Effect of In-pavement Warning Lights on National Highways

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Abstract— 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 multicities. As per the report 'Make Roads Safe: A Decade of Action' by the Commission for Global Road Safety, road accidents lead to the death of about 1.3 million people in the world each year. 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.

Key words: NHAI, Pedestrian, Crosswalk, ESPRIT, WSF

I. INTRODUCTION

A 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 behaviour.

II. 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.

III. CROSSWALKS

All crosswalk is the most commonly used pedestrian treatment and has been standardized by the NHAI.

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.

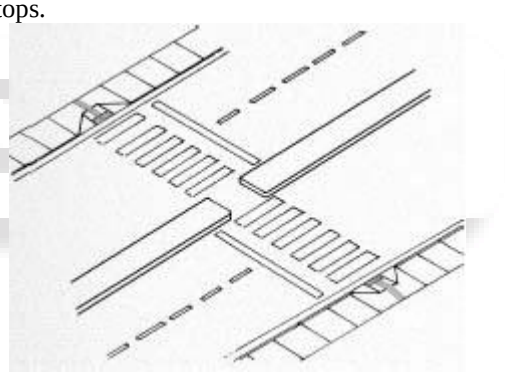

Figure 1: illustrates a midblock crosswalk.

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.

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.

IV. In-Pavement Warning Lights System

Scheduler 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

V. Field Evaluation Results and Analysis

AnA 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 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 1.

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 2.

Lastly, the percentage of pedestrians who used the crosswalks ranged from 44.6 percent to 100.0 percent. Table 3 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.

Crosswalk	% Yield
Partial In-Pavement Lights Systems	
National Highway (NH)- 52 Before	42.5%
OM College Before	50.0%
National Highway (NH)- 52 After w/ Flash	63.9%
OM NH=09College After w/ Flash	100.0%
OM NH- 52College After w/ Flash	100.0%
National Highway (NH)- 52 After w/o Flash	81.6%
OM NH=09College After w/o Flash	95.0%
OM NH- 52College After w/o Flash	80.9%
Complete In-Pavement Lights Systems	
NH- 52 (4lane) towards Ambala w/ Flash	90.6%
NH- 52 (4lane) towards Shiwani w/ Flash	100.0%
NH- 09 (4lane) towards Sirsa w/ Flash	94.6%
NH- 09 (4 lane) towards Delhi w/ Flash	100.0%
NH- 52 (4lane) towards Ambala w/o Flash	94.5%
NH- 52 (4lane) towards Shiwani w/o Flash	98.0%
NH- 09 (4lane) towards Sirsa w/o Flash	94.4%
NH- 09 (4 lane) towards Delhi w/o Flash	90.0%

Table 1: Non-Staged Crosswalk Yielding Percentages

Crosswalk	% Yield
Partial In-Pavement Lights Systems	
National Highway (NH)- 09	30.5%
National Highway (NH)- 52 Before	30.9%
OM College Before	57.8%

National Highway (NH)- 09After	68.1%
National Highway (NH)- 52 After	79.6%
OM NH=09College After	71.6%
OM NH- 52College After	76.9%
Complete In-Pavement Lights Systems	
NH- 09 (4lane) towards Sirsa	95.5%
NH- 09 (4 lane) towards Delhi	93.8%

Table 2: Staged Crosswalk Yielding Percentages

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.

Crosswalk	% Yield
Partial In-Pavement Lights Systems	
National Highway (NH)- 52 Before	63.2%
OM College Before	44.6%
National Highway (NH)- 09After	93.8%
National Highway (NH)- 52 After	93.8%
OM NH=09College After	100.0%
OM NH- 52College After	94.8%
Complete In-Pavement Lights Systems	
NH- 52 (4lane) towards Ambala	90.3%
NH- 52 (4lane) towards Shiwani	90.1%
NH- 09 (4lane) towards Sirsa	94.4%
NH- 09 (4 lane) towards Delhi	77.2%

Table 3: Crosswalk Use Percentages

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 4. 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 5 summarizes the results from staged complete and partial systems comparisons.

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

Complete Crosswalk	Partial Crosswalk	P-Value
NH- 52 (4lane) towards Ambala w/o Flash	National Highway (NH)-52After w/o Flash	0.0470
NH- 52 (4lane) towards Ambala w/o Flash	National Highway (NH)-52 After w/o Flash	0.0420
NH- 52 (4lane) towards Ambala w/o Flash	OM NH=09College After w/o Flash	0.9220
NH- 52 (4lane) towards Ambala w/o Flash	OM NH- 52College After w/o Flash	0.0000
NH- 09 (4lane) towards Shiwani w/o Flash	National Highway (NH)-09After w/o Flash	0.0070
NH- 52 (4lane) towards Shiwani w/o Flash	National Highway (NH)-52 After w/o Flash	0.0090
NH- 52 (4lane) towards Shiwani w/o Flash	OM NH=09College After w/o Flash	0.5410
NH- 52 (4lane) towards Shiwani w/o Flash	OM NH- 52College After w/o Flash	0.0000
NH- 09 (4lane) towards Sirsa w/o Flash	National Highway (NH)-09After w/o Flash	0.0500
NH- 09 (4lane) towards Sirsa w/o Flash	National Highway (NH)-52 After w/o Flash	0.0450
NH- 09 (4lane) towards Sirsa w/o Flash	OM NH=09College After w/o Flash	0.9020
NH- 09 (4lane) towards Sirsa w/o Flash	OM NH- 52College After w/o Flash	0.0000
NH- 09 (4 lane) towards Delhi w/o Flash	National Highway (NH)-09After w/o Flash	0.3540
NH- 09 (4 lane) towards Delhi w/o Flash	National Highway (NH)-52 After w/o Flash	0.2540
NH- 09 (4 lane) towards Delhi w/o Flash	OM NH=09College After w/o Flash	0.4220
NH- 09 (4 lane) towards Delhi w/o Flash	OM NH- 52College After w/o Flash	0.0870

Table 4: Yielding Percentage Comparisons between Complete and Partial In- Pavement Lights Systems

Crosswalk use data produced different results from yielding percentage data although crosswalk use after installation was statistically significantly higher than beforeinstallation 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 6. 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.

Complete Crosswalk	Partial Crosswalk	P-Value
NH- 09 (4lane) towards Sirsa	National Highway (NH)-09After	0.0000
NH- 09 (4lane) towards Sirsa	National Highway (NH)- 52 After	0.0090
NH- 09 (4lane) towards Sirsa	OM NH=09College After	0.0000
NH- 09 (4lane) towards Sirsa	OM NH- 52College After	0.0010
NH- 09 (4 lane) towards Delhi	National Highway (NH)-09After	0.0000
NH- 09 (4 lane) towards Delhi	National Highway (NH)- 52 After	0.0240
NH- 09 (4 lane) towards Delhi	OM NH=09College After	0.0000
NH- 09 (4 lane) towards Delhi	OM NH- 52College After	0.0050

Table 5: Yielding Percentage Comparisons between Staged Complete and Partial In-Pavement Lights Systems

Complete Crosswalk	Partial Crosswalk	P-Value
NH- 52 (4lane) towards Ambala	Combined Partial Crosswalks	0.0050
NH- 52 (4lane) towards Shiwani	Combined Partial Crosswalks	0.0070
NH- 09 (4lane) towards Sirsa	Combined Partial Crosswalks	0.8260
NH- 09 (4 lane) towards Delhi	Combined Partial Crosswalks	0.0000

Table 6: Crosswalk Use Comparisons between Complete and Partial In-Pavement Lights Systems

VI. Conclusion

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.

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