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An Analysis Of The Saftey Effects Of Crosswalks With In-pavement Warning Lights

George Gadiel
University of Massachusetts Amherst, ggadiel@verizon.net

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AN ANALYSIS OF THE SAFETY EFFECTS OF CROSSWALKS WITH IN-PAVEMENT WARNING LIGHTS

A Thesis Presented

by

GEORGE GADIEL

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Approved as to style and content by:

____
Michael A. Knodler, Jr., Chair

____
John Collura, Member

____
Donald L. Fisher, Member

____
Carlton L. Ho
Graduate Program Director, MSCE and Ph. D.
Department of Civil and Environmental Engineering

ABSTRACT

AN ANALYSIS OF THE SAFETY EFFECTS OF CROSSWALKS WITH IN-PAVEMENT WARNING LIGHTS

MAY 2007

GEORGE GADIEL, B.S.I.E., LEHIGH UNIVERSITY
M.S., UNIVERSITY OF MASSACHUSETTS AMHERST
Directed by: Professor Michael A. Knodler, Jr.

Pedestrian safety is among one of the largest concerns in the transportation profession. Many treatments have been developed and implemented to improve pedestrian safety. This current research focuses on the efficiency of in-pavement warning lights systems and involves multiple objectives. The primary objective is to evaluate the yielding rates and crosswalk usage of existing and proposed in-pavement lights systems with comparisons including before and after data through a case study approach. A secondary objective is to evaluate where drivers are looking when they approach in-pavement lights systems and develop a model to evaluate their behavior.

The research described herein formulated these objectives into two research hypotheses and used statistical evaluation methodologies to provide quantitative and/or qualitative responses to the developed hypotheses. Data on pedestrian and driver behavior in the field, and the interaction between, them was collected using video camera technology in the Amherst, Massachusetts area. Data regarding drivers scan patterns during the approach to a crosswalk with in-pavement warning light system was collected using a driving simulator and an eye tracker. In total, 1,949 non-staged pedestrians and 606 staged pedestrians were observed crossing at the seven crosswalk locations in the field experiment and a total of 32 drivers participated in 576 crosswalk scenarios in the driving simulator evaluation.

The field evaluation resulted in increased yielding rates and crosswalk usage after installation of in-pavement warning lights, while driving simulator evaluation resulted in drivers not becoming accustomed to scanning for lights instead of a pedestrian. Recommendations include installation of in-pavement warning lights at traditional, midblock crosswalks and continued exploration of all crosswalks in the driving simulator evaluation.

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CHAPTER 1

INTRODUCTION

Despite the increased emphasis on promoting the accommodation of pedestrians within the transportation system, pedestrians have the highest risk of injury among users of the road system. Specifically, there is a high risk of death or injury due to the interaction of pedestrians and drivers, particularly with the prevalence today of higher speeds: only 15 percent of pedestrians hit at 40 miles per hour survive, while at 20 miles per hour or less, 95 percent survive (4). Given the prevalence of walking as a critical mode of transportation, and the particular vulnerability of pedestrians, pedestrian safety is among one of the most important concerns in the transportation industry. Crashes involving pedestrians are a frequent occurrence and make up two percent of all people injured in traffic crashes and 11 percent of all traffic related fatalities. In the U.S. in 2003, 4,749 pedestrians were killed and 70,000 injured from motor vehicle crashes, which translates to an average of one pedestrian killed every 111 minutes and an average of one pedestrian injured every eight minutes (1).

Extensive research and innovative strategies have been employed in an effort to counter the failures to keep the roadways safe for pedestrians in just the past few years with varying results. One of the more promising pedestrian treatments that has recently been added to the Federal Highway Administration’s (FHWA) Manual on Uniform Traffic Control Devices (MUTCD), which the governs the use of traffic control devices and presents recommendations for regulatory, warning and guide signs, pavement markings, and traffic control and pedestrian signals, is the Crosswalk In-Roadway

Warning Light System (1). Alternatively, this system has been referred to as in-pavement roadway lights. It has been the focus of myriad studies focusing on vehicle compliance and pedestrian use.

Problem Statement

Providing pedestrian safety is a critical objective of the transportation profession and in recent years, increasing amounts of time have been spent researching strategies to reduce the conflicts, or consequences of conflicts, between pedestrians and motor vehicles. Achieving pedestrian safety while simultaneously maintaining a desirable level of service for vehicles is a challenging process for transportation professionals. Although the National Highway Traffic Safety Administration's (NHTSA) National Center for Statistics and Analysis has reported a 15 percent decline over the past 10 years in the frequency of pedestrian fatalities from 5,489 in 1994 to 4,641 in 2004, there is still great concern for pedestrian safety. Specifically, recent developments indicate that there is a need for added research to develop an understanding of existing practices and developments of in pavement lights (1).

The largest proportion of pedestrian fatalities occurs at night when pedestrians are commonly less conspicuous (1). Most of the pedestrian treatments currently employed do not make it easier to see crosswalks; rather they only make drivers aware that a crosswalk exists. The following sections describe how crosswalks are used, the Crosswalk with In-Pavement Warning Light System, and how it interacts with pedestrians and drivers.

Crosswalks

The crosswalk is the most commonly used pedestrian treatment and has been standardized by the MUTCD. A crosswalk is defined by the MUTCD 2003 Edition as consisting of crosswalk markings (1). Specifically the MUTCD states:

> *Crosswalk markings provide guidance for pedestrians who are crossing roadways by defining and delineating paths on approaches to and within signalized intersections, and on approaches to other intersections where traffic stops. Crosswalk markings also serve to alert road users of a pedestrian crossing point across roadways not controlled by highway traffic signals or STOP signs. At nonintersection locations, crosswalk markings legally establish the crosswalk.*

Crosswalks are used to mark intersections where there are substantial conflicts between pedestrian and vehicular movements, but are used at unsignalized midblock pedestrian crossings as well. A midblock crossing is a location between intersections where a crosswalk has been placed and is used when there is heavy pedestrian traffic and there are no nearby existing crosswalks to provide more frequent crossing opportunities. Figure 1 illustrates a midblock crosswalk.

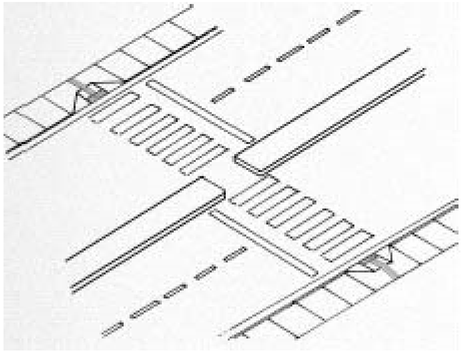


Figure 1 Example of a Midblock Crosswalk (3).

Midblock crosswalks provide access for pedestrians to cross roads with only two directions of traffic allowing for easier crossing (3). Nevertheless, midblock crossings create added challenges for drivers as their expectation is violated as they are less likely to anticipate a crossing. To overcome this challenge, crosswalks are often equipped with warning signage; however, there is also a need during the nighttime or during periods of decreased luminance for adequate lighting to allow vehicles sufficient time to see pedestrians and stop in advance of the crosswalk.

In-Pavement Warning Lights System

A crosswalk with in-pavement warning lights system consists of amber lights embedded in the pavement along both sides of the crosswalk. When a pedestrian activates the lights either by pressing a button or through automated detection the lights flash at a constant rate for a set period of time alerting the driver that a pedestrian is present and therefore the driver should stop to allow the pedestrian to cross. The lights are only activated by a pedestrian and shut off after a predetermined amount of time. Two methods exist for activation of the lights: 1) push a button similar to a pedestrian signal at an intersection, or 2) walk between two bollards which use break beam technology. If technology is installed to detect a pedestrian in the crosswalk, then the flashing time can be extended to allow for slower pedestrians to traverse the crosswalk. Figure 2 depicts a crosswalk with an in-pavement warning system.

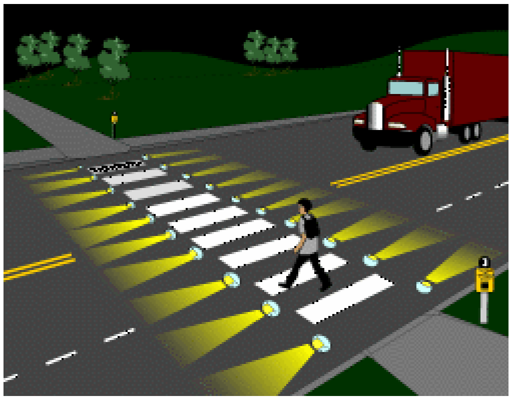


Figure 2 In-Pavement Warning Lights System (5).

The latest edition of the MUTCD approved the use of in-pavement warning system for use at marked crosswalks as an option over other treatments. With respect to In-Roadway Warning Lights the MUTCD specifically states (1):

- *If used, In-Roadway Warning Lights at crosswalks shall be installed only at marked crosswalks with applicable warning signs. They shall not be used at crosswalks controlled by YIELD signs, STOP signs, or traffic control signals.*
- *If used, In-Roadway Warning Lights at crosswalks shall be installed along both sides of the crosswalk and shall span its entire length.*
- *If used, In-Roadway Warning Lights at crosswalks shall initiate operation based on pedestrian actuation and shall cease operation at a predetermined time after the pedestrian actuation or, with passive detection, after the pedestrian clears the crosswalk.*
- *If used, In-Roadway Warning Lights at crosswalks shall display a flashing yellow signal indication when actuated. The flash rate for In-Roadway Warning Lights at crosswalks shall be at least 50, but not more than 60, flash periods per minute.*

The flash rate shall not be between 5 and 30 flashes per second to avoid frequencies that might cause seizures.

- *If used on one-lane, one-way roadways, a minimum of two In-Roadway Warning Lights shall be installed on the approach side of the crosswalk. If used on two-lane roadways, a minimum of three In-Roadway Warning Lights shall be installed along both sides of the crosswalk. If used on roadways with more than two lanes, a minimum of one In-Roadway Warning Light per lane shall be installed along both sides of the crosswalk.*
- *If used, In-Roadway Warning Lights shall be installed in the area between the outside edge of the crosswalk line and 3 m (10 ft) from the outside edge of the crosswalk. In-Roadway Warning Lights shall face away from the crosswalk if unidirectional, or shall face away from and across the crosswalk if bidirectional.*

The intent of in-pavement lights are to provide a better warning to drivers that a pedestrian is present in the vicinity of a crosswalk, and are especially valuable at night when the lights are most visible. In-pavement warning lights systems use amber/yellow lights. Within the transportation system, flashing yellow lights are typically associated with a caution or warning message. In defining the meaning of flashing yellow traffic indications the MUTCD states (1):

> *Flashing yellow—When a yellow lens is illuminated with rapid intermittent flashes, vehicular traffic is permitted to proceed through the intersection or past such signal indication only with caution.*

The MUTCD definition of flashing yellow contradicts the meaning of the flashing yellow/amber light used in the in-pavement warning lights system. When drivers approach a crosswalk with flashing yellow/amber lights they must always yield to pedestrians as they must at all crosswalks because pedestrians have the right of way. The yellow is consistent with current practices before and after the pedestrian has entered the crosswalk.

