An Evaluation of the Effectiveness of an In-pavement Flashing Light System

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An Evaluation of the Effectiveness of an In-pavement Flashing Light System

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ABSTRACT

Strategies used to enhance pedestrian safety on roadways include the in-pavement flashing light system. These lights are to alert both motorists and pedestrians. While the system has been deployed in some locations, limited documentation exists in the literature on systematic evaluations of the effectiveness of these installations. An evaluation of the effectiveness of an in-pavement flashing light system is summarized in this article. The measures of effectiveness (MOEs) used are yielding behavior of motorists, vehicle speeds, yielding distance from the crosswalk, and conflicts. A "before and after" study strategy was used. Statistical tools such as the test for two proportions and the Welch-Satterthwaite t-test have been used to evaluate the significance of the difference in the MOEs between the two study periods. The study corridor was a relatively low volume roadway located on Burkholder Boulevard in the City of Henderson, Nevada, USA. The results show that the installation of the in-pavement lighting system increases the yielding behavior of motorists significantly ($P<0.001$). The vehicular speeds were decreased when pedestrians were waiting at the curb to cross and when they were crossing ($P<0.001$). The yielding distances were different at a 90 percent confidence level. Motorists yielded to pedestrians on an average about 10 feet upstream from the yield markings and the yielding distances were consistent in both directions. However, no significant difference was found when conflicts were evaluated between the two study periods. These lighting systems thus are beneficial in improving safety for motorists and pedestrians at low traffic volume.

BACKGROUND

Traffic safety has been a paramount concern not only in the United States but also around the world. Even though, in recent years, total traffic fatalities are relatively stable, the vehicle miles of travel and auto ownerships have increased (*1*). Pedestrian safety has emerged as an area of increasing concern. Safety of such road users could be enhanced by implementing strategies that enhance the awareness of motorists' and pedestrians' attention of the crossing location and the activities on the crosswalk. One of the strategies used on roadways to enhance motorists' and pedestrians' awareness and to influence their behavior is the in-pavement flashing light system. These lights are installed on the crosswalk to alert both motorists as well as pedestrians. They flash when activated (actively or passively) for a preset duration while the pedestrian crosses the street. An evaluation of the effectiveness of an installation of the in-pavement lighting system is summarized herein.

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LITERATURE REVIEW

Literature document little research on the use and evaluation of in-pavement flashing systems. The mean driving speed was compared with and without pedestrians in the crosswalk in different crosswalk striping and after installing in-pavement lighting system (*2*). The mean speed was reduced by 6.6 mph when pedestrians were present in the crosswalk. However, the mean speed was not compared in the same scenarios, whether pedestrians were present or absent. In a study conducted on crosswalk warning systems evaluation, drivers' yielding behavior to pedestrians was considered in three situations: 1) when a pedestrian is on the sidewalk, 2) when a pedestrian is on the road at the beginning of crosswalk on a crossing maneuver, and, 3) when a pedestrian is in the middle of crosswalk on a crossing maneuver (*3*). Under certain conditions, the device was found to reduce average vehicle speeds up to 1.2 mph to 3.1 mph near the crosswalk zone. The observed speeds were reduced on an average by 1.9 mph and 0.8 mph after installation of the flashing crosswalk with and without the presence of pedestrians, respectively, but the differences were not statistically significant (*4*). While the system has been deployed in some locations, limited documentation was seen in the literature on evaluations of the effectiveness of these installations using broader measures of effectiveness. This paper addresses this need.

