Safety Effectiveness of Leading Pedestrian Intervals Evaluated by a Before–After Study with Comparison Groups

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Strategies to reduce pedestrian–vehicle crashes at intersections should be investigated. Implementation of the leading pedestrian interval (LPI) has been recommended as a strategy for reducing pedestrian–vehicle crashes at signalized intersections; however, research on quantification of the safety effects of the LPI has been limited. Site characteristics, traffic volumes, pedestrian volumes, and crash data were obtained for 10 signalized intersections where the LPI was implemented in State College, Pennsylvania. Similar data were obtained for 14 stop-controlled intersections within the State College area. A before–after with comparison group study design was used to evaluate the safety effectiveness of the LPI implementations. The results suggest a 58.7% reduction in pedestrian–vehicle crashes at treated intersections, which is statistically significant at the 95% confidence level. An economic analysis was also conducted to determine the cost-effectiveness of the strategy. Given the low cost of this strategy, only a modest reduction in crashes is needed to justify its use economically. On the basis of the estimated safety effectiveness, the necessary crash reduction is easily achievable.

Pedestrian safety and the need to reduce pedestrian deaths and injuries are well-documented goals of the transportation profession. A total of 4,784 pedestrian fatalities and 61,000 pedestrian injuries in traffic crashes occurred in the United States in 2006 (*1*). A variety of engineering treatments are available to improve pedestrian safety and mobility. The leading pedestrian interval (LPI) is one treatment that has been implemented at signalized intersections with the goal of improving safety for pedestrians. During an LPI, pedestrians receive the walk indication before the start of the green indication for adjacent vehicular movements. The length of the LPI may vary on the basis of site characteristics, but it is generally 3 to 7 s in duration. The advance walk interval is intended to improve safety by reducing the potential for crashes between pedestrians and vehicles by providing a brief temporal separation for both road users. In addition, the LPI has value in giving pedestrians priority over turning vehicles and encouraging nonmotorized transportation by providing improved pedestrian service at signalized intersections. The presence of right-turn-on-red (RTOR) traffic may reduce the effectiveness of LPIs by allowing the potential for conflicts between pedestrians and vehicles during the leading portion of the pedestrian phase. Restricting RTOR traffic to eliminate conflicts during the LPI can have negative impacts on intersection vehicle capacity.

One measure of effectiveness for the evaluation of pedestrian safety at signalized intersections is pedestrian–vehicle crashes. Surrogate safety measures include conflicts between pedestrians and vehicles, compliance with signals, and the ability of pedestrians to finish crossing by the end of the clearance interval (*2*). Several observational studies have shown that LPIs reduce conflicts between pedestrians and turning vehicles. To date, only limited reporting on before–after crash analysis at sites where LPIs were implemented has been presented.

OBJECTIVE

The objective of the present study was to evaluate the safety effects of the implementation of the LPI at 10 signalized intersections in the central business district in State College, Pennsylvania. The 10 treatment locations were at existing signalized intersections with pedestrian signal heads. A before–after with comparison group study design was used to determine the safety effectiveness of LPIs on pedestrian–vehicle crashes.

LITERATURE REVIEW

The LPI has been specifically described in the 1961, 1971, and 1978 editions of the *Manual on Uniform Traffic Control Devices* (MUTCD). No specific text in the Highway Traffic Signals Section (Part 4) of the MUTCD describes an LPI; however, a signal sequence with an LPI is fully compliant with the guidelines in the manual, as long as the basic principles and rules for signal displays outlined in MUTCD are followed (*3*). Few guidelines on warrants for LPI installation at signalized intersections exist. Hubbard et al. have suggested that a threshold of compromised pedestrian crossings be developed to determine if LPI implementation is appropriate (*4*). For example, an LPI may be appropriate if the number of compromised pedestrian crossings exceeds 15% at a given crosswalk (*4*). At intersections with high pedestrian volumes, high turning-vehicle volumes, and RTOR restrictions for traffic moving parallel to a marked crosswalk, an LPI timed to allow slower walkers to cross at least one moving lane of traffic is recommended to reduce conflicts between pedestrians and turning vehicles (*5*). In *Guidelines and Recommendations to Accommodate Older Drivers and Pedestrians,* the LPI is calculated by using the formula in Equation 1.

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Transportation Research Record: Journal of the Transportation Research Board, No. 2198, Transportation Research Board of the National Academies, Washington, D.C., 2010, pp. 15–22.
DOI: 10.3141/2198-03

$$\mathrm{LPI} = \frac{(\mathrm{ML} + \mathrm{PL})}{\mathrm{WS}}$$

for a minimum of 3 s (1)

where

LPI = time between onset of the walk signal for pedestrians and the green indication (s),
ML = width of lane for moving traffic (ft),
PL = width of parking lane (ft), and
WS = walking speed (a value of 2.8 ft/s is suggested for older pedestrians).