Some research has been completed but additional safety research is needed to address multiple issues with crosswalks, specifically with regard to in-pavement lights systems. First, a field based experiment including a before and after study of in-pavement lights systems is necessary to add to the literature assessing the impact on safety of in-pavement lights. Second, questions exist regarding the scan pattern of drivers approaching a midblock crosswalk, which need to be addressed. Specifically, there is arguably a concern that drivers who are familiar with in-pavement lights will stop glancing to the side for pedestrians when approaching a crosswalk and will, instead, rely solely on the flashing lights to indicate that they must slow for a pedestrian.

<u>Research Hypotheses</u>

Based on the existing research discussed in the previous section and the need for improvement in pedestrian safety in the U.S., the following hypotheses have been developed. The purpose of this research is to complete the stated objectives by testing the following research hypotheses:

Hypothesis 1: Pedestrian treatments which include the use of in-pavement light systems provide for increased yielding rates and greater crosswalk usage as compared to traditional midblock crosswalks.

Hypothesis 2: When drivers approach a crosswalk with in-pavement warning lights systems a consistent scan pattern develops where drivers become accustomed to looking at the lights instead of at the curb for a pedestrian. This applies primarily at night as pedestrians are not as visible as during the day so drivers may come to rely on the in-pavement lights.

Research Objectives

A pair of objectives has been established to directly address the research needs identified in the previous section. The two objectives for the proposed experiment are as follows:

1. Evaluate the safety of alternative in-pavement lights systems with different attributes including advanced dynamic signs and raised crosswalks using a case study approach; and,
2. Evaluate the driver's scan patterns as they approach midblock crosswalks.

Scope

The scope of this research is limited to an examination of the safety effects of crosswalks with in-pavement warning lights systems. Beyond the scope of this research is the added discussion of the myriad established and/or experimental crosswalk treatments beyond those including in-pavement warning lights. The intent of this paper is to evaluate the safety effects of in-pavement warning lights.

CHAPTER II

REVIEW OF THE LITERATURE

Pedestrian safety has been the focus of many research projects in just the past few years with the increased implementation of many new pedestrian treatments (5, 6, 8). To develop a framework from which to consider in-pavement lights systems and identification of potential candidate locations for such systems it is important to consider the following topical areas: increased safety of in-pavement lights systems over traditional, unsignalized midblock crosswalks and drivers' behavior at in-pavement crosswalks, specifically where are they looking and drivers reaction to different colored warning lights. The following sections provide a review of the literature associated with in-pavement treatments and traffic signals and the safety research that has resulted from implementation. Additional discussion involves driver scan patterns when faced with different events on the roadway. Lastly, research covering the human factors, specifically reaction (i.e. braking and scanning), of different color lights is discussed.

In-Roadway Treatments

Midblock crosswalks are not as safe as crosswalks located at intersections but roads without any crosswalks are not necessarily any safer. Fisher et al. reported that Shankar found 78 percent of pedestrian crashes occurred at non-intersection crossings (6) and over 40 percent occurred on roadways without crosswalks in the U.S. (7). As sited in Fisher et al. and Ivan et al. found urban areas accounted for 69 percent of pedestrian fatalities, while over half of those occurred on marked crosswalks with signal control or at locations without marked crosswalks. Although most crashes and fatalities occur in urban areas, death is more likely from a crash in rural areas (6). Another study as sited in Huang et al. found that 93 percent of midblock crosswalk crashes occurred at uncontrolled locations (8). One of the more controversial issues with crosswalks: whether marked crosswalks are safer than unmarked crosswalks. Pedestrians usually believe that marked crosswalks increase their safety because drivers will be able to see the marked white lines and stop for them. Zeeger et al. collected data at 1,000 unmarked crosswalks and 1,000 marked crosswalks at 30 cities across the U.S. (9). Site characteristics and crash data were collected at each site. First, there was no significant difference in pedestrian crashes on two-lane roads between marked and unmarked crosswalks or on multi-lane roads with average daily traffic (ADT) of 12,000 or less. Second, at multi-lane roads with no raised medians of ADTs greater than 12,000 and multi-lane roads with raised medians of ADTs over 15,000, pedestrian crash rates were higher for marked versus unmarked crosswalks. Third, marked crosswalk crash rates increased as ADTs increased, but stayed the same for unmarked crosswalks. Zeeger et al. does not recommend removing marked crosswalks, but suggests more improvements such as raised medians, traffic signals, speed reducing measures, and/or other treatments (9).

As noted many different treatments have been developed for the purpose of increased pedestrian safety. Van Houten et al. conducted research at three midblock crosswalks in Halifax, Nova Scotia (10). In addition to the advance yield markings were pedestrian activated flashing yellow beacons and appropriate signage. Advance yield markings are used to stop drivers in advance of the crosswalk and reduce screening of pedestrians by yielding vehicles. Figure 3 depicts the setup of the advance yield markings and signage in Van Houten's research (10).

Figure 3 Advance Yield Marking in Halifax, Nova Scotia (10).

Advanced yield markings were placed 10, 15, and 25 meters in advance of the crosswalk with a yield to pedestrians here sign. First, a significant reduction in pedestrian-vehicle conflicts of 74 percent, 87 percent, and 57.3 percent occurred at the three crosswalks. Second, moving the markings to 15 meters had an insignificant change from 10 meters. Third, a slightly higher percentage of vehicles yielded to pedestrians when advance yield markings were used and a significant increase in the distance vehicles stopped in advance of the crosswalk occurred. Currently the University of

Massachusetts at Amherst (UMass) is evaluating the efficiency of advance yield markings using a series of field and driving simulator experiments.

Of particular concern when considering the causes of pedestrian crashes and fatalities are the lighting conditions. Sixty percent of all pedestrian fatalities in 2003 occurred between 8:00 pm and 3:59 am (1). Most pedestrian treatments do not take account of nighttime conditions; however this is believed to be one of the major advantages of in-pavement warning lights systems as previously discussed. An in-pavement warning lights system is illustrated in Figure 4.

Figure 4 In-Pavement Warning Lights System in San Jose, CA (13).

Research has been conducted to evaluate these systems. Hakkert et al. performed a before and after study at four sites in Israel (11). Data was collected several weeks and then several months after installation. Although, there were no control sites, the authors expected the two after data collections to show sustained results over time. The results indicated the following (11):

- The speeds near and in advance of the crosswalks at two of four sites significantly decreased;
- The percentage of drivers who yielded to pedestrians who were at beginning of crosswalk doubled at three of four sites;
- The rate of pedestrian-vehicle conflict was reduced to less than one percent at all four sites; and,
- A ten percent reduction was observed in pedestrians who crossed outside of the crosswalk at all four sites.

Hakkert et al. recommended using this system where average vehicle speeds are over 30 kilometers per hour and the percentage of vehicles yielding the right of way is initially low (11).

A similar system was installed in Rockville, Maryland in the spring of 2004. Rousseau et al. conducted a before and after study on driver and pedestrian behavior (12). First, the authors found that the system had no effect on the number of pedestrians who used the crosswalk and led to a significant increase in the percentage of drivers who yielded when lights were activated from 36.0 percent to 70.7 percent on the near side and 64.9 percent to 98.1 percent on the far side. Second, there was an insignificant change in driver yielding from before installation and after installation when lights were not activated. This shows that the warning lights system increases the likelihood that drivers will yield. Third, the number of vehicles that passed before one yielded and the wait times for pedestrians were reduced (12).

Malek completed a before and after study in San Jose on an in-pavement warning lights system installed in April 2000 in one location (13). The research revealed that more drivers yielded after installation, especially at night. Driver yielding rates during the day increased from 10 percent to 44 percent in the northbound direction and from 12 percent to 54 percent in the southbound direction. The rates at night on the same road increased from five percent to 80 percent northbound and 5 percent to 72 percent southbound. Pedestrian and driver surveys were only conducted after installation and the results show drivers notice the crosswalk 71 percent, a pedestrian 89 percent, and flashing lights 42 percent of the time during the day but at night a pedestrian was noticed 100 percent and flashing lights 91 percent of the time. There was no difference from day to night of noticing the crosswalk. The most alarming result from the pedestrian survey was that 18 percent of pedestrians believed that the activating the lights would automatically stop drivers approaching the crosswalk (13).

In 2001, an in-pavement warning lights system began operation in Cedar Rapids, IA. Kannel and Jansen collected spot speed and yielding to pedestrian data as well as pedestrian and driver surveys (14). The results included a slight increase in approach speed and an increase in percentage of drivers yielding. By six months, 100 percent of vehicles arriving second stopped for pedestrians (14).

Another study performed with in-pavement warning lights system was in September 2000 in Denville, NJ (12). Van Derlofske et al. concluded that the system increased noticeability of crosswalks to drivers and reduced the number of vehicles passing over crosswalks while a pedestrian was present, conflicts between drivers and pedestrians, and the mean approach speed initially (15). However, the impact on mean approach speeds diminishes over time.

Pedestrian Signal Treatments

Innovative strategies to improve pedestrian safety are not limited to midblock locations and may also be practical at signalized intersections. Over the past few years, pedestrian signals have been enhanced to increase pedestrian safety. Countdown signals have been used to change pedestrian and driver behavior at marked crosswalks. Leonard et al. performed a study at two locations in Monterrey, CA and concluded the following (16):

- Countdown signals did not prevent pedestrians from beginning to cross at beginning of the DON'T WALK indication;
- Pedestrians did not attempt to cross when there was fewer than 10 to six seconds left;
- Pedestrians increased their speed as time was running out;
- Only a small percentage of pedestrians were stranded;
- Most pedestrians understood the meaning of the countdown signal, said it helped them understand the pedestrian signal, and made them feel safe; and,
- Drivers would most likely not be able to use the information on a countdown signal to anticipate signal change.

Furthermore, Huang and Zeeger compared two intersections with countdown signals and three control intersections in Lake Buena Vista, FL (17). A countdown signal during the flashing DON'T WALK portion of the countdown can be seen in Figure 5.

Figure 5 Countdown Signal in Lake Buena Vista, FL (17).

A pedestrian does not comply with a WALK signal if the pedestrian begins crossing during the flashing or steady DON'T WALK indication. Huang and Zeeger found that the percentage of pedestrians who did not comply with countdown signals was larger than the percentage of pedestrians who did not comply with control signals as seen in Figure 6 (17).

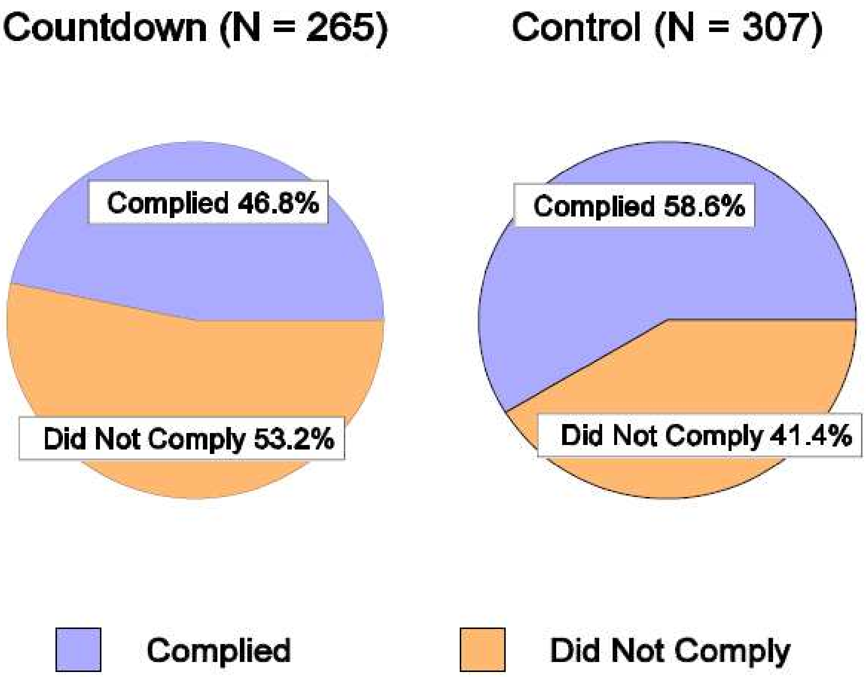


Figure 6 Compliance Levels of Pedestrians in Lake Buena Vista, FL (17).

