striping did not reduce the mean speed at which vehicles approached the crosswalk (Table 3), nor the mean number of vehicles passing over the crosswalk while a pedestrian was waiting to cross (Table 4). Indeed, if anything the effect of clear striping was to increase the number of vehicles passing over the crosswalk while a pedestrian was waiting to cross.

The question that now needs to be considered is what the addition of the in-pavement flashing warning light system adds to the effect of striping. One effect is to enhance the noticeability of the crosswalk to drivers who are not aware of its location (Table 10). Another effect is to reduce the mean speed at which vehicles approach the crosswalk (Table 3). Adding the in-pavement flashing warning light system also reduces the mean number of vehicles that pass over the crosswalk while a pedestrian is waiting (Table 4). From the point of view of pedestrian safety these are all desirable changes. However, over time the mean number of conflicts per crossing event tended to increase slightly (Table 5), while the mean speed with which vehicles approach the crosswalk increased more dramatically (Table 3). These undesirable changes are probably due to the poor reliability of the activating system (Table 9). Essentially, what the in-pavement flashing warning light system provides to the driver is an early warning that the crosswalk is in-use. Unfortunately, if that warning is unreliable, in the sense that a significant number of times, the lights flash when there is no pedestrian either waiting to use the crosswalk or on the crosswalk, local drivers who have previous experience of the crosswalk are likely to ignore the system. Certainly, a number of the pedestrians interviewed nine months after the installation of the in-pavement flashing warning light system commented on the system's lack of impact on drivers (Table 8). What the impact of an accurately functioning system on drivers might be is a matter of conjecture, but it seems likely that it would be to enhance the beneficial effects found soon after installation and discussed above.

CONCLUSIONS

From the data collected, the following conclusions can be drawn:

- Clear striping of a crosswalk enhances the noticeability of the crosswalk to drivers who are not familiar with the location.

- Clear striping of a crosswalk reduces conflicts between pedestrians and vehicles, a conflict being defined as an occasion when a driver moves over the crosswalk while a pedestrian is on the crosswalk, the vehicle passing either in front or behind the pedestrian.

- Clear striping of a crosswalk does not reduce the mean speed at which vehicles approach the crosswalk.

- Clear striping of a crosswalk does not reduce the mean number of vehicles passing over the crosswalk while a pedestrian is waiting to cross.

- Adding an in-pavement flashing warning light system to a crosswalk that is already clearly striped enhances the noticeability of the crosswalk to drivers who are not familiar with the location.

- Adding an in-pavement flashing warning light system to a crosswalk that is already clearly striped reduces the mean speed at which vehicles approach the crosswalk.

- Adding an in-pavement flashing warning light system to a crosswalk that is already clearly striped reduces the mean number of vehicles that pass over the crosswalk while a pedestrian is waiting.

- The impact of adding an in-pavement flashing warning light system to a crosswalk that is already clearly striped on the mean speed at which vehicles approach the crosswalk tends to diminish over time.

RECOMMENDATIONS

The conclusions from this study support the view that adding an in-pavement flashing warning light system to a crosswalk that is already clearly striped does have a beneficial impact on pedestrian safety. Whether these benefits are enough to justify the cost of installing such a system is a matter of judgement beyond the scope of this report. However, given that it is desired to install an in-pavement flashing warning light system, the following recommendations are made with the aim of producing an installation that is effective in enhancing pedestrian safety. The recommendations are divided into three areas; those relating to where an in-pavement flashing warning light system might most usefully be used, those related to the nature of such a system and those related to the implementation of such a system.

An in-pavement flashing warning light system is designed to attract attention to the crosswalk when it is use. An in-pavement flashing warning light system is most appropriately installed on crosswalks where:

- The accident history of the crosswalk reveals that some additional advanced warning to drivers is necessary.

- The crosswalk is in an unusual location, e.g., mid-block, so that drivers are not expecting a crosswalk.

- There are many other features of the surrounding environment besides the crosswalk competing for the driver's attention.

- The distance from which the crosswalk can first be seen is such as to require an immediate response given the prevailing traffic speeds.

For an in-pavement flashing warning light system to be effective in enhancing pedestrian safety, it must perform reliably, i.e., it should only flash when there is a pedestrian waiting to use the crosswalk or on the crosswalk. The reliability of the system installed in Denville is completely inadequate. To improve the reliability of in-pavement flashing warning light systems it is recommended that the New Jersey Department of Transportation:

- Seek out an in-pavement flashing warning light system that is both plowable and more robust to heavy traffic flow.

