Safety Evaluation of Pedestrian Countdown Signals

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FOREWORD

The research documented in this report was conducted as part of the Federal Highway Administration's (FHWA's) Evaluation of Low-Cost Safety Improvements Pooled Fund Study (ELCSI-PFS). FHWA established this PFS in 2005 to conduct research on the effectiveness of the safety improvements identified by the National Cooperative Highway Research Program's Report 500 Series as part of the implementation of the American Association of State Highway and Transportation Officials' Strategic Highway Safety Plan.[(1)] The ELCSI-PFS studies provide a crash modification factor and benefit–cost (B/C) economic analysis for each of the targeted safety strategies identified as priorities by the pooled fund member States.

This study evaluated the safety effectiveness of pedestrian countdown signals (PCSs) by conducting a before–after empirical Bayes analysis on data from 115 treated intersections in Charlotte, NC, and 218 treated intersections in Philadelphia, PA. The study results showed that after the implementation of PCSs, pedestrian crashes decreased by 9 percent, total crashes decreased by 8 percent, and rear-end crashes decreased by 12 percent. All these reductions were statistically significant. The economic analysis revealed a B/C ratio of 23, with a low of 13 and a high of 32. This report will benefit safety and traffic engineers and safety planners by providing greater insight into pedestrian safety.

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Director, Office of Safety and Operations
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16. Abstract

A before–after empirical Bayes analysis was performed using data from 115 treated intersections in Charlotte, NC, and 218 treated intersections in Philadelphia, PA, to evaluate the safety effects of pedestrian countdown signals (PCSs). Additionally, the evaluation included 136 reference intersections in Charlotte, NC, and 597 reference intersections in Philadelphia, PA. The project team also investigated the possibility of using data from two additional cities, but the data from those cities could not be used in this evaluation because of unknown PCS installation dates, lack of pedestrian volume, and crash data reliability concerns.

Following the implementation of PCSs, total crashes decreased by approximately 8 percent, and rear-end crashes decreased by approximately 12 percent. These reductions were statistically significant at the 95 percent confidence level. Pedestrian crashes decreased by about 9 percent, and this reduction was statistically significant at the 90 percent confidence level. The economic analysis revealed a benefit–cost ratio of 23, with a low of 13 and a high of 32.

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APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1,000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2,000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	2.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviations

AADT	annual average daily traffic (vehicles per day)
ANG	angle (crash)
B/C	benefit–cost
CMF	crash modification factor
DCMF	Development of Crash Modification Factors Program
DVRPC	Delaware Valley Regional Planning Commission
EB	empirical Bayes
ELSCI-PFS	Evaluation of Low-Cost Safety Improvements Pooled Fund Study
FHWA	Federal Highway Administration
HSIS	Highway Safety Information System
KABC	injury and fatal (crash type)
PCS	pedestrian countdown signal
PDO	property damage only
PED	pedestrian (crash)
PennDOT	Pennsylvania Department of Transportation
PFS	pooled fund study
RE	rear-end (crash)
SE	standard error
SPF	safety performance function
USD	United States dollars
USDOT	United States Department of Transportation

Symbols

a_0	intercept
a_1 through a_n	coefficients for independent variables X_1 through X_n
C	treatment cost
k	constant for a given model
m	empirical Bayes estimate of the expected number of crashes at a strategy site in the before period
N	expected service life (years)
P	sum of the annual estimates from a safety performance function in the before period at a strategy site
R	discount rate
w	empirical Bayes weight
x	number of crashes at a strategy site in the before period
X_1 through X_n	independent variables
Y	predicted value from the safety performance function
θ	index of effectiveness
λ	expected number of crashes that would have occurred in the after period without the strategy at a strategy site

λ_{sum}	sum of the expected number of crashes that would have occurred in the after period without the strategy
π	number of reported crashes in the after period at a strategy site
π_{sum}	sum of the number of crashes observed during the after period

EXECUTIVE SUMMARY

The Federal Highway Administration established the Development of Crash Modification Factors (DCMF) Program in 2012 to address highway safety research needs for evaluating new and innovative safety strategies (improvements) by developing reliable quantitative estimates of their effectiveness in reducing crashes. The ultimate goal of the DCMF Program is to save lives by identifying new safety strategies that effectively reduce crashes and promoting those strategies for nationwide implementation by providing measures of their safety effectiveness and benefit–cost (B/C) ratios through research. State transportation departments and other transportation agencies need to have objective measures for safety effectiveness and B/C ratios before investing in broad applications of new strategies for safety improvements. Forty State transportation departments provide technical feedback on safety improvements to the DCMF Program and implement new safety improvements to facilitate evaluations. These States are members of the Evaluation of Low-Cost Safety Improvements Pooled Fund Study, which functions under the DCMF Program.