Field evaluations of LPIs have shown reduced conflicts between pedestrians and turning vehicles. In a study of LPI implementation at three sites in St. Petersburg, Florida, the odds of conflict for pedestrians leaving the curb at the beginning of the walk period were reduced by approximately 95% (*6*). The likelihood that a pedestrian would yield to a turning vehicle during the LPI condition also decreased by approximately 60% (*6*). The Pedestrian Safety Countermeasure Deployment Project reported a substantial reduction in "vehicles turning in front of pedestrians" and in "pedestrians finishing crossing on the don't walk indication" at two intersections with LPIs (*7*). In a survey of pedestrians during the same study, about 56% of the respondents believed that the signal timing change made them feel "extremely safe" or "more safe"; however, only 8% were able to identify correctly that a change in signal operation had been made. As described elsewhere (*8*), Malenfant and Van Houten have reported that LPIs in combination with other engineering treatments, such as advance stop lines, have had the strongest influence on motorists yielding to pedestrians and in reducing pedestrian–vehicle conflicts. The research addresses pedestrian–vehicle conflicts and yielding behaviors and suggests that crash data be analyzed in the future to aid with the drawing of conclusions about the pedestrian safety offered by the treatments (*8*).

Only limited documentation of pedestrian–vehicle crash analyses after the implementation of LPIs is available. King reports on the safety effectiveness of LPIs at signalized intersections in New York City (*9*). The New York State Department of Transportation (NYSDOT) investigated 26 locations with LPIs and compared the crash rates for those locations with those for a group of similar intersections nearby where the LPIs were not implemented (a control group). Up to 10 years of crash data for each intersection were obtained from the NYSDOT crash mapping database, providing data for a total of 192 pedestrian–vehicle crashes at the intersections with LPIs and 352 pedestrian–vehicle crashes at the control sites. The basic analysis established eight crash rates for each intersection with an LPI: before and after absolute, before and after factored for severity, before and after absolute at control sites, and before and after factored for severity at control sites. The rates at each intersection with an LPI were compared to give an absolute rate of change, which was then factored for severity. Similar calculations were performed for the control site locations. The absolute numbers were then compared with those at the control sites to provide a relative rate of change, which was then factored for severity. The crash analysis suggests that LPIs have a positive effect on pedestrian safety, particularly for crashes involving a turning vehicle (28% reduction compared with the rate for control sites and a 64% reduction factored for severity) (*9*). The statistical significance of the results was not reported, which makes it difficult to assess the impact of the LPIs. The results also indicated an increase in all injury crashes at the intersections, but again, the significance of these results was not reported.

Other sources have indicated a 5% reduction in crashes because of the implementation of LPIs (*10–12*). A case study description of LPI implementation at one location indicated that accident rates remained unchanged at the treatment location (*13*). As indicated in the report of that study, the impetus for LPI installation was reactionary and the extent of the crash analysis was not reported (*13*).

STUDY AREA CHARACTERISTICS

The study area (the borough of State College, Pennsylvania) experienced an average of 19 pedestrian–vehicle crashes per year in a review of 8 years of crash data. Figure 1 displays the number of crashes per year for the entire study area, showing crashes for both the central business district and residential areas. Pedestrian–vehicle crash rates at the downtown intersections were more than three times as great as those at the intersections in residential areas.

LPIs were installed at 10 signalized intersections in downtown State College in March 2005. The treatment sites are located along two urban principal arterial highways (State Route 26 and College and Beaver Avenues), which form a one-way couplet in the central business district. Each arterial street has two through lanes, with the aver-

FIGURE 1 Pedestrian–vehicle crashes by year (boroughwide).

TABLE 1 Summary of Data for 10 Treatment Sites

Variable	Mean	Minimum	Maximum
Number of years of data per site before LPIs	4	4	4
Number of years of data per site after LPIs	3	3	3
Pedestrian–vehicle crashes per site per year before LPIs	0.60	0	3
Pedestrian–vehicle crashes per site per year after LPIs	0.47	0	3
Total daily traffic volume per site before LPIs	12,450	8,891	16,910
Total daily traffic volume per site after LPIs	13,404	10,057	17,527

age daily traffic values being approximately 13,500 and 12,000 for College and Beaver Avenues, respectively. College Avenue has on-street parking adjacent to both travel lanes, and Beaver Avenue has on-street parking on one side of the street. The crossing distance for pedestrians at the treatment sites did not vary significantly between intersections. Two travel lanes were crossed at all major-street pedestrian crosswalks in the treatment area. For the minor street crossings, three of the treatment sites involved crosswalks traversing three travel lanes, whereas the remainder of the minor street sites involved crosswalks traversing two travel lanes. All major and minor approaches at the treatment sites have speed limits of 25 mph. The treatment sites also have similar levels of nighttime lighting because of the consistent placement of streetlights in the downtown area.