The experiment resulted in no statistically significant difference in the number of pedestrians who were left in the crosswalk when countdown signal ended. Lastly, Huang and Zeeger concluded that more pedestrians started running when the flashing DON'T WALK indication appeared in the control signals (17). Figure 7 shows the percentage of pedestrians who started running when the flashing DON'T WALK indication appeared in the countdown and control signals.

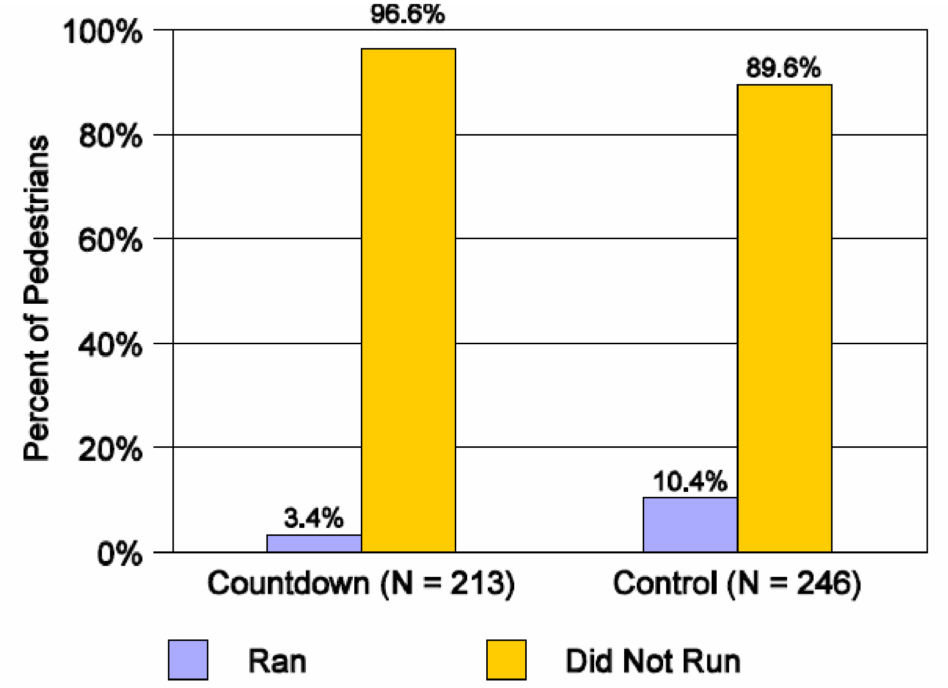


Figure 7 Pedestrians who started running when flashing DON'T WALK indication appeared (17).

Another innovation in pedestrian signals is the animated LED "Eyes" pedestrian signal as seen in Figure 8.

Figure 8 Animated LED "Eyes" Pedestrian Signal in Clearwater, FL (18).

This pedestrian signal consists of a traditional pedestrian signal with a WALK, Flashing DON'T WALK, and steady DON'T WALK indication with two eyes with eyeballs that scan left and right for the entire time or a portion of the WALK indication. This is used to remind pedestrians to look both ways for turning vehicles (18). Houten et al. performed a study with LED "Eyes" at two signalized intersections in Clearwater, FL (18). Condition one was the baseline condition with traditional pedestrian signal head. The LED "Eyes" were displayed for 2.5 seconds at the beginning of the WALK interval then followed by the WALK symbol for condition two. The duration of the WALK indications ranged from seven seconds to 40 seconds at the different intersection legs. Condition three displayed the LED "Eyes" for the initial 2.5 seconds of the WALK interval concurrently with the WALK symbol then the LED "Eyes" were turned off for the remainder of the WALK indication. For the fourth condition the LED "Eyes" were illuminated for the initial 2.5 seconds with the WALK symbol then the LED "Eyes" were displayed every 9.5 seconds concurrently with the WALK indication (18) for a total cycle time ranging from 30 to 40 seconds.

The results indicated that for condition two the percentage of pedestrians not looking for turning vehicles was reduced from 32 percent to 10 percent and 26 percent to five percent at the two intersections from the baseline. Condition three resulted in an even larger reduction to three percent at both intersections and condition four did not have any change from condition three. The percentage of pedestrians not looking for turning vehicles after six months was two percent. The number of pedestrian-vehicle conflicts was reduced from 2.7 before installation to 0.6 and 0.4 at the two intersections after installation. The number of conflicts stayed low after six months as well. Houten et al. recommend displaying the “Eyes” concurrently with the WALK indication for 2.5 seconds and repeating it every 9.5 seconds to benefit pedestrians who start walking later during the phase (18).

Although animated LED “Eyes” and countdown signals have been employed at signalized intersections to improve safety, they are not suited for midblock locations. In-pavement lights are more appropriate for midblock crosswalks and will be evaluated for this research.

Driver Scan Patterns

Substantial research has used driver scan patterns as a method of evaluation to determine how drivers react when faced with different situations while on the roadway. Knodler tracked driver eye movements at permissive left turns using a driving simulator equipped with head and eye tracking equipment (19). The results showed where drivers were looking and if they fixated on an object or just glanced at it. Furthermore, Knodler concluded that the application of the simulator and head and eye tracking equipment were appropriate for this type of analysis (19).

An additional study using driver scan patterns involved airport terminal signs. Kichhanagari et al. evaluated how drivers scan for their airline to determine in which terminal it is located (20). A standard condition was compared with an alphabetical condition. The standard condition consisted of four terminal signs with airlines listed in three columns but not in alphabetical order while the alphabetical condition differed by only alphabetical listings of airlines. The results indicated that drivers scanned twice as many columns in the standard condition as the alphabetical condition. Kichhanagari et al. concluded that this type of advanced warning sign might be helpful in other situations when a large number of destinations need to be listed on several different signs (20).

A third study using driver eye scan patterns involved comparing experienced drivers and novice drivers as they scanned for hazardous events. Underwood et al. found novice drivers showed less extensive scanning on demanding sections than experienced drivers (21). Underwood et al. believe that the underlying reason was because novice drivers have not developed an understanding for the types of events that can occur on the highway (21).

Previous research on scan patterns is important to the research In this paper because where drivers scan when approaching a crosswalk with in-pavement lights is essential to the safety of these crosswalks. The locations where a driver scans will determine whether or not the driver is looking for a pedestrian.

Reaction to Different Colored Warning Lights

Research that involves using non-amber lights for crosswalks with in-pavement warning lights systems does not exist; however, research has been conducted involving the use of non-amber warning lights on construction vehicles and in snowy conditions. Ullman performed an evaluation of blue lights with amber lights on construction vehicles on five urban freeways in Houston and San Antonio, Texas (25). The results showed that the combination of blue and amber lights significantly reduced speeds at which drivers passed the test locations by five to six mph as compared to solely the use of amber lights at two of the five sites. The amber and blue warning lights resulted in a higher braking percentage at three of four sites where nighttime data were collected versus the amber only lights. Additionally, the blue/amber combinations produced a significantly higher percentage of brake applications than the amber light alone at one site. Furthermore, Ullman conducted a survey which resulted in drivers saying that amber lights communicate the least amount of hazard, followed by blue, and then red (25). Additionally, the survey results indicated that blue and amber combination indicates more hazard then amber alone. Ullman concluded that the application of blue light with amber offers a potential to improve safety (25).

Mima and Kajiya conducted a study in Japan to determine the visibility of different color LED lights in snowy conditions (26). The colors tested were red, yellow, green, blue, and white. During the daytime with a white snowy mountain in the background, blue had the greatest visibility and yellow had the second worst visibility with only white being worse. Again, blue had the greatest visibility, when used in blowing and falling snow conditions. Mima and Kajiya recommend using blue with yellow lights in snowy conditions because visibility is greater with blue and people are not used to seeing blue, so the use of yellow as well will cause less confusion (26).

Summary

The preceding sections describe current topics in the transportation industry related to pedestrian safety improvements and scan pattern evaluation. First, many different pedestrian treatments at crosswalks both with the pavement markings, in pavement lighting systems, and alternative signals have been evaluated by researchers in recent years. Researchers have found that some treatments are more successful than others at increasing safety for pedestrians; however research is needed to evaluate the effects on safety of in-pavement warning lights systems versus traditional, unsignalized midblock crosswalks. Second, driver eye scan patterns has been successful in evaluating permissive left-turns, airport terminal signs and comparing novice and experienced drivers when looking for hazardous events. Third, in-pavement warning lights are typically amber, but there is a lack of research about using other colors or color combinations. Research has been conducted involving construction vehicles with different colors and color combinations other than the standard amber only. The use of blue and amber lights has produced better results than amber alone, but more research is needed. Additional research indicates blue lights had greater visibility than yellow when shown in snowy conditions. The following sections summarize the research hypotheses and experimental design of this research project.

CHAPTER III

EXPERIMENTAL DESIGN AND RESEARCH METHODOLOGY

A series of tasks were developed to successfully complete the research objectives and test the established hypotheses presented previously. The sections below describe in detail the four research tasks completed.

Task 1: Literature Review

The initial task was a review of previous literature associated with pedestrian safety. The literature review remained ongoing throughout the entire research process. Several aspects of pedestrian safety were considered in order to identify significant accomplishments to date. First, different types of treatments were reviewed including both in-roadway lights and signals, specifically their effectiveness and how drivers and pedestrians interact with them. Second, research involving driver scan patterns when faced with different situations on the roadway is discussed. Third, research on driver reaction to different colors and color combinations of lights was conducted. The results of the literature review task were described previously in Chapter II.

Task 2: In-Pavement Crosswalk Field Evaluation

This task was a case study which evaluated the existing and proposed in-pavement lights and compared them to each other as well as before and a month after installation at the proposed site. Video camera data was collected at seven total locations, with the following breakdown:

- Four existing in-pavement lights; and,
- Three proposed in-pavement lights both before and after installation.

The hours of collection ranged from 8:00 am to 8:00 pm at the four locations of crosswalks with in-pavement warning lights and 8:00 am to 6:00 pm at the other three locations. The different collection times are a result of daylight conditions and it staying light out longer when data was collected at the crosswalks with existing in-pavement lights. The video cameras were used to analyze pedestrian and vehicular behavior and interaction. Table 1 lists the seven locations where video data was collected.