This study investigated the effectiveness of pedestrian countdown signals (PCSs). It was hypothesized that PCSs may reduce pedestrian (PED) crashes but also affect other types of crashes. The project team obtained geometric, traffic, and crash data from signalized intersections in Charlotte, NC, and Philadelphia, PA, to evaluate the safety effect of PCSs. A before–after empirical Bayes analysis was performed using data from 115 treated intersections in Charlotte, NC, and 218 treated intersections in Philadelphia, PA. The evaluation also included 136 reference intersections in Charlotte, NC, and 597 reference intersections in Philadelphia, PA. The project team also investigated the possibility of using data from two additional cities, but the data from those cities could not be used because of unknown PCS installation dates, lack of pedestrian volume counts, and crash data reliability concerns.

Table 1 shows the crash modification factors (CMFs) for the PCS treatment. The CMFs for total crashes (about an 8 percent reduction) and rear-end (RE) crashes (about a 12 percent reduction) were both statistically significant at the 95 percent confidence level. The CMF for PED crashes (about a 9 percent reduction) was statistically significant at the 90 percent confidence level, which may be regarded as a reasonable standard for such rare crash types. The economic analysis revealed a B/C ratio of 23, with a low of 13 and a high of 32.

Table 1. CMFs for PCSs.

Crash Type	CMF	Standard Error of CMF
Total	0.921*	0.017
Injury and fatal (KABC)	0.988	0.026
RE	0.875*	0.027
Angle (ANG)	1.027	0.042
PED	0.912#	0.055

*CMF is statistically significant at the 95 percent confidence level.
#CMF is statistically significant at the 90 percent confidence level.

CHAPTER 1. INTRODUCTION

BACKGROUND ON STRATEGY

The pedestrian countdown signal (PCS) treatment involves the display of a numerical countdown that shows how many seconds are left in the flashing DON'T WALK interval (figure 1). The intention of this treatment is to provide pedestrians with more information on the crossing time remaining. The countdown timer could start at the beginning of the pedestrian WALK phase, but the *Manual on Uniform Traffic Control Devices for Streets and Highways* recommends starting the timer at the onset of the flashing DON'T WALK interval.(2)

Source: FHWA.

Figure 1. Photo. PCS example.(3)

BACKGROUND ON STUDY

In 1997, the American Association of State Highway and Transportation Officials' Standing Committee on Highway Traffic Safety, with the assistance of the Federal Highway Administration (FHWA), the National Highway Traffic Safety Administration, and the Transportation Research Board Committee on Transportation Safety Management, met with safety experts from various organizations in the fields of driver, vehicle, and highway issues to develop a strategic plan for highway safety. These participants developed 22 key areas that affect highway safety.(4)

The National Cooperative Highway Research Program published a series of guides to advance the implementation of countermeasures targeted to reduce crashes and injuries.(1) Each guide addresses 1 of the 22 emphasis areas and includes an introduction to the problem, a list of objectives for improving safety in that emphasis area, and strategies for each objective. Each strategy is designated as "proven," "tried," or "experimental." Many of the strategies discussed in these guides have not been rigorously evaluated; approximately 80 percent of the strategies are considered tried or experimental.

In 2005, to support the implementation of the guides, FHWA organized a pooled fund study (PFS) of States to evaluate low-cost safety strategies as part of this strategic highway safety effort. Over the years, the pooled fund has grown in size and now includes 40 States. The purpose of the Evaluation of Low-Cost Safety Improvements Pooled Fund Study (ELCSI-PFS) is to evaluate the safety effectiveness of high-priority tried and experimental low-cost safety strategies selected by member States through scientifically rigorous crash-based studies. The member States selected PCSs as a strategy to be evaluated as part of this effort.

ELCSI-PFS conducts its research within FHWA's Development of Crash Modification Factors (DCMF) Program, which is a comprehensive, long-term safety research effort. FHWA established the DCMF Program in November 2012 to support and complement the efforts of the ELCSI-PFS. The ultimate goal of the DCMF Program is to save lives by identifying new safety countermeasures that effectively reduce crashes and to promote those countermeasures for nationwide installation by providing measures of their safety effectiveness, including benefit–cost (B/C) ratios, through research.

LITERATURE REVIEW

The objective of this literature review was to draw key information from past studies that looked at evaluating the safety of PCSs. Results of this review informed the collection of data and methodology used to conduct this analysis.