The pedestrian volumes in the crosswalks measured at the treatment intersections generally ranged from 100 to 1,000 pedestrians per hour during peak periods. The large fluctuation in pedestrian volumes results from the close proximity of the Pennsylvania State University, downtown businesses, apartments, and offices. The large pedestrian volumes during peak periods are associated with class schedules at the university. Pedestrian volumes during nonpeak periods were substantially lower. The 10 treatment sites included existing signalized intersections with pedestrian walk–don’t walk signal heads. Eight of the 10 traffic signals with LPIs are two-phase signals, and the remaining two treatment sites operate as three-phase signals with a leading left-turn phase for a minor street. The length of the LPI at each treatment site is 3 s. Countdown pedestrian signals were added to two of the 10 treatment sites at approximately the same time as the LPIs. A summary of the data for the 10 treatment sites is provided in Table 1.

A comparison group was selected from stop-controlled intersections within the borough of State College. In choosing a comparison group, it is preferable to obtain sites from the same jurisdiction in which the treatment was implemented. This helps to account for temporal and regional factors, such as crash reporting, driver behavior, and weather patterns. It is also desirable to include sites that are geometrically and operationally similar to the treated sites. An obvious choice for comparison sites would be other signalized intersections along the corridors where the LPI was implemented. However, too few intersections remained along the treated corridors. In addition, the treated corridors were one-way streets, and State College has no other one-way streets from which to select comparison sites. As such, the present study made use of 14 stop-controlled intersections along the treated corridors for the comparison group. Pedestrian–vehicle crash rates were obtained for the 10 treatment sites and 14 comparison sites. The study period encompassed the years 2000 through 2008, excluding 2002, for which complete data were not available. The number of crashes observed at the 10 treatment sites by year is shown in Figure 2.

METHODOLOGY

Various methods for the evaluation of the LPI in downtown State College were considered. The empirical Bayes (EB) before–after method was a primary candidate because it accounts for many of the shortcomings of the traditional before–after method (*14*). In particular, the EB method can account for regression to the mean (RTM) and changes that occur during the study period (e.g., traffic volume and other annual trends). Essentially, the EB method estimates the

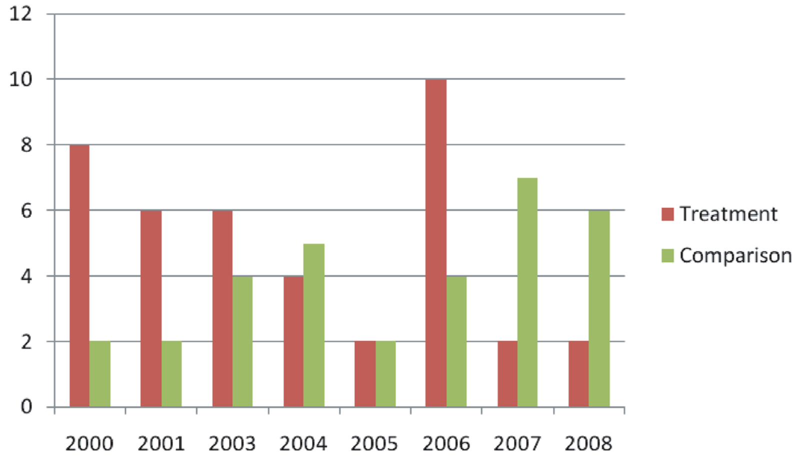

FIGURE 2 Pedestrian–vehicle crashes by year at treatment and comparison sites.

safety for a particular site had nothing been implemented and compares that level of safety with the level of safety observed with the treatment installed.

Although the EB before–after method is considered a rigorous methodological design with which to develop reliable crash reduction factors, limitations may preclude its use in highway safety analysis. One disadvantage of the EB method is the requirement for reference sites (i.e., a group of sites similar to those treated, but without the treatment in question). The requirement for a reference group can increase the cost of a study because of the costs associated with the collection of additional data. In some cases, a sufficient reference group may not be available, which precludes the use of the EB method.

Fundamental to the EB method is the development of a safety performance function (SPF). The reference group is used to develop the SPF, which is then used to predict crashes at the treatment locations, assuming that nothing has been implemented. As such, the reference group should be carefully selected to match the treatment sites as closely as possible, aside from the treatment in question. The LPI in the present study was implemented at 10 signalized intersections along the two main corridors in downtown State College. Recall from the previous section that the two corridors form a one-way couplet. This posed a problem when an attempt was made to identify a suitable reference group. Ideally, the reference group would include a large sample of other signalized intersections in the downtown area that have similar geometries, traffic volumes, and operational characteristics (e.g., one-way operation). Unfortunately, few signalized intersections, other than the treatment locations, match these criteria. As such, an SPF could not be calibrated for use in the EB analysis, and so other analytical options were explored. The before–after study with comparison groups was selected and used for the final analysis. This method can help to account for many of the shortcomings of the naïve before–after method. The comparison group is essentially used to control for factors (other than the treatment itself) that may cause a change in safety when a treatment is implemented (*15*). The intent is to separate the effect due to the treatment from changes in safety due to other factors.