Table 1 Crosswalk Location for Video Data

Town	Crosswalk Treatments	In-Pavement Roadway System Type	Primary Rd.	Secondary Rd.
Amherst	Existing[a]	Complete[c]	Route 9	Boltwood Ave.
Amherst	Existing	Complete	Route 9	Grosvenor Dr.
Amherst	Existing	Complete	Route 9	Seelye St., Both sides
Amherst	Existing	Complete	Route 9	Dickinson St.
Amherst	Proposed[b]	Partial[d]	Route 116	Hitchcock Rd.
Amherst	Proposed	Partial	Route 116	Walnut Rd.
Amherst	Proposed	Partial	Route 116	Amherst College Service Rd. B

[a] Existing in-pavement roadway system
[b] Proposed in-pavement roadway system
[c] Complete system includes raised crosswalk
[d] Partial system includes at-grade crosswalk

A map of crosswalk locations in Amherst, MA is presented in Figure 9, and the attributes for the different crosswalks are listed in

Table 2. By comparison, Table 3 lists the comparisons that were made between the different crosswalk types and scenario variables.

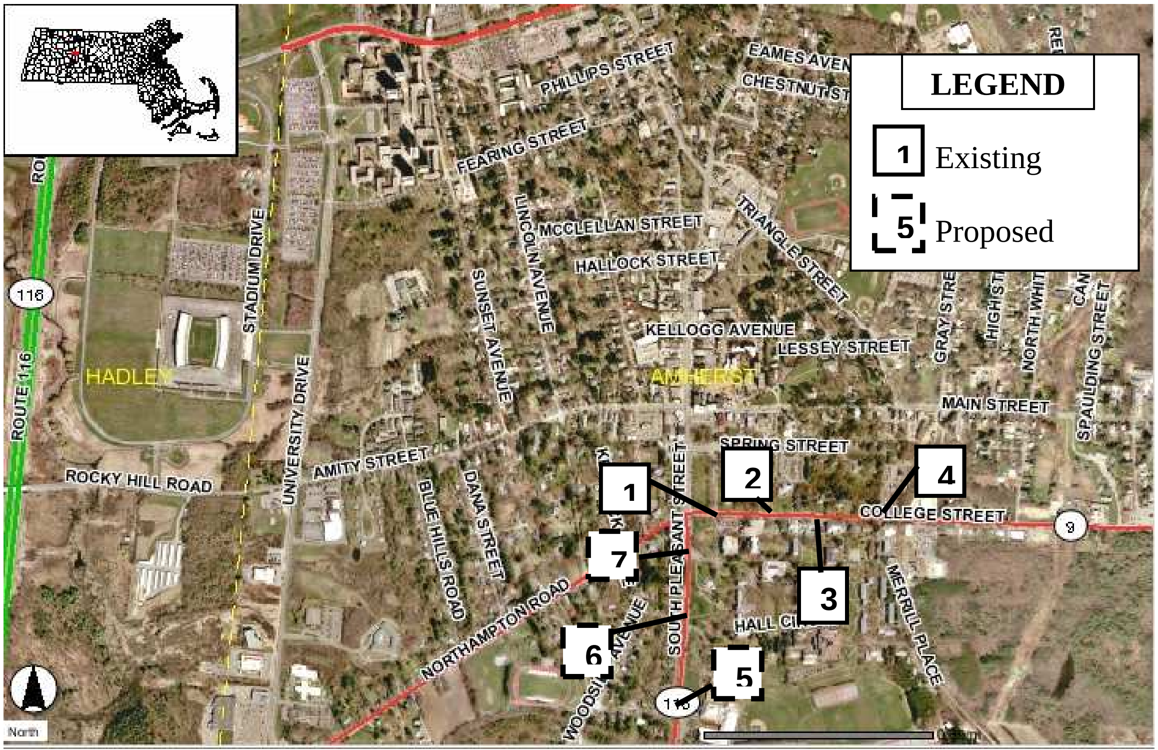


Figure 9 GIS Map of Amherst, MA Crosswalk (22).

Table 2 Crosswalk Attributes

Crosswalk Type	Raised Crosswalk	Pavement Light Direction	Pedestrian Crossing Markings	Refuge Island	LED Pedestrian Sign
Complete In-Pavement Lights System	Yes	Out[a]	Yes	No	Yes
Partial In-Pavement Lights System	No	Both[b]	Yes	Yes	No

Crosswalk Type	Advanced Yield Markings	Retroflective Pedestrian Crossing Signs	Centerline Pedestrian Crossing Signs	Speed (MPH)
Complete In-Pavement Lights System	No	Yes	No	25
Partial In-Pavement Lights System	Yes	Yes	Yes	40

[a] Lights are directed towards vehicles only

[b] Lights are directed out towards vehicles and in towards crosswalk

Table 3 Crosswalk Comparisons

Crosswalk Type and Scenario Variables for Comparison	Partial IPLS After Installation with Flashing	Partial IPLS After Installation with No Flashing	Complete IPLS with No Flashing
Partial IPLS[a] Before Installation	X	X	
Partial IPLS After Installation with Flashing[b]		X	
Complete IPLS with Flashing	X		X
Complete IPLS with No Flashing		X	

[a] In-Pavement Lights System
[b] Activated Lights

Comparisons were made between, but not limited to, the following:

- Partial in-pavement lights systems
    - Before installation and after installation with flashing
    - Before installation and after installation with no flashing
    - After installation with flashing and after installation with no flashing
- Complete in-pavement lights systems
    - With flashing and with no flashing
- Complete in-pavement lights system with flashing and partial in-pavement lights system with flashing
- Complete in-pavement lights system with no flashing and partial in-pavement lights system with no flashing

The measures used to analyze these data are:

- Percentage of drivers who yield to pedestrians crossing at the crosswalk; and,
- Percentage of pedestrians who cross within the crosswalk;

Figure 10 shows the setup of the video camera in the field.

Figure 10 Video Camera Setup in the Field.

The video camera recordings included crosswalk staging where a researcher crosses the crosswalk once a vehicle reaches a certain distance upstream from the crosswalk. Staging provides for a worst-case scenario of the naturalistic range to allow for a consistent method of evaluating in-pavement warning lights. Staging was completed by measuring a specified distance upstream from the crosswalk (based upon approach speed) and posting a research member at that location. When a free flowing vehicle reached that point, the posted member signified to the other member who is standing on the side of the road at the crosswalk three feet back from the curb to start walking at a steady pace. Safety was involved at all stages of the procedure as the crossing researcher only did so in the event that a vehicle yields during this experiment. This process was completed 25 times per direction at each experimental crosswalks and the pedestrian-vehicle interaction was recorded using the video camera. The distances for staging ranged from 100 feet to 200 feet and as noted were based upon the crosswalk approach speed. A distance of 200 feet was chosen on Route 116 because that was the closest distance that allowed drivers to see the pedestrian and choose whether or not to stop. The distances were smaller for Route 9 due to the lower posted speed limit and the close proximity of each crosswalk. The difference between the Boltwood Ave., Grosvenor Dr, and Seelye St., and Dickinson St. distance is Dickinson St. is located at the bottom of a downgrade, so a larger distance was chosen. Staging was conducted at two of the existing locations and the three proposed locations both before and after installation.

Table 4 lists the distance upstream chosen for crosswalk staging.

Table 4 Crosswalk Staging Distances

Location Number	Crosswalk Location	Distance Upstream (ft)
1	Route 9 at Boltwood Ave.	100
2	Route 9 at Grosvenor Dr.	100
3	Route 9 at Seelye St.	100
4	Route 9 at Dickinson St.	150
5	Route 116 at Hitchcock St.	200
6	Route 116 at Walnut St.	200
7	Route 116 at Amherst College Service Road B	200

Both a power analysis test of proportions was completed on the collected data where there was an acceptable sample size. The data used for the statistical analysis was the percentage of drivers who yielded to crossing pedestrians and percentage of pedestrians who used crosswalk. Here the test of proportions was used to determine if in-pavement warning lights increase safety.

Task 3: Driving Simulator Evaluation

The methodology of evaluation to identify driver scan patterns on the approach to a crosswalk with in-pavement warning lights was done using a fixed base, fully interactive driving simulator with an eye and head tracker in the Human Performance

Laboratory (HPL) at UMass. The driving simulator consists of a 1995 four door Saturn sedan. Drivers are able to control the steering, braking, and acceleration just as they would if they were driving the vehicle on the road as the roadway adjusts accordingly to the driver's actions (23). The virtual scenes are displayed on three screens, one in front and two on the side, to create a field of view that subtends 150 degrees (24). Additional features of the simulator include three speakers, one on the left, one on the right, and a subwoofer in front of the vehicle (24), resolution up to 1024 x 768 dots per inch and a refresh rate of 60Hz (23). The driving simulator can also provide realistic noises including wind, road, and other vehicles with appropriate direction, intensity, and Doppler shift (24). The HPL driving simulator is pictured in Figure 11. Designer's Workbench by Coryphaeus Software, Inc. was used to create the simulated in-pavement warning lights crosswalks. Real Drive Scenario Builder (RDSB) software created by Monterey Technologies, Inc. was used to program the driving and interaction with pedestrians in the roadway system (23).

The eye tracker shown in Figure 12 allows for unrestricted head movement of the driver. The eye tracker output is a crosshair coordinated with the driver's eye position signifying where the driver is looking and records the driver eye position every 60 seconds. The tracker was used to determine where the driver is looking and not used for looking at sequential scan patterns. The accuracy of where the driver is looking was reported. The crosshair displayed over a typical simulated screen is pictured in Figure 13. The eye and head tracker was created by Applied Science Laboratories (23).

Figure 11 Human Performance Lab Driving Simulator at University of Massachusetts Amherst.

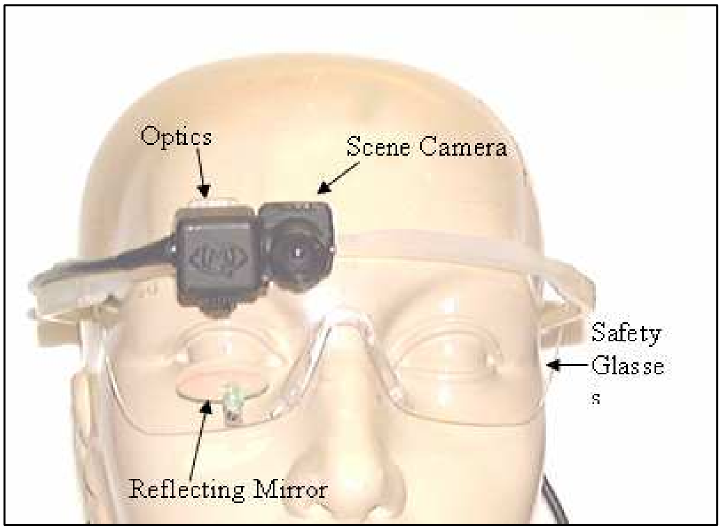


Figure 12 Applied Science Laboratories Eye and Head Tracker.