- Abandon the use of passive activation of the in-pavement flashing warning light system. Instead, a simple active control system, preferably a pedestrian push-button, should be used. If used responsibly, this would eliminate the false-positive activation of the in-pavement flashing warning light system. This, in turn, would ensure that drivers would come to recognize the meaningfulness of the flashing warning lights. The use of a simple active control system would also reduce the price of purchasing an in-pavement flashing warning light system by about 40%.

- Provide feedback to the pedestrian when the in-pavement lights are flashing.

- Clean the lenses of any in-pavement flashing warning light system exposed to heavy traffic at least once every six months.

For an in-pavement flashing warning light system to be effective in enhancing pedestrian and traffic safety, it is necessary for both pedestrians and drivers to know what is expected of them. This is particularly important while such systems are rare. To educate both pedestrians and drivers about the correct way to use and to respond to in-pavement flashing warning lights at crosswalks it is recommended that the New Jersey Department of Transportation:

- Determine the legal status of in-pavement flashing warning lights installed on crosswalks, and inform all law enforcement agencies of the same.

- Develop an education program about the correct use and response to flashing in-pavement flashing warning lights at crosswalks. This education program should be aimed at both drivers and pedestrians.

APPENDIX A: TRAFFIC FLOW DATA

Table 11. Traffic flow in number of vehicles per hour on 12th June 1999, with the original single crosswalk.

Starting time	Direction 1	Direction 2	Direction 3	Direction 4	Directions 5 and 6
11.00	258	276	138	348	102
12.00	192	294	78	270	54
13.00	228	204	150	294	36
14.00	306	204	108	264	30
15.00	192	162	126	186	30
16.00	240	228	84	222	18
17.00	222	228	96	192	12
18.00	114	270	108	120	0
19.00	180	168	72	144	18
Mean	215	226	107	227	33
Standard deviation	54	47	27	74	30

Table 12. Traffic flow in number of vehicles per hour on 13th May 2000, with the two striped crosswalks.

Starting time	Direction 1	Direction 2	Direction 3	Direction 4	Directions 5 and 6
11.00	186	252	132	360	24
12.00	198	234	186	348	6
13.00	222	480	186	336	42
14.00	240	252	126	246	60
15.00	258	240	132	216	36
16.00	210	306	114	246	6
17.00	252	162	162	246	72
18.00	204	180	138	240	36
19.00	234	120	54	186	96
Mean	223	247	137	269	42
Standard deviation	25	104	40	62	30

Table 13. Traffic flow in number of vehicles per hour on 23rd September 2000, with the two striped crosswalks with in-pavement flashing warning lights installed.

Starting time	**Direction 1**	**Direction 2**	**Direction 3**	**Direction 4**	**Directions 5 and 6**
11.00	174	258	90	234	84
12.00	216	354	120	258	6
13.00	150	210	120	252	36
14.00	144	180	54	144	0
15.00	132	186	36	114	12
16.00	150	90	72	162	6
17.00	90	114	96	156	6
18.00	108	66	66	222	72
19.00	120	174	12	66	0
Mean	143	181	74	179	25
Standard deviation	37	89	37	67	32

Table 14. Traffic flow in number of vehicles per hour on 9th June 2001, with the two striped crosswalks and with in-pavement flashing warning lights installed.

Starting time	**Direction 1**	**Direction 2**	**Direction 3**	**Direction 4**	**Directions 5 and 6**
11.00	132	168	66	144	18
12.00	228	258	126	228	30
13.00	240	222	138	210	18
14.00	144	186	114	222	0
15.00	264	126	72	138	6
16.00	162	192	72	156	36
17.00	210	240	96	318	54
18.00	240	180	84	216	36
19.00	-	-	-	-	-
Mean	203	197	96	204	25
Standard deviation	50	42	27	59	18

Table 15. Traffic flow in number of vehicles per hour on 13th September 2001, with the two striped crosswalks and with in-pavement flashing warning lights installed.

Starting time	Direction 1	Direction 2	Direction 3	Direction 4	Directions 5 and 6
11.00	-	-	-	-	-
12.00	138	234	102	282	6
13.00	240	174	66	198	18
14.00	228	282	72	162	18
15.00	216	312	66	138	12
16.00	240	288	84	276	24
17.00	462	360	156	258	66
18.00	-	-	-	-	-
19.00	-	-	-	-	-
Mean	254	275	91	219	24
Standard deviation	109	64	35	62	21

APPENDIX B: APPROACH SPEED DATA

Table 16. Mean approach speed for direction 1, with and without a pedestrian present, for each hour of video record, on 12th June 1999, with the original single crosswalk.