SITE DESCRIPTION

The study area is located along Burkholder Boulevard in the City of Henderson, in the southeast part of the Las Vegas metropolitan area, Nevada, USA. Two driveways, one on either side, are located proximate to the study location. The driveway on the north side, Cinnamon Ridge, provides access to a residential complex and the driveway on the south side provides access a park. Burkholder Boulevard consists of two through lanes, one left turn, and one curb lane in both directions. The schematic sketch of the study location is shown in Figure 1. The curb-to-curb length of the crosswalk is 84 ft. The posted speed limit is 35 mph and the average traffic volume is about 300 vehicles per hour per direction along Burkholder Boulevard during peak hours. The in-pavement lights are placed on both the upstream and downstream edges of the crosswalk. These lights are activated by pedestrian push buttons located on either side of the street. Yield markings are placed 45 ft and 77 ft in advance of the crosswalk on eastbound and westbound direction, respectively. On both sides of the street "yield here to pedestrian" signs with pedestrian pictogram, Manual on Uniform Traffic Control Devices code is R1-5, are also placed (*5*). A photograph of the site with crosswalk and signs is shown in Figure 2. The installed in-pavement flashing light system is shown in Figure 3.

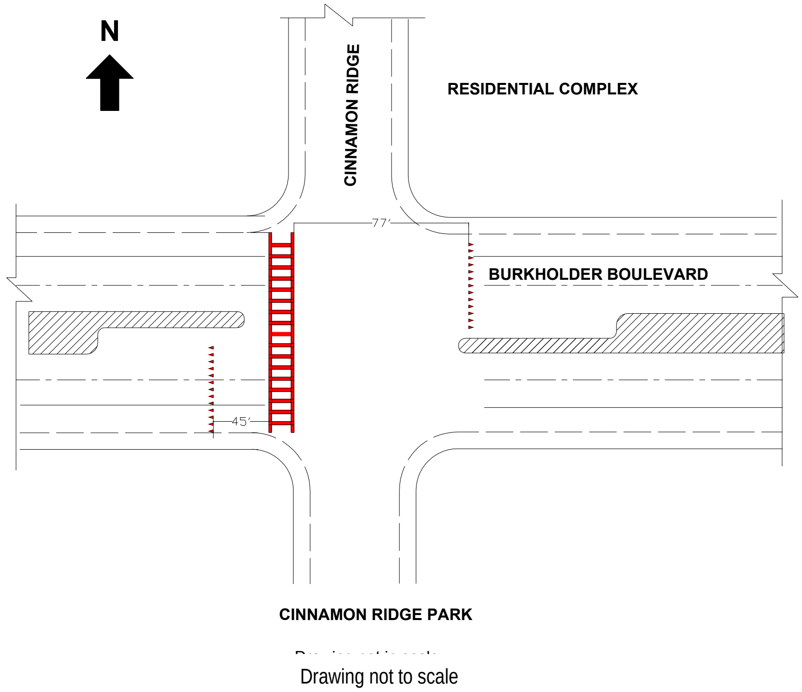

FIGURE 1 Schematic layout of the study location

FIGURE 2 Crosswalk with signs at the study location

FIGURE 3 Installed in-pavement flashing light system at the study location

METHODOLOGY

A before and after study strategy was conducted to evaluate the effectiveness of an in-pavement lighting system at the study location which was previously described. Data were collected in the morning and afternoon peak periods. This was done both prior to the activation of the in-pavement lighting system (the "before" condition) and after the activation of the in-pavement lighting system (the "after" condition). The yielding behavior of motorists, vehicle speeds, yielding distance, and conflicts were identified as measures of effectiveness (MOEs) for comparison of the before and after study periods. The stopping sight distance (SSD) is an important variable to observe in the study of the yielding behavior of motorists. The required distance for motorists to stop safely within perception and brake reaction time is called SSD. The SSD is the sum of the distance traveled during the brake reaction time and the distance traveled for the vehicle to stop after brake is applied. The SSD is given as follows (*6*):

$$d = 1.47Vt + 1.075\frac{V^2}{a} \qquad (1)$$

where,

- d = SSD, ft;
- t = brake reaction time, s;
- V = design speed, mph;
- a = deceleration rate, 11.2 ft/s^2

The posted speed limit for the roadway at the study location is 35 mph. Before the installation of the in-pavement lighting system at the crosswalk, drivers generally are particularly less aware of potential pedestrians' activities. So, a brake reaction time of 2.5 sec (as is used typically for unexpected stimuli) was used to obtain the SSD. After the installation of signage and the in-pavement lighting, motorists were expected to be more aware of the pedestrian activities; therefore, a brake reaction time of 1 sec was used for SSD (*7*). The site was at a level grade. Therefore, the SSDs for the before and after study conditions were 246 ft and 169 ft respectively, as obtained using Equation (1).