The comparison group method also has potential limitations. Although a comparison group can be used to control for RTM, this can be problematic because the treatment and comparison sites must be matched on crash frequency (*14*). For example, a treatment site with 10 crashes in the before period should be matched with a comparison site that had 10 crashes in the same period to control for the effects of RTM. Because of the cumbersome nature of this process to account for RTM by use of the comparison group method, the EB approach is preferred for situations in which RTM might be at play. In this evaluation, the treatment sites were not selected on the basis of crash history. Instead, the LPI strategy was implemented at all signalized intersections in the downtown area. Although the potential for RTM still exists, it is not as much a cause for concern had the treatment sites been selected on the basis of high crash counts.

Another shortcoming of the comparison group method is the need for comparability between the treatment and comparison sites (*14*). Comparability means that the crash trends in the comparison group are sufficiently similar to those in the treatment group in both the before and the after periods. Simply stated, if crashes increase by 5% per year in the treatment group in the before period, the comparison group should demonstrate a similar increase. The sequence of odds ratios can be calculated from historical crash counts to test the comparability between the treatment and comparison groups (*14*). If the sample mean of the odds ratios is close to 1 and the variance is relatively small, then the comparison group is deemed "comparable." Equation 2 can be used to estimate the sample odds ratio for a specific time series (*14*).

$$o = \frac{\dfrac{(AD)}{(BC)}}{\left(1 + \dfrac{1}{B} + \dfrac{1}{C}\right)} \tag{2}$$

where

o = estimate of sample odds ratio,
A = observed crash count for treatment group in Year 1,
B = observed crash count for treatment group in Year 2,
C = observed crash count for comparison group in Year 1, and
D = observed crash count for comparison group in Year 2.

The sample odds ratios are computed for each sequential time series in the before period. Then, the mean, $m(o)$, and variance, $s^2(o)$, are computed for the overall series of sample odds ratios. The crash counts are presented below for both the treatment and the comparison groups for each of the 4 years in the before period.

Year	*Treatment Group*	*Comparison Group*	*Odds Ratio*
1	8	2	
2	6	2	0.80
3	6	4	1.20
4	4	5	1.25

In this case, $m(o)$ is equal to 1.08 and $s^2(o)$ is equal to 0.06, so there is no evidence that the underlying mean, $E(\omega)$, is significantly different from 1.0. Therefore, the comparison group is sufficiently similar and the variance of the mean, $\text{Var}(\omega)$, is estimated by using Equation 3.

$$\text{Var}(\omega) = s^2(o) - \left(\frac{1}{K} + \frac{1}{L} + \frac{1}{M} + \frac{1}{N}\right) \quad \text{if} > 0 \text{ and } 0 \text{ otherwise} \tag{3}$$

where

$\text{Var}(\omega)$ = variance of underlying mean of the odds ratios,
K = observed crash count for treatment group in before period,
L = observed crash count for treatment group in after period,
M = observed crash count for comparison group in before period,
N = observed crash count for comparison group in after period, and
$s^2(o)$ = variance of sample odds ratios.

The analysis procedure outlined by Hauer was followed for this before–after with comparison group study (*14*). The procedure requires estimation of the following parameters by Equations 4 through 9.

$$\lambda = L \tag{4}$$

$$\text{Var}(\lambda) = L \tag{5}$$

$$r_T = r_C = \frac{\left(\dfrac{N}{M}\right)}{\left(1 + \dfrac{1}{M}\right)} \tag{6}$$

$$\frac{\mathrm{Var}(r_T)}{r_T^{\,2}} = \frac{1}{M} + \frac{1}{N} + \mathrm{Var}(\omega) \tag{7}$$

$$\pi = r_T K \tag{8}$$

$$\mathrm{Var}(\pi) = \pi^2 \left(\frac{1}{K} + \frac{\mathrm{Var}(r_T)}{r_T^{\,2}} \right) \tag{9}$$

where

λ = expected number of crashes at treatment sites in after period,
π = expected number of crashes at treatment sites in after period had no treatment been implemented,
Var(π) = variance of expected number of crashes in after period had no treatment been implemented,
Var(λ) = variance of expected number of crashes in after period,
r_C = ratio of expected crash counts for comparison group, and
r_T = ratio of expected crash counts for treatment group.