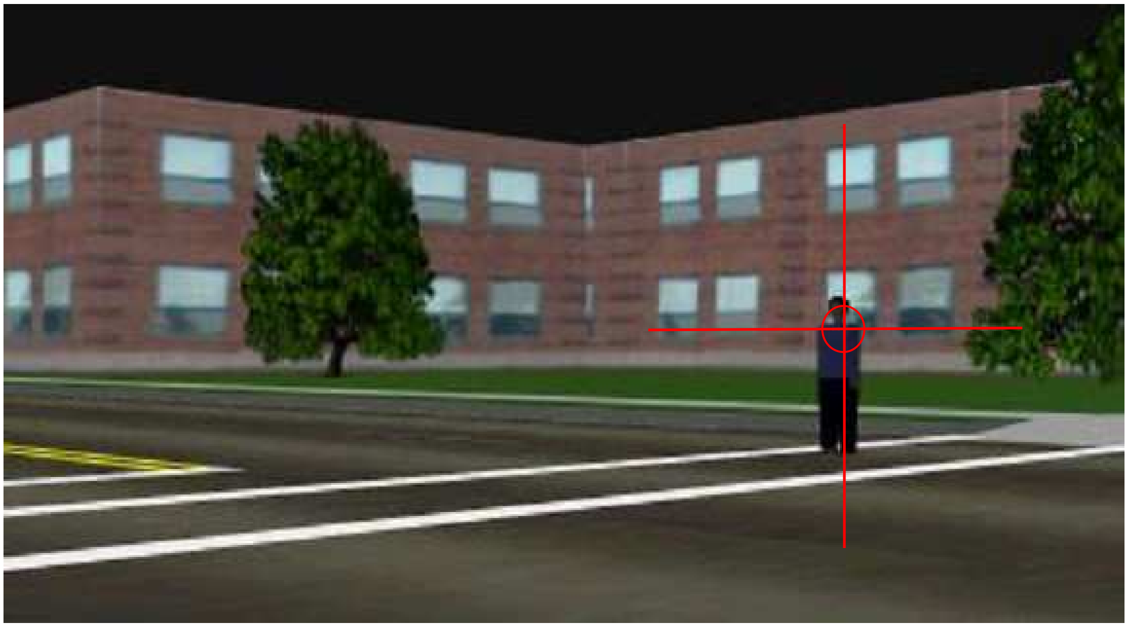


Figure 13 Simulator Screen Capture featuring Eye and Head Tracker Crosshairs.

The experiment consisted of 32 men and women ranging in age from 18 to 65 with a valid drivers' license and an assumed 20/40 vision (corrected) or better and were not screened for demographics. The goal was to have a balanced number of men and women participate in the experiment, with an equal number of men and women in two groups: an experimental and a control group. The experimental condition consisted of 18 crosswalks at night. The first 17 crosswalks consisted of either flashing or no flashing lights. The flashing lights had a pedestrian crossing from either the right or left and the crosswalks without flashing lights did not have a pedestrian. Four different random patterns of flashing and no flashing lights were chosen for the experimental group and are listed in Table 5. The last crosswalk had no flashing lights, but a pedestrian to test if drivers had been reconditioned to look for flashing lights; rather than for pedestrians queued on the curb. Each crosswalk had a pedestrian crossing sign to warn drivers to be alert for potential pedestrians.

Table 5 Simulator Scenarios

	Simulator Scenarios			
Crosswalk	1	2	3	4
1	Flash[a]	No Flash	No Flash	Flash
2	Flash	No Flash	Flash	Flash
3	No Flash[b]	Flash	No Flash	Flash
4	Flash	Flash	Flash	No Flash
5	No Flash	No Flash	No Flash	No Flash
6	No Flash	Flash	Flash	Flash
7	Flash	No Flash	Flash	No Flash
8	Flash	Flash	No Flash	No Flash
9	No Flash	No Flash	Flash	Flash
10	No Flash	Flash	No Flash	Flash
11	Flash	No Flash	No Flash	No Flash
12	No Flash	No Flash	Flash	No Flash
13	Flash	Flash	Flash	Flash
14	No Flash	No Flash	No Flash	Flash
15	No Flash	Flash	Flash	No Flash
16	Flash	Flash	Flash	Flash
17	Flash	Flash	No Flash	No Flash
18	No Flash and a Pedestrian	No Flash and a Pedestrian	No Flash and a Pedestrian	No Flash and a Pedestrian

[a] Lights Activated
[b] Lights Not Activated

The control group was similar to the experimental however, there were no flashing lights at any of the crosswalks. A total of 16 different subjects participated in each group.

The research identified driver scan patterns to determine if the driver was looking at the lights, scanning for pedestrians, or looking elsewhere by comparing the experimental group to the control group. Additionally, the researcher recorded if the driver yielded to the pedestrian and any driver behavior.

The data collected with the driving simulator was used to determine if drivers are looking exclusively at the flashing lights. Additionally, the data collected from this simulator evaluation -- percentage of drivers who yield to pedestrians -- was compared to data collected from simulator evaluations involving traditional marked crosswalks using statistical analysis. This comparison was used to establish whether crosswalks with in-pavement warning lights are safer than traditional marked crosswalks.

Task 4: Documentation of Findings

The results of this research were documented in the form of a Master's Thesis in accordance with the University of Massachusetts Amherst policies and guidelines (27).

CHAPTER IV

ANALYSIS OF EXISTING AND PROPOSED IN-PAVEMENT LIGHTS

The primary objective of this analysis was to evaluate the safety of alternative in-pavement lights systems by comparing data collected in the field of different types of crosswalks and different scenario variables, i.e. flashing, no flashing, before installation, and/or after installation. The two measures used in this analysis were percentage of drivers who yield to pedestrians crossing at the crosswalk and percentage of pedestrians who cross within the crosswalk. This analysis was comprised of three primary subtasks, watching of the video recordings, compiling of recorded data, and analyzing and comparing data between the different types of crosswalks and scenario variables. The following section describes the results of field evaluation. As described in Chapter III, a complete statistical analysis was completed on all results.

Field Evaluation Results and Analysis

A total of 1,949 non-staged pedestrians and 606 staged pedestrians were observed crossing at the seven crosswalk locations. The percentage of drivers who yielded to pedestrians crossing at crosswalks with the complete in-pavement lights system when lights were activated ranged from 90.6 percent to 100.0 percent. The percentage of drivers who yielded to pedestrians crossing at crosswalks with the complete in-pavement lights system when lights were not activated ranged from 90.0 percent to 98.0 percent. At the proposed sites before partial in-pavement lights systems were installed the percentage of drivers who yielded to pedestrians crossing at the crosswalk ranged from

42.5 percent to 50.0 percent. The proposed sites with partial in-pavement lights system installed had a range of 63.9 percent to 100.0 percent when lights were activated and 80.9 percent to 95.0 percent when lights were not activated. A summary of all non-staged yielding percentages is shown in Table 6.

The percentage of drivers who yielded to staged pedestrians crossing at the crosswalks ranged from a low of 30.5 percent to a high of 95.5 percent. A complete summary of all staged yielding percentages can be found in Table 7.

Lastly, the percentage of pedestrians who used the crosswalks ranged from 44.6 percent to 100.0 percent. Table 8 lists the percentage of pedestrians who used the crosswalks evaluated in this study.

Comparisons were made between individual crosswalks, but when the number of observed pedestrians was small, observations from similar crosswalks were combined. Using the test of proportions with a 95 percent confidence interval, a p-value was calculated for all comparisons. A p-value greater than 0.05 indicates that the null hypothesis can be accepted at the 95 percent level, and a p-value less than 0.05 indicates that the null hypothesis can be rejected at the 95 percent level. For all comparisons the null hypothesis was yielding percentages were equal and the alternative hypothesis was yielding percentages were not equal.

When comparing yielding percentage at crosswalks before and after partial in-pavement lights systems were installed a statistically significant difference between before and after with lights activated (p=0.016) and before and after without lights activated (p=0.000) occurred. There was no significant difference between after installation with and without lights activated (p=0.066). Drivers are much more likely to yield to pedestrians crossing crosswalks when partial in-pavement lights systems are installed than when no lights systems exist and no other differences are present. The results show that just the presence of the lights increases yielding whether or not the lights are activated. The effect of the medians was not accounted for in the before and after comparisons as an isolated variable.

Table 6 Non-Staged Crosswalk Yielding Percentages

Crosswalk	% Yield
Partial In-Pavement Lights Systems	
Walnut Before	**42.5%**
Amherst College Before	**50.0%**
Walnut After w/ Flash	**63.9%**
South Amherst College After w/ Flash	**100.0%**
North Amherst College After w/ Flash	**100.0%**
Walnut After w/o Flash	**81.6%**
South Amherst College After w/o Flash	**95.0%**
North Amherst College After w/o Flash	**80.9%**
Complete In-Pavement Lights Systems	
Boltwood w/ Flash	**90.6%**
Grosvenor w/ Flash	**100.0%**
Seelye w/ Flash	**94.6%**
Dickinson w/ Flash	**100.0%**
Boltwood w/o Flash	**94.5%**
Grosvenor w/o Flash	**98.0%**
Seelye w/o Flash	**94.4%**
Dickinson w/o Flash	**90.0%**

Table 7 Staged Crosswalk Yielding Percentages

Crosswalk	% Yield
Partial In-Pavement Lights Systems	
Hitchcock Before	**30.5%**
Walnut Before	**30.9%**
Amherst College Before	**57.8%**
Hitchcock After	**68.1%**
Walnut After	**79.6%**
South Amherst College After	**71.6%**
North Amherst College After	**76.9%**
Complete In-Pavement Lights Systems	
Seelye	**95.5%**
Dickinson	**93.8%**

Table 8 Crosswalk Use Percentages

Crosswalk	% Yield
Partial In-Pavement Lights Systems	
Walnut Before	**63.2%**
Amherst College Before	**44.6%**
Hitchcock After	**93.8%**
Walnut After	**93.8%**
South Amherst College After	**100.0%**
North Amherst College After	**94.8%**
Complete In-Pavement Lights Systems	
Boltwood	**90.3%**
Grosvenor	**90.1%**
Seelye	**94.4%**
Dickinson	**77.2%**

Only one crosswalk with complete in-pavement lights systems had a statistically significant difference between lights activated and lights not activated (p=.0080). The p-values for two of the other three crosswalks with complete in-pavement lights systems are 0.305 and .9140. Not enough observations were made for the fourth crosswalk.

The comparisons between complete and partial in-pavement lights systems were broken down into light activation and no light activation. Each individual crosswalk when lights were activated did not produce enough observations for individual comparisons so the observations were combined for all complete systems and for all partial systems. There was a statistically significant difference between complete systems with lights activation and partial systems with lights systems (p=0.000). Due to the large amount of data collected when lights were not activated each crosswalk with complete in-pavement lights systems was compared with each crosswalk with partial in-pavement lights systems. A total of 16 comparisons were made between complete and partial systems and nine produced statistically significant differences. The comparisons and respective p-values are presented in Table 9. The results show that complete in-pavement lights systems are safer than partial in-pavement lights systems due to the larger percentage of drivers yielding to pedestrians crossing the crosswalks. These results can be attributed to the main differences between the complete and partial systems including raised crosswalks for the complete systems.

Staging produced significant results as well. Three before and after installation of partial in-pavement lights systems comparisons were made and all three resulted in statistically significant differences (p=0.000, 0.000, and .0240). Again, the effect of the median was not accounted for as an isolated variable in the staged comparison between before and after installation. A significant increase in yielding percentage of drivers to pedestrians crossing in the crosswalk resulted after installation. Additionally, eight comparisons were made between complete and partial in-pavement lights systems with staging. All eight resulted in statistically significant differences with higher yielding percentages for complete systems. Table 10 summarizes the results from staged complete and partial systems comparisons.