A landmark was established at a distance equal to the SSD upstream of the crosswalk for both directions of travel. The "yielding" behavior of motorists to pedestrians was observed. The yielding behavior of the motorist was observed only in the presence of pedestrians in the crosswalk or when a pedestrian was facing oncoming traffic in the crosswalk while crossing. Motorists downstream of the landmark after the pedestrian has entered the roadway can be scored as yielding to pedestrians, but not for failing to yield. Motorists upstream of the landmark when the pedestrian entered the crosswalk were scored as yielding or not yielding because they have sufficient distance to safely stop. When the pedestrian first starts to cross, only drivers in the first half of the roadway are scored for yielding. Once the pedestrian approaches middle of the roadway, the yielding behaviors of motorists in the remaining lanes of the second half of the crosswalk were scored. The yielding observations on motorists were tabulated in terms of the percentage of motorists "yielding" and "not yielding" to pedestrians. Motorists within the SSD in the presence of pedestrians in the crosswalk were not scored. The "yielding" behavior of motorists beyond the SSD was scored as "yielding to pedestrians" or "not yielding to pedestrians." A motorist who allowed pedestrians, who are already in the crosswalk, to cross was scored as "yielding to pedestrians." On the contrary, motorists who speed up, or took other evasive actions such as change lane, etc., and thus who do not allow pedestrians to cross safely was scored as "not yielding to pedestrians." The yielding behaviors of the motorists due to platoon effect and motorists behind the yielded motorists were not recorded (*8*).

The space mean speed of the vehicles was to determine if any changes in speed occurred between the before-and-after evaluation periods. The length of a segment of 246 ft upstream from the edge of the crosswalk on either side was used to determine the speed. The mean speed, median speed, and the 85th percentile speeds were obtained for each evaluation period. These speeds were observed for three scenarios: in the absence of pedestrian(s), while pedestrian(s) were waiting to cross, and while pedestrian(s) were crossing.

The yielding distance upstream of the crosswalk in either direction was also recorded for all motorists who yielded to pedestrians. Curbs were marked on either side of the crosswalk at 20 foot intervals to measure the yielding distance. The yielding distance was approximately estimated if motorists yielded, not parallel to the marking on the road, but in between the markings on the curbs. When a vehicle or a pedestrian had to change the intended path due to an action of either one of them, the outcome is considered a conflict. Conflicts were also observed for both before and after evaluation periods. During long periods when pedestrians were not seen in the crosswalk, an observer acted as a staged pedestrian and crossed the crosswalk facing the oncoming traffic. Four observers, stationed two on either side, recorded the vehicular speeds, the yielding behaviors, the yielding distance, and conflicts.

Data Analysis and Test of Hypotheses

Yielding Proportion

Data were stratified and analyzed for morning and evening peak hours, direction of travel, and based on total observations. The percentages of motorists yielding were obtained for both before and after study evaluation periods. The test for two proportions, a statistical tool, was used to determine if the proportions obtained during the two study periods are significantly different.