The traffic volumes were slightly different between the comparison group and the treatment group. The comparison sites were selected from the same corridors as the treatment sites, so the major-road volumes and changes from the before to the after period were identical. However, the minor-road volumes at the treated signalized intersections were higher than those at the unsignalized comparison sites. An increase in traffic also occurred from the before to the after period. At the treatment sites, the average total entering volume increased from 12,450 to 13,404 vehicles per day from the before to the after period. The average total entering volume at the comparison sites increased from 9,076 to 9,389 vehicles per day from the before to the after period.

Although it is common to use a comparison group to account for the effects of changes in all factors, including traffic volume, it is more appropriate to use the comparison group to account for only those factors that cannot be accounted for explicitly (*14*). In the present study, the traffic volumes are known for both the treatment and the comparison groups in both the before and the after periods. Hence, the effect of changes in traffic volume can be accounted for explicitly.

The procedure outlined by Hauer was used to account for changes in traffic volume from the before to the after period at both the comparison and the treatment sites (*14*). First, the observed number of crashes in the before period at each comparison site must be adjusted before the calculation of *M,* the sum of observed crashes for the comparison group in the before period. The adjustment removes the change in safety because of the change in traffic volume so that the comparison group can be used to account for only those factors that cannot be accounted for explicitly (i.e., factors other than traffic volume). The adjustment to the comparison sites is accomplished by using Equation 10. This adjustment assumes a linear relationship between the expected number of crashes and traffic volume. Although it is generally more accurate to use a nonlinear safety performance function to explain this relationship, a linear relationship is a close approximation for small changes in traffic volumes, as is the case in the present study.

$$C_{\mathrm{adj}_i} = \frac{\mathrm{TEV}_{AC_i}}{\mathrm{TEV}_{BC_i}} \tag{10}$$

where

C_{adj_i} = adjustment factor for observed number of crashes in before period at comparison site *i*,
TEV_{AC_i} = total entering traffic volume at comparison site *i* in after period, and
TEV_{BC_i} = total entering traffic volume at comparison site *i* in before period.

For each comparison site, the adjusted crash counts in the before period are calculated by multiplying the observed crash counts in the before period by the respective adjustment factor, C_{adj_i}. The adjusted before period crash counts are then summed to estimate M_{adj}, which replaces *M* in Equations 6 and 7.

The next step is to adjust for changes in traffic volume from the before to the after period at the treatment sites. This is accomplished by applying the adjustment factor in Equation 11 to π, the expected number of crashes in the after period had no treatment been applied. Again, Equation 11 assumes a linear relationship between crashes and traffic volume. Equation 8 is now replaced by Equation 12.

$$r_{tf} = \frac{\mathrm{TEV}_{AT}}{\mathrm{TEV}_{BT}} \tag{11}$$

$$\pi = r_T K r_{tf} \tag{12}$$

where

r_{tf} = adjustment factor for change in traffic volume at treatment sites,
TEV_{AT} = average total entering traffic volume at treatment sites in after period, and
TEV_{BT} = average total entering traffic volume at treatment sites in before period.

All other variables were defined earlier in the paper.

An adjustment is also necessary because the durations of the before and the after periods are different. This does not affect the estimate of π, because the durations of the before and the after periods are similar for the treatment and comparison sites. This does, however, affect the estimate of Var(π). To account for this, an adjustment is made to Equation 9. Specifically, the adjustment is calculated by using Equation 13, and Equation 9 is replaced by Equation 14. The computation of Var(π) in Equation 14 should also include an adjustment for Var(r_{tf}). However, the calculation of Var(r_{tf}) requires the coefficient of variation, which is not available in this case.

$$r_d = \frac{\mathrm{years}_A}{\mathrm{years}_B} \tag{13}$$

$$\mathrm{Var}(\pi) = \pi^2 \left(\frac{1}{K} + \frac{\mathrm{Var}(r_T)}{r_t^{\,2}} \right) r_d^{\,2} \tag{14}$$

where

r_d = adjustment factor for different durations of before and after periods,
years_A = duration of after period (year), and
years_B = duration of before period (year).

All other variables were defined earlier in the paper.