Table 9 Yielding Percentage Comparisons between Complete and Partial In-Pavement Lights Systems

Complete Crosswalk	Partial Crosswalk	P-Value
Boltwood w/o Flash	Hitchcock After w/o Flash	**0.0470**
Boltwood w/o Flash	Walnut After w/o Flash	**0.0420**
Boltwood w/o Flash	South Amherst College After w/o Flash	**0.9220**
Boltwood w/o Flash	North Amherst College After w/o Flash	**0.0000**
Grosvenor w/o Flash	Hitchcock After w/o Flash	**0.0070**
Grosvenor w/o Flash	Walnut After w/o Flash	**0.0090**
Grosvenor w/o Flash	South Amherst College After w/o Flash	**0.5410**
Grosvenor w/o Flash	North Amherst College After w/o Flash	**0.0000**
Seelye w/o Flash	Hitchcock After w/o Flash	**0.0500**
Seelye w/o Flash	Walnut After w/o Flash	**0.0450**
Seelye w/o Flash	South Amherst College After w/o Flash	**0.9020**
Seelye w/o Flash	North Amherst College After w/o Flash	**0.0000**
Dickinson w/o Flash	Hitchcock After w/o Flash	**0.3540**
Dickinson w/o Flash	Walnut After w/o Flash	**0.2540**
Dickinson w/o Flash	South Amherst College After w/o Flash	**0.4220**
Dickinson w/o Flash	North Amherst College After w/o Flash	**0.0870**

Table 10 Yielding Percentage Comparisons between Staged Complete and Partial In-Pavement Lights Systems

Complete Crosswalk	Partial Crosswalk	P-Value
Seelye	Hitchcock After	**0.0000**
Seelye	Walnut After	**0.0090**
Seelye	South Amherst College After	**0.0000**
Seelye	North Amherst College After	**0.0010**
Dickinson	Hitchcock After	**0.0000**
Dickinson	Walnut After	**0.0240**
Dickinson	South Amherst College After	**0.0000**
Dickinson	North Amherst College After	**0.0050**

Crosswalk use data produced different results from yielding percentage data. Although crosswalk use after installation was statistically significantly higher than before installation with all three p-values equal to 0.000, the results from comparisons between complete and partial systems were the opposite of the previous results with yielding percentages. Comparisons of each crosswalk with complete systems and combined data from the four crosswalks with partial systems resulted in statistically significant differences in three of the four complete crosswalks which are presented in Table 11. Possible explanation for the difference between crosswalk usage at the partial and complete crosswalks are the sidewalks are adjacent to the roadway and the speed limit was less at the complete crosswalks. The difference between crosswalk use and yielding percentages by drivers is crosswalk use was higher at the partial systems than the complete systems, the opposite of yielding percentage data. Combined data from partial systems was used due to the difference in the amount of data collected between complete and partial systems.

Table 11 Crosswalk Use Comparisons between Complete and Partial In-Pavement Lights Systems

Complete Crosswalk	Partial Crosswalk	P-Value
Boltwood	Combined Partial Crosswalks	**0.0050**
Grosvenor	Combined Partial Crosswalks	**0.0070**
Seelye	Combined Partial Crosswalks	**0.8260**
Dickinson	Combined Partial Crosswalks	**0.0000**

Summary

The findings of the field based in-pavement roadways lights experiment include:

- The installation of partial in-pavement roadway lights statistically improves the percentage of drivers who yield to pedestrians crossing in crosswalks over traditional midblock crosswalks.

- Activation of the lights at both partial and complete systems does not statistically improve driver yielding percentage over no light activation leading to the belief that the existence of in-pavement roadway lights increases safety for pedestrians.
- Complete in-pavement lights systems are safer than partial in-pavement lights systems due to the statistically significant differences between yielding percentages.
- Crosswalk use among pedestrians is statistically higher at crosswalks with partial in-pavement roadway lights than crosswalks with complete systems.

Overall the use of in-pavement roadway lights significantly improves the safety of pedestrians at midblock crosswalks. When possible complete in-pavement lights systems should be installed at midblock crosswalks, but partial in-pavement lights systems are better than no lights at all. Results from this study and previous experiments present the success of in-pavement roadway lights.

CHAPTER V

ANALYSIS OF DRIVER'S SCAN PATTERNS

The objective of this analysis was to determine if a consistent scan pattern develops where drivers become accustomed to looking at the in-pavement lights instead of at the curb for a pedestrian. The driver scan evaluation was just the preliminary research to look at scan patterns at crosswalk 18 and then determine if further research should be conducted to delve into the other 17 crosswalks. Furthermore, comparisons were made between yielding percentages and how drivers responded at crosswalks with in-pavement lights and without in-pavement lights. To complete the analysis, drivers were first given a practice course to get accustomed to driving the simulator. Next the drivers were asked to maneuver through a virtual network of crosswalks with and without flashing lights which were created for use in the driving simulator with the eye tracking equipment described in Chapter III. Thirty-three drivers were recruited to participate; however one driver was unable to complete the experiment due to vehicle sickness. Nevertheless, the remaining 32 drivers were split evenly between the experimental course with nine flashing crosswalks with a crossing pedestrian, eight crosswalks with no pedestrian and a final crosswalk with no flashing lights and a pedestrian standing at the curb and a control course with no flashing lights, eight crosswalks with a crossing pedestrian, eight crosswalks without a pedestrian, and a final crosswalk with a pedestrian standing at the curb. While each subject was completing the course, data on yielding and how drivers responded at each crosswalk was recorded on a scorecard as shown in Appendix B. In addition, each subject was asked to complete a follow-up evaluation as shown in Appendix C. This section below presents the data analysis and results from this experiment.

The first section of this chapter provides a demographic description of the drivers that participated in the analysis. The following sections describe the results of the driver comprehension analysis including the yielding percentage and driving responses, follow-up evaluation responses, and the results of the eye tracking data for each of the 32 drivers at each crosswalk scenario. The eye tracker outputs were used to make precise inferences about where drivers were looking while approaching each crosswalk.

Demographics

A total of 32 drivers participated in the driving simulator experiment and follow-up evaluation. In total 576 crosswalk scenarios were evaluated in the driving simulator. Table 12 provides a breakdown of the driver demographics from the experimental and control courses. The sample size in the simulator did not allow for the disaggregating of demographic variables while still allowing for appropriate statistical comparisons.

Table 12 Breakdown of Driver Demographics for Task 3 Experiment

Category	Level	Experimental Course		Control Course	
		No. of Drivers	% of Total[a]	No. of Drivers	% of Total[a]
Gender	Male	8	50	8	50
	Female	8	50	8	50
Age	Under 25	13	81	7	44
	25 to 44	3	19	8	50
	Over 44	0	0	1	6
Annual Miles Driven	Under 10,000	7	44	4	25
	10,000 to 20,000	8	50	9	56
	More than 20,000	1	6	3	19

[a] Percent of sample based on 16 drivers in simulator evaluation

Driving Simulator and Follow-Up Evaluation Results

The following three sections describe the results from the driving simulator evaluation. The first section describes the yielding and driver responses manually recorded during the evaluation followed by the responses from the follow-up evaluation. Finally, the last section describes the results from the scan behavior at crosswalk 18.

Yielding and Braking Responses

Yielding and driver responses were collected manually for all 32 drivers and recorded on the scorecard. Data was summarized individually for the experimental and control groups. Data was broken down into five main categories: scenario 18 with a pedestrian on the left side of the street, scenario 18 with pedestrian on the right side of the street, all crosswalks with no pedestrian on either side of the street, all crosswalks with a pedestrian arriving from the right side of the street, and all crosswalks with a pedestrian arriving from the left side of the street. For each of the main categories, the summarized data included whether or not a pedestrian yielded and any driver responses as they approached the crosswalk. The summarized yielding and response behavior for the experimental group is shown in Table 13 and for the control group in Table 14.

Table 13 Yielding and Driver Response Behavior Experimental Group

		Scenario #18	Scenario #18	Scenario	Scenario	Scenario
		Left Pedestrian	Right Pedestrian	No Pedestrian	Right Pedestrian	Left Pedestrian
		No Flash	No Flash	No Flash	Flash	Flash
Yield	Yes	2	0	16	61	55
	No	6	8	112	10	17
Driver Response Behavior	Slight Brake[a]	0	2	19	0	0
	Advanced Yield[b]	0	0	0	3	3
	Swerved[c]	0	0	0	1	0
	Late Yield[d]	0	0	0	13	11
	Accelerated[e]	0	0	0	1	1
	Barely Waited[f]	0	0	0	2	0

[a] Driver briefly braked, but then accelerated or continued at speed across crosswalk

[b] Driver yielded well in advance of crosswalk

[c] Driver did not brake for the pedestrian, instead swerved to avoid hitting the pedestrian

[d] Driver slammed on the brakes right before traversing crosswalk to avoid hitting the pedestrian

[e] Driver accelerated to traverse crosswalk before the pedestrian appeared in the driver’s path

f Driver traversed crosswalk just as the pedestrian passed out of the path of the driver

Table 14 Yielding and Driver Response Behavior Control Group

		Scenario #18	Scenario #18	Scenario	Scenario	Scenario
		Left Pedestrian	Right Pedestrian	No Pedestrian	Right Pedestrian	Left Pedestrian
		No Flash	No Flash	No Flash	Flash	Flash
Yield	Yes	0	2	19	49	38
	No	8	6	109	23	33
Driver Response Behavior	Slight Brake[a]	2	0	15	0	0
	Swerved[b]	0	0	0	1	0
	Late Yield[c]	0	0	3	16	8

[a] Driver briefly braked, but then accelerated or continued at speed across crosswalk
[b] Driver did not brake for the pedestrian, instead swerved to avoid hitting the pedestrian
[c] Driver slammed on the brakes right before traversing crosswalk to avoid hitting pedestrian

Comparisons were made between the experimental and control groups across the same platforms: crosswalk 18 with a pedestrian on the left side of the street, crosswalk 18 with a pedestrian on the right side of the street, no pedestrian on either side of the street, a pedestrian arriving from the right side of the street, and a pedestrian arriving from the left side of the street. Using the test of proportions with a 95 percent confidence interval, a p-value was calculated for all comparisons. A p-value greater than 0.05 indicates that the null hypothesis can be accepted at the 95 percent level, and a p-value less than 0.05 indicates that the null hypothesis can be rejected at the 95 percent level. For all comparisons the null hypothesis was yielding percentages were equal and the alternative hypothesis was yielding percentages were not equal.

When comparing the experimental group with the control group a statistically significant difference occurred between the experimental and control groups at the crosswalks with a pedestrian approaching from the right side of the street and at crosswalks with a pedestrian approaching from the left side of the street. Drivers were significantly more likely to yield to a pedestrian approaching from either the right or left side of the street when the pedestrian activated the in-pavement lights than if no flashing lights exist. The evaluation did not produce significant results for when no pedestrian existed or at crosswalk number 18 where there were no flashing lights and a pedestrian was present for both the experimental and control group. Table 15 presents the results from the comparison between the experimental group and control group.