Let P_B = proportion of vehicles yielding during the "before" period
P_A = proportion of vehicles yielding during the "after" period

Then, the null hypothesis (H_0) is that the percentage of motorists yielding during "before" period (P_B) and "after" period (P_A) is the same. The alternative hypothesis (H_a) is the percentage of motorists yielding during "after" (P_A) period is more than the percentage of motorists yielding during "before" period (P_B). These hypotheses are expressed mathematically as follows:

H_0: $P_B = P_A$, and
H_a: $P_B < P_A$

The one-tailed test for proportions was used to test these hypotheses at the 95 percent confidence level.
Let X_B = number of vehicles yielding in the "before" period, out of a total of n_B vehicles
X_A = number of vehicles yielding in the "after" period, out of a total of n_A vehicles
The population proportions P_A and P_B are estimated by the sample proportions:

$\hat{P}_A = X_A / n_A$ and $\hat{P}_B = X_B / n_B$

For large sample sizes, the two sample proportions are approximately normally distributed (*9*), and the Z-test for testing the equality of the two proportions vs. the 1-sided alternative can be used. The test statistic used is Z_0, and it is defined as follows

$$Z_0 = \frac{\hat{P}_B - \hat{P}_A}{\sqrt{\hat{P}(1-\hat{P})\left(\frac{1}{n_B} + \frac{1}{n_A}\right)}}$$

where (2)

$$\hat{P} = \frac{X_B + X_A}{n_B + n_A}$$

Z_0 is distributed approximately N (0, 1) when H_0 is true.

The significance probability or P-value for equality of proportions vs. the 1-sided alternative is calculated by:

P-value = $P(Z < Z_0)$

The null hypothesis is rejected if the P-value < 0.05 (for 95% confidence level).

Speeds

A two-sample t-test, the Welch-Satterthwaite t test, was used to compare if speeds are statistically different at two evaluation periods at the 95 percent confidence level. The Welch-Satterthwaite t test is used when the assumption that the two populations have equal variances seems unreasonable. It provides a t-statistic that asymptotically approaches a t-distribution as the sample sizes become large, allowing for an approximate t-test to be calculated when the population variances are not equal. This test is different from the ordinary Student's t-distribution. The variances of the two groups are assumed equal for the Student's t distribution (*10*).

The Welch's t-test will be used to identify the difference between means of independent samples. Let

μ_B = population mean during before evaluation period,
n_B = number of observations during before evaluation period,
$\bar{x}_B$ = sample mean of n_B observations,
s_B^2 = sample variance of observations during before study.

Similarly, μ_A, n_A, $\bar{x}_A$, and s_A^2 are the population mean, number of observations, sample mean, and sample variance of after evaluation period, respectively.

The null hypothesis of equal means for "before" and "after" periods vs. the 1-sided alternative is expressed as:

H_0: $\mu_B - \mu_A = 0$
H_a: $\mu_B - \mu_A > 0$

The test statistic computed from the sample is:

$$t_O = \frac{\bar{x}_B - \bar{x}_A}{\sqrt{\frac{s_B^2}{n_B} + \frac{s_A^2}{n_A}}} \quad (3)$$

The distribution of the test statistic when H_0 is true is a t-distribution with approximate degree of freedom (*11*) given by:

$$df = \frac{\left(\frac{s_B^2}{n_B} + \frac{s_A^2}{n_A}\right)^2}{\frac{\left(\frac{s_B^2}{n_B}\right)^2}{n_B - 1} + \frac{\left(\frac{s_A^2}{n_A}\right)^2}{n_A - 1}} \quad (4)$$

The significance probability or P-value for equality of means vs. the 1-sided alternative is calculated by:

P-value = $P(t_{df} > t_0)$

If the obtained P-value is more than the critical α-value, i.e., 0.05 at the 95 percent confidence level then H_0 is accepted. Similarly, if the P-value is less than the α-value, then H_0 is rejected at the 95 percent confidence level.

Speeds of Drivers Facing the Sun
The Welch-Satterthwaite t test was also used to compare the mean speed of drivers facing the sun (μ_{FS}) and the mean speed of drivers with the sun behind them (μ_{BS}). The speeds for drivers facing the sun are observations on eastbound during AM peak hours and westbound during PM hours. Similarly, the speeds for drivers with the sun behind them are observations on eastbound PM hours and westbound AM peak hours. Then, the hypotheses are expresses as follows:

The null hypothesis, $H_0: \mu_{FS} = \mu_{BS}$
The alternative hypothesis, $H_a: \mu_{FS} \neq \mu_{BS}$

The P-value for the Welch-Satterthwaite t test in this case is given by:

$$\text{P-value} = 2\ P(t_{df} > |t_0|).$$

The null hypothesis of equal means is rejected if P-value < 0.05.