Finally, the index of effectiveness (θ) and the variance of θ are estimated by using Equations 15 and 16, respectively.

$$\theta = \frac{\dfrac{\pi}{\lambda}}{1+\left(\dfrac{\mathrm{Var}(\pi)}{\pi^2}\right)} \tag{15}$$

$$\mathrm{Var}(\theta) = \sqrt{\frac{\theta^2\left(\dfrac{\mathrm{Var}(\pi)}{\pi^2}+\dfrac{\mathrm{Var}(\lambda)}{\lambda^2}\right)}{\left(1+\dfrac{\mathrm{Var}(\lambda)}{\lambda^2}\right)^2}} \tag{16}$$

The percent change in crash rates is calculated using Equation 17. Thus, a θ value of 0.8 with a standard deviation of 0.05 indicates a 20% reduction in crashes with a standard deviation of 5%.

$$\text{percent change in crashes} = 100 * (1-\theta) \tag{17}$$

RESULTS

The before-and-after crash counts are presented below for both the treatment and the comparison groups. The crash counts represent those from a 4-year before period and a 3-year after period. The parameter estimates are shown in Table 2. All parameter estimates used to compute θ are reported. For the present study, Var(ω) was estimated to be –0.188 and is assumed to be equal to 0 for the remaining calculations, as noted in Equation 12.

Period	*Time (year)*	*Treatment Group*	*Comparison Group*
Before	4	24	13
After	3	14	17

The results indicate that the implementation of LPIs at the 10 sites in downtown State College resulted in a 58.7% reduction in pedestrian–vehicle crashes with a standard error of 6.4. The 95% confidence interval for the expected reduction in crashes, after implementation of the LPIs, is 46.2% to 71.3%. The confidence interval does not include 0; therefore, the reduction is significant at the 95% confidence level.

A disaggregate analysis was completed to determine if the LPI may be more effective under specific conditions. For example, one might expect the LPI to be more effective when pedestrian volumes are higher and when more pedestrian–vehicle crashes occur. This was explored by comparing crashes along College Avenue and Beaver Avenue. The five treated intersections along College Avenue (i.e., the route adjacent to the Pennsylvania State University campus) had much greater pedestrian activity and observed numbers of crashes than the five treated intersections along Beaver Avenue. A comparison group was not used for the disaggregate analysis. Instead, the crash rates per site year were compared for the before and the after periods. The disaggregate analysis indicated an overall crash rate reduction on College Avenue after LPI implementation; crashes decreased from 0.9 crash per site year before LPI implementation to 0.5 crash per site year after LPI implementation. No change in crash rates occurred when the overall number of crashes on Beaver Avenue is evaluated: 0.4 crash per site year before and after implementation of the LPIs.

TABLE 2 Parameter Estimates

Parameter	Estimate	Variance
λ	14	14
$r_T = r_C$	1.19	0.13
π	30.85	94.23
ω	1.08	0
θ	0.41	0.004

ECONOMIC ANALYSIS

Although it is important to understand the expected reduction in the number of crashes associated with a particular countermeasure, it is also important to know if the countermeasure is cost-effective. In other words, do the costs associated with the expected reduction in crashes outweigh the cost of implementing the countermeasure? This is a common question for state and local agencies because safety funds are limited and it is important to allocate funds where they will be most effective. The following economic analysis provides some insight into the cost-effectiveness of implementation of the LPI.

Crash costs were estimated on the basis of a recent FHWA crash cost document (*16*). The mean comprehensive cost associated with a pedestrian–vehicle crash at a signalized intersection with a speed limit of less than 50 mph is $164,029. Comprehensive crash costs are used in this analysis because human capital costs do not capture the full burden of injury. Comprehensive cost estimates include all monetary costs associated with the crash (e.g., medical care, emergency response, property damage, and lost productivity), as well as nonmonetary costs related to the reduction in quality of life.

The cost of implementing the LPI in State College, Pennsylvania, was $1,000 per intersection in 2005. The cost included controller programming and the additional cabinet wiring required to accommodate the existing controller assembly. The costs to implement the LPI in a new controller assembly in a shop before installation would likely be much less. On the basis of data from the Office of Management and Budget, a discount rate of 2.6% per year was selected for this cost–benefit analysis, if a service life of 10 years is assumed. The annualized costs were computed by using Equation 13. The annualized cost of the LPI was computed to be $115 per intersection per year; therefore, if the savings in crashes is greater than $115 per year, the LPI is cost-effective.

$$\text{annual cost} = \frac{C * R}{1-(1+R)^{-N}} \tag{18}$$

where

C = installation cost,
R = discount rate, and
N = expected service life (year).

The results in Table 2 indicate that 30.85 pedestrian–vehicle crashes would be expected at the 10 sites during the 3-year after period if the LPI was not implemented. The LPI was implemented, however, and 14 crashes were actually observed at the 10 sites during the 3-year after period. Expressed as the number of crashes per intersection per year, the results indicate a reduction of 0.56 crash per intersection per year. This is equated to a cost savings of $92,130 per intersection per year (i.e., 0.56 crash per year times $164,029 per crash). The resulting benefit-to-cost ratio is 801, which indicates a tremendous savings in crash costs compared with the cost of implementation.