Table 15 Yielding Percentage Comparison Between Experimental and Control Groups

Scenario	P-Value
Scenario #18: Left Pedestrian	0.1306
Scenario #18: Right Pedestrian	0.1306
No Pedestrian on Either Side	0.5922
Pedestrian Approaching From the Right	0.0115
Pedestrian Approaching From the Left	0.0040

Some of the more common driver responses for the both the experimental and control groups were braking briefly then either accelerating or continuing at speed when no pedestrian appeared from either side of the road and slamming on the brakes right before traversing the crosswalk as they noticed the pedestrian approaching from either side of the street at the last second.

Follow-Up Evaluation

All drivers who completed the driving simulator evaluation were asked to fill out a follow-up evaluation about in-pavement roadway lights. The results are presented in Table 16.

A majority of the driving simulator participants have encountered in-pavement warning lights as a driver, but not many have encountered them as pedestrians. Due to very few participants using in-pavement roadway lights as a pedestrian, only a few responses were recorded for question three. The participants who have used in-pavement lights typically activate the lights always or only at night. A majority of the participants who responded to questions four and five feel safer as pedestrians and/or as drivers at crosswalks with in-pavement warning lights. Finally, the participants feel crosswalks with in-pavement warning lights make them more aware of possible pedestrians. These results show that most drivers and pedestrians believe that in-pavement warning lights increase safety for both pedestrians and drivers at crosswalks, and most importantly make drivers more aware that a pedestrian might be traversing the roadway.

Table 16 Summary of Follow-Up Evaluation

Question Number	Question Response	Number of Responses
Encounter IPWLS[a] as a driver?	Yes	22
	No	10
Encounter IPWLS as a Pedestrian?	Yes	7
	No	25
Typically activate the lights?	Always	2
	Night	3
	Approaching Vehicle	1
	Occasionally	1
	Never	0
	No Response	0
	N/A	25
Feel safer as a pedestrian at crosswalks with IPWLS?	Yes	9
	No	4
	No Response	0
	N/A	19
Feel safer as a driver at crosswalks with IPS?	Yes	19
	No	2
	No Response	2
	N/A	9
IPWLS make you more aware of pedestrians as a driver?	Yes	20
	No	1
	No Response	2
	N/A	9

[a] In-Pavement Warning Light System

Scanning Behavior from Crosswalk 18

This paper focuses on the scanning behavior at crosswalk number 18. Comparisons of the scanning behavior at crosswalk 18 were made between the experimental and control groups to determine if drivers were becoming accustomed to looking for the lights instead of a pedestrian on the curb. As described earlier, crosswalk 18 in both the experimental group and the control group did not contain flashing lights, but a pedestrian was standing on either the left or right curb. Scanning data was obtained from the eye tracker to determine if the driver did or did not scan left, right or in both directions for a pedestrian. This data was compared to determine if a pattern of scanning for lights occurred at crosswalks with in-pavement lights. It is important to note the limitation of the experimental approach when comparing crosswalk 18 is drivers are being conditioned the way the researchers would like. A summary of the subject's driver scan behavior is shown in table 17.

Table 17 Summary of Subject Scanning Behavior

Group	Number of Drivers Who Scanned in Each Direction		
	Scanned Left Only	Scanned Right Only	Scanned Right & Left
Exp.	0	3	9
Control	1	2	8

The driving simulator evaluation resulted in the following:

- When the driver looked only in one direction, that direction was more likely to be to the right,

- When a driver looked right, it did not matter if the pedestrian was approaching from the right or left side,
- Drivers scanned in both directions equally between the experimental and control group, and,
- When drivers scanned in both directions, they typically scanned in both directions several times

Drivers were more likely to scan only to the right no matter which direction the pedestrian was approaching from possibly because a pedestrian approaching from the right side will appear in the driver's path of motion faster than a pedestrian approaching from the left. The difference between the control group and the experimental group was that there were no flashing lights in the control group. Both the control group and experimental group had no flashing lights and a pedestrian standing on the right or left curb at crosswalk 18. This allowed for accurate comparisons to determine if drivers would become accustomed to looking at the lights instead of scanning for a pedestrian. This was not the case because it would be expected that drivers in the experimental group would be less likely to scan for pedestrians as compared to the control group where they are not being conditioned with lights and pedestrian simultaneously. Since the number of drivers who scanned in both directions did not differ between the experimental and control group, the in-pavement lights are not leading drivers to look for just the lights. Further research into the other 17 crosswalks will delve into determining more specific scan pattern differences between the control and experimental groups.

Summary

The findings of the driving simulator experiment include:

- Drivers were significantly more likely to yield to pedestrians approaching from either the left or right side of the street when in-pavement warning lights were flashing than when no in-pavement lights existed.
- Drivers and pedestrians both feel safer at crosswalks with in-pavement lights and drivers are more aware of possible pedestrians at crosswalks with in-pavement warning lights.
- Drivers are more likely to scan only to the right over scanning only to the left, no matter if the pedestrian is approaching from the right or left and drivers scanned to the left and right equally between the experimental and control group.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Previous research has shown that the in-pavement warning lights system increases percentage of drivers who yield to pedestrians at crosswalks, reduces the rates of pedestrian-vehicle conflicts, reduces the number of pedestrians who cross outside of a crosswalk, and increased noticeability of crosswalks. As a result of these findings, in-pavement warning lights systems have become more popular to install at traditional, midblock crosswalks. After a wide array of research on the topic, a series of questions related to the safety of in-pavement warning lights systems remain and must be evaluated before in-pavement warning lights become more widespread. This research formulates several questions regarding the safety of in-pavement warning lights into research hypotheses with the overall objective of addressing these questions. A series of tasks were developed to successfully meet all of the research objectives and to statistically evaluate each of the developed hypotheses.

Two separate experiments were evaluated to complete the analysis. A total of 1,949 non-staged pedestrians and 606 staged pedestrians were observed crossing at the seven crosswalk locations for the field evaluation and 32 drivers participated in the driving simulator experiment for a total of 576 crosswalk scenarios. The following sections provide summaries of the findings and results from each task, followed by a series of conclusions that addresses each research hypothesis.

Field Evaluation

The analysis of the safety of alternative in-pavement lights systems was completed by comparing data collected in the field of different types of crosswalks and different scenario variables, i.e. flashing, no flashing, before installation, and/or after installation. The results indicate a significant difference between yielding percentage at crosswalks before and after partial in-pavement lights systems were installed when lights were activated (p=0.016) and when lights were not activated (p=0.000) occurred. There was no significant difference between yielding percentage after installation with and without lights activated (p=0.066).

The percentage of drivers who yielded to pedestrians crossing at crosswalks with the complete in-pavement lights system when lights were activated ranged from 90.6 percent to 100.0 percent. The percentage of drivers who yielded to pedestrians crossing at crosswalks with the complete in-pavement lights system when lights were not activated ranged from 90.0 percent to 98.0 percent. At the proposed sites before partial in-pavement lights systems were installed the percentage of drivers who yielded to pedestrians crossing at the crosswalk ranged from 42.5 percent to 50.0 percent. The proposed sites with partial in-pavement lights system installed had a range of 63.9 percent to 100.0 percent when lights were activated and 80.9 percent to 95.0 percent when lights were not activated.

Staging at three crosswalks before and after installation of partial in-pavement lights systems resulted in a significant difference in percentage of drivers who yielded at crosswalks (p=0.000, 0.000, and .0240).

Crosswalk use after installation was statistically significantly higher than before installation with all three p-values equal to 0.000

Driving Simulator Evaluation

The yielding and driver responses were compared between the experimental and control groups. The results from the yielding and driver responses indicated a significant difference between yielding percentage in the experimental group and control group when a pedestrian approached from the right side of the street (p=0.0115) and when a pedestrian approached from the left side of the street (p=0.0041). No significant difference occurred when no pedestrian was presented or at crosswalk 18 when a pedestrian was waiting on the left or right curb.

Driver responses from the follow-up evaluation show that drivers and pedestrians feel safer when traversing crosswalks with in-pavement warning lights than crosswalks without the warning lights. Most importantly drivers are more aware of possible pedestrians at crosswalks with in-pavement roadway lights which is a typical problem at traditional, midblock crosswalks where drivers are not expecting a pedestrian to be crossing the roadway.

The scanning behavior at crosswalk 18 resulted in no significant difference between scan patterns at the control and experimental group. The unique patterns occurring at crosswalk 18 are drivers are more likely to scan only right versus only left no matter which direction the pedestrian approaches from, drivers scan left and right equally between the experimental and control group, and finally, drivers were more likely to scan both directions several times than only once

Conclusions of Research Hypotheses

The research presented herein was directed at addressing the research hypotheses. The following provides a review of the research hypotheses and research finding that pertain to each. A discussion of the research results is also included.

1. *Pedestrian treatments which include the use of in-pavement light systems provide for increased yielding rates and crosswalk usage as compared to unsignalized midblock crosswalks.*

   In the field evaluation, yielding percentage was statistically higher at crosswalks with either partial or complete in-pavement warning lights systems with and without lights activated than traditional, midblock crosswalks. Staging produced similar results with a significantly higher percentage of drivers yielding to pedestrians at crosswalks after installation of in-pavement warning lights compared to before installation. In addition, pedestrians were significantly more likely to use a crosswalk with in-pavement warning lights than a crosswalk without in-pavement warning lights.

2. *When drivers approach a crosswalk with in-pavement warning lights systems a consistent scan pattern develops where drivers become accustomed to looking at the lights instead of at the curb for a pedestrian. This applies primarily at night as pedestrians are not as visible as during the day so drivers may come to rely on the in-pavement lights.*

   In the driving simulator evaluation, the number of drivers scanning left and right at crosswalk 18 did not differ significantly. Drivers did not become accustomed to looking for the lights instead of for a pedestrian as there was no difference between the control and experimental group. In addition, drivers were more likely to scan to the right than to the left and drivers who scanned in both directions were more likely to scan several times in each direction than only one time in each direction.

Recommendations

The data and conclusions of this research effort have led to a series of research recommendations as follows:

- The increased percentage of drivers yielding to pedestrians at crosswalks with in-pavement warning lights and increased use by pedestrians over traditional, midblock crosswalks is consistent with previous research findings. As a result, it recommends the installation at of in-pavement warning lights at traditional, midblock crosswalks.
- Bollards for automatic activation of in-pavement warning lights should be installed at all crosswalks with in-pavement warning lights. This will allow for light activation whenever a pedestrian traverses the road, day or night, taking the decision away from the pedestrian of whether or not to activate the lights.
- Further research into the remaining 17 crosswalks in the driving simulator evaluation to determine more in depth scan patterns at crosswalks with in-pavement warning lights.

Future Research

Although the installation of the in-pavement warning lights is recommended, several additional areas of future research related to the topics detailed herein have been identified. Future research recommendations include the following:

- Continued exploration of safety of drivers and pedestrians at in-pavement warning lights. Although the research indicated drivers are more likely to yield at crosswalks with in-pavement warning lights and pedestrians are more likely to use crosswalks with in-pavement warning lights, the results were obtained shortly after the lights were installed. Further research of safety at crosswalks with in-pavement crosswalks should be conducted to ensure that drivers and pedestrians continue to use the crosswalks properly six months and a year after in-pavement warning lights are installed.
- Continued research of scan patterns at crosswalks with in-pavement warning lights. The research in this report indicated that a scan pattern of looking for the lights did not occur, but future research should be conducted to evaluate the remaining crosswalks from the simulator evaluation to discover in more detail where drivers are scanning when they approach crosswalks with and without in-pavement warning lights.
- Previous research evaluated the use of blue and amber lights on construction vehicles and the visibility of different colored lights in snowy conditions. The results indicated the combination of blue and amber lights on construction vehicles significantly reduced speeds that vehicles passed the construction vehicles and increased the braking percentage as vehicles

approached the construction vehicles. In another experiment, blue lights had the greatest visibility during snowy conditions in daylight while yellow lights had the second worst visibility. Future research needs to evaluate the use of different color and color combinations of warning lights to determine if amber is the safest colored warning light.