Yielding Distance
The Welch-Satterthwaite t test was used to compare the yielding distance before and after the installation of the in-pavement lighting system. The null hypothesis of equal the means of yielding distances before study period, μ_{BY}, and after study period, μ_{AY} vs. the 1-sided alternative is expressed as:

$H_0: \mu_{BY} = \mu_{AY}$
$H_a: \mu_{BY} < \mu_{AY}$

The P-value for the Welch-Satterthwaite t test in this case is given by:
$$\text{P-value} = P(t_{df} > |t_0|)$$
The null hypothesis of equal means is rejected if P-value < 0.10 at the 90 percent confidence level.

Conflicts
The test for two proportions was used to compare the percentages of conflicts before and after the installation of the in-pavement lighting system. The null hypothesis (H_0) is that the percentage of conflicts before (P_{BC}) and after (P_{AC}) the installation of the in-pavement lighting system is the same. The alternative hypothesis (H_a) is 2-sided, i.e., the two proportions are different. These hypotheses are expressed mathematically as follows:

H_0: $P_{BC} = P_{AC}$, and
H_a: $P_{BC} \neq P_{AC}$.

The two-tailed test for proportions was used to test these hypotheses at the 95 percent confidence level. The P-value is calculated from:

$$\text{P-value} = 2\ P(Z > |Z_0|)$$

The null hypothesis of equal proportions is rejected if P-value < 0.05.

RESULTS

Motorists' Yielding

The proportion of motorists yielding to pedestrians during the two study periods is shown in Table 1. The proportion of motorists yielding before the installation of the in-pavement lighting system were about 34, 38, and 36 percent for AM, PM, and AM and PM total observations, respectively. These motorists yielding proportions after the installation of the in-pavement lighting system *increased by* about 31, 40, and 37 percent for AM, PM, and AM and PM total, respectively. The increase in the proportion of motorists' yielding during after study period was highly significant. The P-values are presented in Table 1. The P-values are less than the critical α-value (0.05 for 95 percent confidence) so that the null hypothesis was rejected. Hence the in-pavement lighting system was seen to help increase motorists' yielding. Motorists are more cautious about the presence of signage, markings, and illumination of the in-pavement lighting.

TABLE 1 Motorists Yielding to Pedestrians Before and After In-Pavement Light System Installation

Data collection periods	Before			After			Hypotheses test		
	Total sample size	Number of motorists yielding	Percentage of motorists yielding	Total sample size	Number of motorists yielding	Percentage of motorists yielding	Estimated difference of means	P-value	Null hypothesis
AM	62	21	33.87	88	57	64.77	-30.90	<0.001	Reject
PM	56	21	37.50	160	123	76.88	-39.37	<0.001	Reject
AM and PM	118	42	35.59	247	180	72.87	-37.28	<0.001	Reject

Note: (H_0: $P_B = P_A$, and H_a: $P_B < P_A$)

Speeds

The average, median, and the 85th percentile speeds in three scenarios: no pedestrians in the crosswalk, pedestrians waiting to cross, and pedestrians crossing in the crosswalk are shown in Table 2, Table 3, and Table 4, respectively. The observed speeds with no pedestrians during the two study periods were not significantly different at the various study periods. In this case, average speeds were not significantly different before and after the installation of the in-pavement lighting system while no pedestrians were present in the crosswalk. Therefore, the null hypothesis cannot be rejected except for AM data set. The statistical summary of the differences of means is shown in Table 5. Along with the implementation of the in-pavement lighting, other signage, and pavement markings were also installed; these devices help make alert the motorists. Consequently, this affects the vehicle speed after implementation of the in-pavement lighting system even though no pedestrians were present at the crosswalk. Another reason may be that if motorists who are far upstream from the crosswalk see flashing lights on the crosswalk while pedestrians are crossing on the crosswalk may reduce their speed. By the time they reach the landmark, their speed could be reduced even though the in-pavement lights were turned off. Thus, their speeds are lower even though no pedestrians are present in the crosswalk.