Starting time	Pedestrian absent	Pedestrian present
11.00	28	19
12.00	31	25
13.00	31	26
14.00	28	25
15.00	28	26
16.00	28	23
17.00	31	23
18.00	25	23
19.00	29	23
Mean	29	24
Standard deviation	2.0	2.2

Table 17. Mean approach speed for direction 1, with and without a pedestrian present, for each hour of video record, 13th May 2000, with the two striped crosswalks.

Starting time	Pedestrian absent	Pedestrian present
11.00	29	29
12.00	32	25
13.00	34	23
14.00	34	26
15.00	34	25
16.00	35	24
17.00	35	23
18.00	41	25
19.00	41	22
Mean	35	25
Standard deviation	3.9	2.1

Table 18. Mean approach speed for direction 1, with and without a pedestrian present, for each hour of video record, on 23rd September 2000, with the two striped crosswalks with in-pavement flashing warning lights installed.

Starting time	Pedestrian absent	Pedestrian present
11.00	37	25
12.00	29	23
13.00	30	17
14.00	29	24
15.00	29	20
16.00	25	22
17.00	24	22
18.00	25	20
19.00	25	19
Mean	28	21
Standard deviation	4.0	2.5

Table 19. Mean approach speed for direction 1, with and without a pedestrian present, for each hour of video record on 9th June 2001, with the two striped crosswalks and with in-pavement flashing warning lights installed.

Starting time	Pedestrian absent	Pedestrian present
11.00	29	24
12.00	28	23
13.00	29	24
14.00	27	24
15.00	22	20
16.00	28	22
17.00	24	25
18.00	27	25
19.00	-	-
Mean	27	23
Standard deviation	2.5	1.7

Table 20. Mean approach speed for direction 1, with and without a pedestrian present, for each hour of video record on 13th September 2001, with the two striped crosswalks and with in-pavement flashing warning lights installed.

Starting time	Pedestrian absent	Pedestrian present
11.00	-	-
12.00	31	30
13.00	29	29
14.00	34	29
15.00	26	27
16.00	25	25
17.00	27	25
18.00	-	-
19.00	-	-
Mean	29	28
Standard deviation	3.4	2.2

APPENDIX C: VEHICLES PASSING WAITING PEDESTRIAN DATA

Table 21. Number of pedestrian crossing events and the associated number of vehicles passing over the crosswalk while a pedestrian was waiting, for each hour of video record, on 12th June 1999, with the original single crosswalk.

Starting time	**Number of pedestrian crossing events**	**Number of vehicles passing over the crosswalk while pedestrian waiting**
11.00	8	11
12.00	5	3
13.00	8	15
14.00	9	14
15.00	12	17
16.00	13	17
17.00	13	31
18.00	9	10
19.00	5	2
Mean	9	13
Standard deviation	3.1	8.6

Table 22. Number of pedestrian crossing events and the associated number of vehicles passing over the crosswalk while a pedestrian was waiting, for each hour of video record, 13th May 2000, with the two striped crosswalks.

Starting time	**Number of pedestrian crossing events**	**Number of vehicles passing over the crosswalk while pedestrian waiting**
11.00	14	15
12.00	17	27
13.00	7	11
14.00	16	48
15.00	9	12
16.00	12	15
17.00	10	12
18.00	12	20
19.00	11	19
Mean	12	20
Standard deviation	3.2	11.7

Table 23. Number of pedestrian crossing events and the associated number of vehicles passing over the crosswalk while a pedestrian was waiting, for each hour of video record, on 23rd September 2000, with the two striped crosswalks with in-pavement flashing warning lights.

Starting time	**Number of pedestrian crossing events**	**Number of vehicles passing over the crosswalk while pedestrian waiting**
11.00	11	10
12.00	20	18
13.00	6	7
14.00	16	29
15.00	28	11
16.00	35	67
17.00	32	42
18.00	14	14
19.00	20	16
Mean	20	24
Standard deviation	10.3	19.5

Table 24. Number of pedestrian crossing events and the associated number of vehicles passing over the crosswalk while a pedestrian was waiting, for each hour of video record on 9th June 2001, with the two striped crosswalks and with in-pavement flashing warning lights.

Starting time	**Number of pedestrian crossing events**	**Number of vehicles passing over the crosswalk while pedestrian waiting**
11.00	-	-
12.00	14	29
13.00	18	32
14.00	16	15
15.00	5	0
16.00	17	7
17.00	12	4
18.00	10	4
19.00	-	-
Mean	13	13
Standard deviation	4.6	12.8

Table 25. Number of pedestrian crossing events and the associated number of vehicles passing over the crosswalk while a pedestrian was waiting, for each hour of video record on 13th September 2001, with the two striped crosswalks and with in-pavement flashing warning lights.