APPENDIX A

DRIVING SIMULATOR FORMS

INFORMED CONSENT DOCUMENT

PROJECT TITLE: Evaluation of Traffic Operations in a Driving Simulator

PRINCIPAL INVESTIGATOR: Michael Knodler, Ph.D.

PURPOSE: You have been invited to participate in an experiment to evaluate driver's response to traffic elements presented through simulation. You have been selected because you have a valid driver's license, have normal or corrected to normal vision, and have no apparent limitations impeding your ability to drive. Please read this form and ask any questions you have before agreeing to participate in the study.

If you are particularly susceptible to motion sickness please inform the laboratory assistant before starting the experiment. He or she will determine whether you should continue in the experiment.

PROCEDURE:

BACKGROUND INFORMATION: You will be asked to fill out a demographic questionnaire.

TRAINING: You will be seated in the driver's seat in the driving simulator. The driving simulator consists of a Saturn sedan. The engine has been taken out and the car is unable to move. A three-section screen is placed in front of the Saturn. The screen displays the world ahead of you just as it would were you to be driving on the open road. The laboratory assistant will show you how to stop and how to turn. You will then learn how to do these maneuvers yourself. It should be no more difficult to learn these maneuvers on the Saturn than it is on any car that you have previously driven.

EXPERIMENT: After learning how to drive the simulator, you will begin the experimental session. You will be given a complete set of instructions at that time. There will be 2 testing sessions. The driving portion of each testing session will last approximately 8 minutes. This will be followed up with a short review survey lasting approximately 5 minutes. Training and testing is expected to take no more than 30 minutes.

POSSIBLE RISKS OR DISCOMFORTS:

SIMULATED CRASHES AND ACCIDENTS: You will see other vehicles on the road with you, some in front and some coming at you in the opposite lane. You only have control over your vehicle. These other vehicles will stay in their own lane. However, if you wandered over into their lane or turn in front of them you could collide with them. Do not panic! This is only a simulation. No one will be hurt. As much as we try to make the car you are driving handle like one on a real road, it still differs in several ways from real cars. Thus, you cannot generalize from your performance on the driving simulator directly to your performance on the open road.

SIMULATOR DISCOMFORT DURING THE EXPERIMENT: There is some chance of simulator discomfort (light headedness, dizziness, nausea, motion sickness) while operating the driving simulator. A laboratory assistant will be near the car at all points in time. ***You should indicate to the experimenter as soon as you experience the slightest sign of simulator discomfort***. Usually, this just means that you need to slow down and turn corners more smoothly. However, if the symptoms do not disappear immediately, then the laboratory assistant will stop the simulation and escort you from the vehicle. Your payment for participation in the experiment will remain the same, regardless of when you might first feel discomfort. ***Again, you should indicate to the experimenter as soon as you experience the slightest sign of simulator discomfort***

DRIVING HOME: If you do experience simulator discomfort and do not feel able to drive home, provisions will be made to return you home in a safe and timely manner. Either the laboratory assistant will drive you home in your car or, if you prefer, the assistant will call a taxi and follow you home in your car.

POSSIBLE BENEFITS: By participating in this study you will gain traffic operation knowledge. This may improve driving safety.

SAFEGUARDS: Safeguards associated with crashes, simulator discomfort during the experiment, and possible difficulties driving home have been mentioned above. Additionally, since the car used in the driving simulator will for most individuals be one with which they are not familiar, a spotter will be present as you enter and exit the vehicle to assure that you don't miss-step or lose your balance.

ALTERNATE PROCEDURES: Since the nature of this experiment is to evaluate the effectiveness of driving in a simulated environment, there are no safer alternative procedures. Using a driving simulator provides the realism of driving without the concern for safety.

QUESTIONS AND ANSWERS: Any questions concerning the research, research related injury, or your rights as a participant, will be answered by the investigators before or after testing. Should you have any questions about the experiment, your treatment or any other matter relative to your participation in this project, you may call *Donald L. Fisher* at *413-545-1657* or *Michael Knodler at (413) 545-0228*. If you would like to discuss your rights as a participant in a research study, or wish to speak with someone not directly involved in the study you may contact *Hilary Woodcock, Ph.D., IRB Administrator at hilaryw@ora.umass.edu; (413) 545-3428.*

WITHDRAWAL: Participation is strictly voluntary. You are free to withdraw consent and discontinue participation in the study at any time without prejudice. There are no penalties or loss of benefits from not participating or withdrawing from the study, however, you will not be compensated for participation if you voluntarily withdraw.

CONFIDENTIALITY: None of the information collected during this session will be used to assess your actual driving capabilities. All data obtained during testing will be kept confidential with respect to your identity. You will not be identified by name in any data summaries, nor in any publication or paper derived from this investigation, without your prior consent.

COMPENSATION: You will be compensated **$10** for your participation in this study. No special treatment or compensation by the University of Massachusetts will be available to you if physical injury occurs in connection with the conduct of this research. However, we will do everything possible to help obtain assistance for you in the event of injury. Compensation will be provided after completing the study.

STATEMENT: The investigators have read and understand the General Guidelines of the Rights and Welfare of Human Subjects (Senate Document 79-012) and agree to fulfill these guidelines to the best of their ability.

STATEMENT OF VOLUNTARY CONSENT: I have read the above informed consent. The nature, demands, risk, and benefits of the research have been explained to me in a language that I could understand. I have had the opportunity to ask questions and have received satisfactory answers. I knowingly assume any risk involved, and understand that I may withdraw my consent and discontinue participation at any time without penalty or loss of benefit to myself. In signing this consent form I am not waiving any legal claims, rights or remedies. A copy of this consent will be given to me.

Subject's signature ___________________________ Date _____________

STUDY REPRESENTATIVE STATEMENT

1. I certify that I have explained to the above individual the nature and purpose, the potential benefits and possible risks associated with participation in this research, have answered any questions that been raised, and have witnessed the above signature.

2. I have provided the participant a copy of this signed consent document.

Signature of investigator _______________________ Date _____________

Payment Voucher

Evaluation of Traffic Operations in a Driving Simulator

I have participated in the driving simulator study and have been paid **$10** for my participation. My signature verifies that I have received payment.

Signature:_________________________________Date:______________________

Name (please print):
____

Address:
____

City:_______________________________ State: __________Zip Code: _________

Driving Simulator Study

Demographic Questions

Please answer the following questions by placing a “x” in the appropriate box:

1. Are you:
   ☐ Male
   ☐ Female

2. Your age is:
   ☐ < 24
   ☐ 24 to 44
   ☐ 44-65
   ☐ > 65

3. How many miles have you driven in the past year?
   ☐ 0
   ☐ 1 to 10,000 miles
   ☐ 10,000 to 20,000 miles
   ☐ More than 20,000 miles

4. What is the highest level of education you have completed?
   ☐ I did not graduate from High School
   ☐ I completed High School
   ☐ I completed some College
   ☐ I have a College Degree

APPENDIX B

DRIVING SIMULATOR SCORECARD

SCORECARD

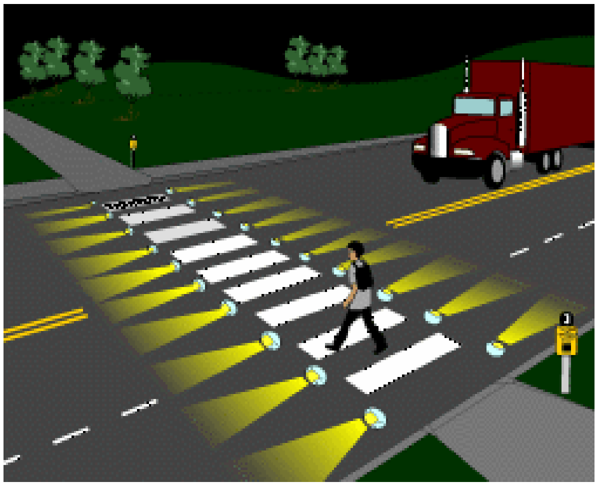
Subject #	__________		**Scenario**	_________	
Crosswalk	Flashing	**Ped. Direction**	**Yield**	**Ped. Conflict**	**Braked Where & Notes**
1	Flash	**R L**	**Y N**	**Y N**	
2	Flash	**R L**	**Y N**	**Y N**	
3	No Flash	**R L**	**Y N**	**Y N**	
4	Flash	**R L**	**Y N**	**Y N**	
5	No Flash	**R L**	**Y N**	**Y N**	
6	No Flash	**R L**	**Y N**	**Y N**	
7	Flash	**R L**	**Y N**	**Y N**	
8	Flash	**R L**	**Y N**	**Y N**	
9	No Flash	**R L**	**Y N**	**Y N**	
10	No Flash	**R L**	**Y N**	**Y N**	
11	Flash	**R L**	**Y N**	**Y N**	
12	No Flash	**R L**	**Y N**	**Y N**	
13	Flash	**R L**	**Y N**	**Y N**	
14	No Flash	**R L**	**Y N**	**Y N**	
15	No Flash	**R L**	**Y N**	**Y N**	
16	Flash	**R L**	**Y N**	**Y N**	
17	Flash	**R L**	**Y N**	**Y N**	
18	No Flash, w/ Ped	**R L**	**Y N**	**Y N**	

APPENDIX C

DRIVING SIMULATOR FOLLOW-UP STATIC EVALUATION

Follow-Up Evaluation

Pictured is a typical in-pavement warning lights system, which is a relatively new treatment in use today. A crosswalk with in-pavement warning lights system consists of yellow lights embedded in the pavement along both sides of the crosswalk. When a pedestrian activates the lights either by pressing a button or through automated detection the lights flash at a constant rate for a set period of time. You may possibly have encountered a similar system to this in Amherst along Route 9 and 116 at Amherst College



Please answer the following questions by placing an “x” in the appropriate box:

1. Have you encountered in-pavement warning lights systems as a driver?

   ☐ Yes
   ☐ No

2. Have you encountered in-pavement warning lights systems as a pedestrian?

   ☐ Yes

   ☐ No

NOTE: If you answered yes to questions 1 and/or 2 please continue on other side; however, if you have answered no to both questions 1 and 2, you have completed the survey. Thanks!

3. If you have encountered in-pavement warning lights systems as a pedestrian do you typically activate the lights?

☐ Always
☐ Only at night
☐ Only when seeing an approaching car
☐ Occasionally
☐ Never
☐ N/A

4. Do you feel safer as a pedestrian at crosswalks with in-pavement warning lights systems?

☐ Yes
☐ No
☐ N/A

Comments:

5. Do you feel safer as a driver at crosswalks with in-pavement warning lights systems?

☐ Yes
☐ No
☐ N/A

Comments:

6. As a driver do crosswalks with in-pavement warning lights systems make you more aware of possible pedestrians?

☐ Yes
☐ No
☐ N/A

Comments:

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