TABLE 2 Vehicle Speeds with No Pedestrians in the Crosswalk Before and After In-Pavement Light System Installation

Description	Before				After			
	Average speed (mph)	Median speed (mph)	85^{th} percentile speed (mph)	Sample size (n)	Average speed (mph)	Median speed (mph)	85^{th} percentile speed (mph)	Sample size (n)
AM	36.25	36.07	42.16	78	32.42	32.88	40.57	106
PM	38.54	36.54	49.70	103	40.88	41.31	49.64	192
AM and PM	37.55	36.22	46.90	181	37.87	38.12	47.39	298
Eastbound	36.10	34.47	43.00	98	35.89	35.61	45.50	160
Westbound	39.27	37.86	50.60	83	40.17	39.32	49.03	138
Eastbound (AM) and westbound (PM)	38.28	34.51	49.00	99	36.80	36.50	47.53	162
Eastbound (PM) and westbound (AM)	36.68	37.15	43.93	82	39.15	39.23	46.81	136

The average speeds before the installation of the in-pavement lighting system were higher than after the installation of the in-pavement lighting system while pedestrians were waiting to cross except during PM peak hours. These speed data are shown in Table 3 and their statistical significance before and after evaluation periods are shown in Table 5. The P-values to compare the means between the two study periods are less than 0.05 so that the mean speeds are different except for PM observations at the 95 percent confidence level. The average speed after the installation of the in-pavement lighting system was reduced by 4.7 mph based on the observations during the AM and PM periods.

TABLE 3 Vehicle Speeds with Pedestrians Waiting to Cross Before and After In-Pavement Light System Installation

Description	Before				After			
	Average speed (mph)	Median speed (mph)	85^{th} percentile speed (mph)	Sample size (n)	Average speed (mph)	Median speed (mph)	85^{th} percentile speed (mph)	Sample size (n)
AM	37.49	35.46	45.36	69	28.37	28.38	34.33	50
PM	33.43	35.54	43.04	15	38.43	42.14	49.25	19
AM and PM	35.90	34.99	46.04	84	31.14	30.61	40.01	69
Eastbound	33.76	33.08	39.93	53	28.25	27.93	35.68	36
Westbound	41.92	41.41	50.74	31	34.29	33.55	43.54	33
Eastbound (AM) and westbound (PM)	33.68	32.89	37.99	40	31.50	29.43	40.77	39
Eastbound (PM) and westbound (AM)	39.58	40.09	49.48	44	30.68	31.50	39.12	30

The average, median, and the 85^{th} percentile speeds were decreased after the installation of the in-pavement lighting system while pedestrians were crossing in the crosswalk. These values are depicted in Table 4. The means of the speeds at different data collection timings are significantly lower after the installation of the in-pavement lighting system at the 95 percent confidence level. The P-values are lower than 0.05 so the null hypothesis is rejected.

TABLE 4 Vehicle Speeds with Pedestrians Crossing Before and After In-Pavement Light System Installation

Description	Before				After			
	Average speed (mph)	Median speed (mph)	85th percentile speed (mph)	Sample size (n)	Average speed (mph)	Median speed (mph)	85th percentile speed (mph)	Sample size (n)
AM	26.71	24.27	35.89	41	22.82	20.22	32.07	78
PM	28.38	28.72	38.71	41	20.72	17.28	32.18	80
AM and PM	27.55	26.73	37.30	82	21.56	18.40	32.21	158
Eastbound	28.23	27.72	37.41	53	21.48	18.71	30.61	82
Westbound	26.30	22.91	37.06	29	22.06	18.07	33.82	76
Eastbound (AM) and westbound (PM)	27.52	26.81	33.54	16	21.38	17.72	32.07	84
Eastbound (PM) and westbound (AM)	27.55	26.73	38.04	66	22.19	19.15	32.42	74