DISCUSSION OF RESULTS

On the basis of the before–after analysis of 10 signalized intersections in State College, Pennsylvania, implementation of the LPI appears to be a cost-effective measure to reduce pedestrian–vehicle crashes. The results are likely due to the change in operation at the signalized intersections for pedestrians and drivers. The LPI allows pedestrians to begin crossing before the start of the adjacent vehicular movement, generally reducing the potential time that pedestrians and turning vehicles would be in conflict. The LPI also allows pedestrians to gain priority in the crosswalk by establishing presence, which results in a higher incidence of yield behavior from drivers.

To interpret and apply the results of the present study properly, it is important to understand the basis of the analysis. When only the change in crash rates at the treatment sites is evaluated, a 23% reduction (6 crashes per year before and 4.67 crashes per year after) can be found. However, this is a naïve comparison that does not account for RTM bias or other changes that occur at the treatment sites over time. In fact, when only the comparison sites are evaluated, a 74% increase in crash rates (3.25 crashes per year before and 5.67 crashes per year after) can be found. This comparison illustrates one of the key reasons for using a comparison group (i.e., the comparison group helps to account for changes in other factors between the before and the after periods).

Potential limitations of the study should also be discussed. First, the available sample of comparison sites was not sufficient to match sites on the basis of crash counts. As such, the comparison group cannot be used to account for RTM. Although RTM is always a possibility in before–after studies, it is more of a concern when sites are selected for treatment on the basis of crash history. In the present study, the LPI was more of a blanket treatment (i.e., sites were not selected on the basis of crash history), so less of a chance for RTM exists. Second, the analysis is based on a relatively small sample size (i.e., 10 deployments). In a before–after with comparison group analysis, the sample size required to detect a specific percent change in crash rates is related to the number of crashes in the before and the after periods. Because this analysis is based on pedestrian–vehicle crashes, relatively few crashes were observed in the before and the after periods. The implications are as follows:

- It is not possible to detect relatively small percentage changes in crash rates between the before and after periods.
- If the expected reduction in crashes is relatively large (as is the case for the LPI), it is possible to detect significant changes, but the confidence interval is relatively large.

When these results are applied in other jurisdictions, it is important to consider the applicability. If the site conditions for the location of interest are significantly different from those included in the present analysis, it may not be appropriate to assume that the reduction in pedestrian–vehicle crash rates will be similar. The present study included both three-legged and four-legged intersections along the two primary east–west routes through downtown State College. Both of the major roads are one-way, nearly all of the minor roads are two-way, and all roads have 25-mph speed limits. The average daily traffic on the two major routes ranged from 12,000 to 13,500 vehicles per day. Pedestrian crossing volumes reached nearly 1,000 pedestrians per hour per crosswalk during peak periods because of class schedules at the university, but pedestrian volumes were much smaller during off-peak times. The LPIs were installed at existing traffic signals with pedestrian signal heads.

The disaggregate analysis indicated that LPIs may be more effective at locations with higher pedestrian volumes and more crashes in the before period. Application of the results on the basis of a disaggregate analysis has advantages and disadvantages. The disaggregate analysis can shed light on the specific conditions under which strategies may be more effective; however, disaggregate analyses are, by nature, based on smaller sample sizes than aggregate analyses. Smaller sample sizes lead to larger confidence intervals and less precise results. The disaggregate analyses in the present study are based on very limited sample sizes and use rudimentary techniques. As such, it is difficult to draw firm conclusions, but the results were intuitive: the effects of the LPIs were more pronounced at intersections with higher pedestrian volumes and more observed crashes before their implementation.

CONCLUSIONS

The general conclusion from the research described here is that a reduction in pedestrian–vehicle crashes can be expected with the installation of LPIs. Despite the limited sample size and number of observed crashes, the analysis indicates a statistically significant reduction in pedestrian–vehicle crashes. The standard error and confidence interval, however, are relatively large. The confidence interval indicates with 95% confidence that the true percent reduction in crashes due to LPIs is between 46.2 and 71.3. Pedestrian–vehicle crashes decrease at the treatment sites from the before to the after period, whereas similar crashes increase at the comparison sites during the same period. On the basis of these results, implementation of the LPI appears to be an effective countermeasure for reducing pedestrian–vehicle crashes at signalized intersections, but uncertainty in the magnitude of the reduction exists. The general reduction in pedestrian–vehicle crashes is consistent with that found in previous studies on the effects of LPIs (*9*).

From a practical standpoint, the aggregate analysis supports the conclusion that a crash rate reduction of at least 46.2% can be expected with the installation LPIs. This conclusion is based on the conservative lower 95% confidence limit associated with the aggregate analysis. The lower 95% confidence limit is suggested because the analysis is based on a relatively small number of sites with a limited number of observed crashes in the before and the after periods. However, it may be necessary to use the point estimate (58.7% reduction) when potential countermeasures are compared, particularly when confidence limits are not available for all potential strategies. In this way, all countermeasures are treated equally when a cost–benefit comparison is conducted.