Starting time	Number of pedestrian crossing events	Number of vehicles passing over the crosswalk while pedestrian waiting
11.00	-	-
12.00	21	27
13.00	21	40
14.00	32	37
15.00	25	35
16.00	26	14
17.00	30	45
18.00	-	-
19.00	-	-
Mean	26	33
Standard deviation	4.5	11.0

Table 26. Number of pedestrian crossing events and the associated number of conflicts, for each hour of video record, on 12th June 1999, with the original single crosswalk.

Starting time	Number of pedestrian crossing events	Number of conflicts
11.00	8	6
12.00	5	2
13.00	8	5
14.00	9	3
15.00	12	5
16.00	13	2
17.00	13	0
18.00	9	2
19.00	5	1
Mean	9	3
Standard deviation	3.1	2.0

Table 27. Number of pedestrian crossing events and the associated number of conflicts, for each hour of video record, 13th May 2000, with the two striped crosswalks.

Starting time	Number of pedestrian crossing events	Number of conflicts
11.00	14	0
12.00	17	0
13.00	7	0
14.00	16	0
15.00	9	0
16.00	12	0
17.00	10	0
18.00	12	0
19.00	11	0
Mean	12	0
Standard deviation	3.2	0

Table 28. Number of pedestrian crossing events and the associated number of conflicts, for each hour of video record, on 23rd September 2000, with the two striped crosswalks with in-pavement flashing warning lights.

Starting time	Number of pedestrian crossing events	Number of conflicts
11.00	11	2
12.00	20	1
13.00	6	1
14.00	16	0
15.00	28	0
16.00	35	1
17.00	32	1
18.00	14	0
19.00	20	1
Mean	20	1
Standard deviation	10.3	0.67

Table 29. Number of pedestrian crossing events and the associated number of conflicts, for each hour of video record on 9th June 2001, with the two striped crosswalks and with in-pavement flashing warning lights.

Starting time	**Number of pedestrian crossing events**	**Number of conflicts**
11.00	-	-
12.00	14	1
13.00	18	1
14.00	16	3
15.00	5	0
16.00	17	1
17.00	12	0
18.00	10	0
19.00	-	-
Mean	13	1
Standard deviation	4.6	1.07

Table 30. Number of pedestrian crossing events and the associated number of conflicts, for each hour of video record on 13th September 2001, with the two striped crosswalks and with in-pavement flashing warning lights.

Starting time	**Number of pedestrian crossing events**	**Number of conflicts**
11.00	-	-
12.00	21	1
13.00	21	1
14.00	32	2
15.00	25	0
16.00	26	1
17.00	30	2
18.00	-	-
19.00	-	-
Mean	26	1
Standard deviation	4.5	0.75

APPENDIX D: PEDESTRIAN QUESTIONNAIRE

Pedestrian Questionnaire for NJDOT Crosswalk Study

Interview Details
Time:
Gender of Interviewee: Male / Female
Age of Interviewee: Child / Teen / Young Adult / Mature Adult / Elderly Adult
Number and Age Mix of People Crossing:___________________________

Questions

1) How often do you use this crosswalk?

2) How safe do you consider this crosswalk to be, relative to the one on the main road nearby and others in town? (on a scale from 1 = not safe at all, and 5 = very safe)

3) When waiting to cross, how well can you usually see approaching traffic? (One answer, on a scale from 1 = not safe at all, and 5 = very safe)

4) Have you had or seen an accident or near-miss involving a pedestrian here? (Answer simply yes or no. If the answer is yes, then get a description of what happened)

5) Any other comments about this crosswalk?

REFERENCES

1. National Highway Traffic Safety Administration, *Fatal Accident Reporting System*, US Department of Transportation, Washington, DC, 1992

2. Light Guard Systems Inc., http://www.lightguardsystems.com (accessed 25th January, 2002)

3. Traffic Safety Corporation, http://www.xwalk.com (accessed 25th January, 2002)

4. US Federal Highways Administration, Manual of Uniform Traffic Control Devices Millennium Edition, http://www.mutcd.fhwa.dot.gov (accessed 25th January, 2002)

5. Whitlock and Weinberger Transportation Inc., *An Evaluation of a Crosswalk Warning System Utilizing In-Pavement Flashing warning lights*, Whitlock and Weinberger Transportation Inc., 1998.