TABLE 5 Estimated Difference of Mean Speeds in Three Scenarios

Description	No pedestrians			Pedestrians waiting to cross			Pedestrians crossing		
	Estimated difference of means	P-value	Null hypothesis	Estimated difference of means	P-value	Null hypothesis	Estimated difference of means	P-value	Null hypothesis
AM	3.82	<0.001	Reject	7.09	<0.001	Reject	3.88	0.013	Reject
PM	-2.35	0.972	Do not reject	-5.00	0.925	Do not reject	7.65	<0.001	Reject
AM and PM	-0.32	0.648	Do not reject	4.75	0.001	Reject	5.78	<0.001	Reject
Eastbound	0.20	0.418	Do not reject	5.50	<0.001	Reject	6.74	<0.001	Reject
Westbound	-0.91	0.741	Do not reject	7.62	<0.001	Reject	4.24	0.037	Reject

Note: (H_0: $\mu_B - \mu_A = 0$ and H_a: $\mu_B - \mu_A > 0$)

The mean speeds were also compared to evaluate if there is any significant difference in speeds when facing the sun while driving, i.e., facing the sun while driving eastbound in the morning peak hours and westbound in the evening peak hours. Therefore, the mean speeds of two peak hours eastbound (AM) and westbound (PM), μ_{FS}, and eastbound (PM) and westbound (AM), μ_{BS}, were compared for three scenarios: while pedestrians in the crosswalk, pedestrians waiting to cross, and pedestrians crossing for both before and after study periods. The mean, median, and the 85th percentile speeds are shown in Table 2, Table 3, and Table 4, and the difference of the mean speeds and their statistical significance are shown in Table 6. However, the differences in means as shown in Table 6 are statistically different only in two cases: pedestrians were waiting to cross before the installation of the in-pavement lighting system and no pedestrians were present in the crosswalk after the installation of the in-pavement lighting system. This does not lead to any conclusive finding in this regard.

TABLE 6 Comparison of Speeds for Drivers Facing the Sun in Eastbound (AM) and Westbound (PM) Vs. Drivers with the Sun Behind Them in Eastbound (PM) and Westbound (AM)

Description	Before			After		
	Estimated difference of means	P-value	Null hypothesis	Estimated difference of means	P-value	Null hypothesis
No pedestrians	1.60	0.219	Do not reject	-2.34	0.024	Reject
Pedestrians waiting to cross	-5.89	<0.001	Reject	0.81	0.695	Do not reject
Pedestrians crossing	-0.03	0.987	Do not reject	-0.80	0.619	Do not reject

Note: (H_0: $\mu_{FS} = \mu_{BS}$, H_a: $\mu_{FS} \neq \mu_{BS}$)

Yielding Distance

Yield markings were placed 45 ft and 77 ft away from the crosswalk in eastbound and westbound directions, respectively. Results show that motorists yielded on an average about 9 ft further upstream of the crosswalk for the eastbound direction after installation of the in-pavement lighting. However, for the westbound direction motorists' average yielding distance was reduced by an average of about 20 ft toward the crosswalk after the installation of the in-pavement lighting. The crosswalk in the westbound direction is located after the driveway. Motorists yield to pedestrians before the driveway. For the "before condition," they used to yield far away from the driveway. After installation of the in-pavement lighting, they generally yielded close to the yield marking, which is 77 ft away from the crosswalk. Interestingly, the average yielding distance was on an average about 10 ft further upstream from the yield marking in both directions. The mean yielding distance and corresponding sample size for before and after the installation of the in-pavement lighting system are shown in Table 7. The yielding distances before and after study evaluation periods were significantly different at the 90 percent confidence level. The estimated difference of means for eastbound and westbound directions and P-values are shown in Table 8. It is interesting to note that the mean yielding distance in the westbound direction was greater in the "before" scenario than in the "after" scenario. This is possibly because of the fact that in the "before" scenario there was no clear identification of the location where vehicles were expected to stop (because of the driveway that was located immediately upstream of the crosswalk). This could have led the motorists to stop (yield) well in advance of where the yield markings were subsequently put in place.