A disaggregate analysis showed a more pronounced reduction in pedestrian–vehicle crashes along College Avenue compared with the number for the treated intersections along Beaver Avenue. College Avenue has greater pedestrian activity than Beaver Avenue, and College Avenue had more crashes per site year before implementation of the LPI. The results suggest that the LPI may be more effective as pedestrian volumes increase and at intersections with more pedestrian–vehicle crashes before treatment. Although the results of disaggregate analysis can help to prioritize locations for treatment, these results are based on a very limited sample size.

Given the low cost of LPIs, particularly at locations where pedestrian signals already exist, only a modest reduction in crashes is needed to justify their use (i.e., if the savings in crashes is greater than $115 per year). On the basis of the evidence provided by the aggregate analysis, the necessary crash reduction required to obtain a positive benefit–cost ratio is easily achieved. Therefore, implementation of the LPI has the potential to reduce pedestrian–vehicle crashes cost-effectively.

ACKNOWLEDGMENTS

The authors acknowledge the assistance of Amy Story and R. Scott Ohs for providing background information and crash statistics for the research. Students in CE 597K for the Spring 2008 semester at the Pennsylvania State University and Paul P. Jovanis provided data on pedestrian volumes at the study area intersections.

REFERENCES

1. *Traffic Safety Facts 2006.* NHTSA, Washington, D.C. http://www-nrd.nhtsa.dot.gov/Pubs/TSF2006FE.PDF. Accessed July 28, 2008.
2. *NCHRP Report 500,* Vol. 10. *A Guide for Reducing Collisions Involving Pedestrians.* Transportation Research Board of the National Academies, Washington, D.C., 2004.
3. *Manual on Uniform Traffic Control Devices Frequently Asked Questions.* FHWA, U.S. Department of Transportation. http://mutcd.fhwa.dot.gov/knowledge/faqs/faq_part4.htm. Accessed July 24, 2008.
4. Hubbard, S. M. L., R. J. Awwad, and D. M. Bullock. Assessing the Impact of Turning Vehicles on Pedestrian Level of Service at Signalized Intersections: A New Perspective. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2027,* Transportation Research Board of the National Academies, Washington, D.C., 2007, pp. 27–36.
5. *Guidelines and Recommendations to Accommodate Older Drivers and Pedestrians.* Publication FHWA-RD-01-051. Turner–Fairbank Highway Research Center, FHWA, U.S. Department of Transportation, McLean, Va., 2001.
6. Van Houten, R., R. A. Retting, C. M. Farmer, and J. Van Houten. Field Evaluation of a Leading Pedestrian Interval Signal Phase at Three Urban Intersections. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1734,* TRB, National Research Council, Washington, D.C., 2000, pp. 86–92.
7. *Pedestrian Safety Countermeasure Deployment Project.* FHWA, U.S. Department of Transportation. http://safety.fhwa.dot.gov/ped_bike/ped/ped_scdproj/sf_ch1.htm. Accessed July 24, 2008.
8. *Making Crosswalks Safer for Pedestrians.* Center for Urban Transportation Research, University of South Florida, Tampa, 2000.
9. King, M. R. Calming New York City Intersections. *Transportation Research Circular E-C019: Urban Street Symposium.* TRB, National Research Council, Washington, D.C., 2000.
10. *Intersection Safety Issues Brief No. 8: Toolbox of Countermeasures and Their Potential Effectiveness to Make Intersections Safer.* ITE and FHWA, U.S. Department of Transportation, 2004.
11. *Toolbox of Countermeasures and Their Potential Effectiveness for Pedestrian Crashes.* FHWA, U.S. Department of Transportation, 2008.
12. *Desktop Reference for Crash Reduction Factors.* Publication FHWA-SA-07-015. FHWA, U.S. Department of Transportation, 2007.
13. *PEDSAFE: Pedestrian Safety Guide and Countermeasure Selection System.* Publication FHWA-SA-04-003. FHWA, U.S. Department of Transportation, 2004.
14. Hauer, E. *Observational Before–After Studies in Road Safety: Estimating the Effect of Highway and Traffic Engineering Measures on Road Safety.* Pergamon Press, Elsevier Science Ltd., Oxford, United Kingdom, 1997.
15. Persaud, B. N. *NCHRP Synthesis of Highway Practice 295: Statistical Methods in Highway Safety Analysis.* TRB, National Research Council, Washington, D.C., 2001.
16. Council, F., E. Zaloshnja, T. Miller, and B. Persaud. *Crash Cost Estimates by Maximum Police-Reported Injury Severity Within Selected Crash Geometries.* FHWA, U.S. Department of Transportation, McLean, Va., 2005.

The Pedestrians Committee peer-reviewed this paper.