TABLE 7 Yielding Distance Before and After In-Pavement Light System Installation

Direction	Before			After		
	Mean yielding distance (ft)	Median yielding distance (ft)	Sample size	Mean yielding distance (ft)	Median yielding distance (ft)	Sample size
Eastbound	44.4	45.0	24	53.4	45.0	81
Westbound	110.1	100.0	17	89.7	80.0	86

TABLE 8 Comparison of Yielding Distance Before and After In-Pavement Light System Installation

Description	Estimated difference of means (before - after)	P-value	Null hypothesis at 90% confidence level
Eastbound	-9.05	0.078	Reject
Westbound	20.40	0.063	Reject

Note: (H_0: $\mu_{BY} = \mu_{AY}$ and H_a: $\mu_{BY} < \mu_{AY}$)

Conflicts

The conflict observations were recorded when a pedestrian interacts with one or more motorists while crossing in the crosswalk. Before and after the installation of the in-pavement light about 10 and 12 percent of conflicts were observed, respectively. A marginal difference in conflict was found before and after the installation of the in-pavement lighting system. However, the observed difference in conflict was not statistically significant at the 95 percent confidence level. The number of observations, the percentage of conflicts, and the P-value are shown in Table 9.

TABLE 9 Conflict Observations Before and After In-Pavement Light System Installation

Study periods	Number of observations	Number of conflicts	Conflicts (%)	Estimated difference of means (before - after)	P-value
Before	118	12	10.17	-1.93	0.578
After	248	30	12.10		

Note: (H_0: $P_{BC} = P_{AC}$, and H_a: $P_{BC} \neq P_{AC}$)

CONCLUSIONS

The in-pavement lighting system appears to be an effective strategy to increase motorists' yielding behavior in case of low traffic and pedestrian volumes. The speed of vehicles was also reduced after installation of the in-pavement lighting system while pedestrians were waiting to cross and pedestrians were crossing. The yielding distance of motorists was also increased due to the installation of the in-pavement lighting system by about 9 ft in the eastbound direction. However, the yielding distance in the westbound direction was reduced by about 20 ft. This could be because the motorists might not be sure where to yield for pedestrians to cross before the installation of the in-pavement lighting system when the driveway was just upstream of the crosswalk. The yielding distance was consistent from the yielding markings for both directions, i.e., on an average 10 ft upstream from the yield markings. The advance yield markings provide motorists as a guidance to yield pedestrians upstream of the crosswalk when pedestrians are present in the crosswalk. Marginal differences in conflicts were observed in both study periods, although this was not statistically significant. Thus, the in-pavement lighting system evaluated was seen to be beneficial in improving pedestrian safety at a low traffic volume location.

RECOMMENDATIONS

Installation of an in-pavement lighting system at locations with low traffic volume yields was seen to offer safety benefits for both pedestrians and motorists by reducing speed and increasing yielding behavior. The findings presented in this paper will be beneficial for agencies considering installing the in-pavement flashing light system. The motorists' yielding behavior also depends on pedestrian and traffic volumes. Locations with comparatively high pedestrian and traffic volumes might experience more vehicular delays after implementation of the in-pavement lighting system. Thus, further research is recommended to quantify pedestrians and vehicular delay due to installation of in-pavement flashing systems under different traffic and pedestrian volume combinations. Also, the impact of the lower vehicular speeds after the installation of the in-pavement lighting system along corridor with signal progression merits further analysis.

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