Markowitz et al. conducted one of the first crash-based evaluations of PCSs.(5) The authors examined pedestrian injury events at nine pilot PCS intersections in San Francisco, CA. They also analyzed statistics for locations that experienced higher-than-average collision rates in the pretreatment period. Their crash analysis showed a statistically significant reduction of 52 percent in pedestrian injury crashes after the introduction of PCSs. However, they cautioned that some of these effects might have been due to regression to the mean, given that the pilot intersections were selected based on pedestrian safety-related criteria. The behavioral observations at these pilot intersections showed reductions in the percentage of pedestrians in the crosswalk when the signal turned red and the percentage of observed pedestrian–motor-vehicle conflicts.

Prior to Markowitz et al., Leonard et al. and Zegeer and Huang evaluated the effects of PCSs on pedestrian behavior.(5–7) Leonard et al. studied two signalized intersections in Monterey, CA.(6) They observed 760 pedestrians and found that 83 percent of them began crossing the intersection at the beginning of the pedestrian phase and completed the crossing during that same phase. They concluded that PCSs did not pose any significant safety hazards for pedestrians. Zegeer and Huang evaluated the effectiveness of PCSs at two treated intersections (and three comparison intersections) in Lake Buena Vista, FL, using three measures: (1) pedestrian compliance with the WALK signal, (2) pedestrians who ran out of time when crossing, and (3) pedestrians who began crossing the intersection after the flashing DON'T WALK signal appeared.(7) Their results indicated a statistically significant difference in walk signal compliance, with pedestrians less likely to comply with the WALK signal at PCS sites than at comparison sites.

Despite this effect, there was no statistically significant difference in the number of pedestrians who finished crossing the intersection before the steady DON'T WALK signal. However, the results showed a statistically significant reduction in the number of pedestrians who began to run at the appearance of the flashing DON'T WALK signal at the treatment sites when compared with comparison sites. The authors concluded that the PCS had both positive and negative effects on pedestrian behavior at the treatment sites.(7) While more pedestrians began crossing during the flashing DON'T WALK signal when the PCS was present, this change in behavior had little effect on the ability of pedestrians to finish crossing the intersection in time.

Eccles et al. studied the before–after effects of PCSs on both pedestrian and motorist behavior.(8) The authors observed movements at 20 crosswalks at 5 intersections in Montgomery County, MD, where PCSs were installed. Their results showed mixed effects on pedestrian behavior. They observed a statistically significant decrease in the number of pedestrians who entered on the WALK signal at 2 of the 20 crosswalks. However, they also observed a statistically significant increase in pedestrians correctly entering the intersection on the WALK signal at 6 of the 20 crosswalks. They also observed the number of phases during which pedestrians were still in the intersection when conflicting traffic was present. The results showed no statistically significant increase in the number of phases in which a pedestrian was still in the crosswalk when conflicting traffic was released. At four of the five intersections, they found significantly fewer pedestrian–motor-vehicle conflicts after the PCSs were installed. They also found that the PCSs had no effect on vehicle approach speeds during the countdown pedestrian clearance interval.

In 2008, FHWA prepared a report on pedestrian safety for the U.S. Congress, and the Transportation Association of Canada prepared an unpublished informational report[1] on PCSs.(9) A review of these reports showed that PCS technology is relatively straightforward and easy to apply. The reports also indicated the following results:

- Between 26 and 80 percent of pedestrians did not understand the meaning of the conventional flashing hand display.
- Between 50 and 97 percent of pedestrians understood the meaning of the pedestrian countdown timer display.
- Between 78 and 94 percent of pedestrians found PCSs easier to understand than conventional pedestrian signals.
- Between 80 and 92 percent of pedestrians felt the PCSs were an improvement over conventional pedestrian signals.

Both of these reports pointed to the Markowitz et al. study, citing a reduction in PED crashes and conflicts due to the installation of PCSs.(5) However, a lack of studies evaluating the effectiveness of PCSs to reduce PED crashes (at that time) was cited as a concern in both reports.(9)

Following these reports, Van Houten et al., Srinivas et al., Camden et al., Richmond et al., and Kapoor and Magesan evaluated the effects of PCSs on PED and total overall crashes.(10–14)

Van Houten et al. conducted a crash-based evaluation of PCSs installed in Detroit, MI, and Kalamazoo, MI.(10) The analysis provided evidence that PCSs helped reduce PED crashes. The authors identified a 70 percent reduction in PED crashes in Detroit, MI, and a 52 percent reduction in PED crashes in Kalamazoo, MI. However, the authors noted that a smaller sample size and low level of baseline crashes might have been linked to the reduction found in Kalamazoo, MI.

[1]An unpublished 2008 Transportation Association of Canada report entitled *An Information Report on Pedestrian Countdown Signals (PCS).*

Srinivas et al. evaluated the effects of PCSs at 106 signalized intersections in Charlotte, NC.[11] Their analysis showed a statistically insignificant decrease in the number of pedestrian–motor-vehicle crashes after the installation of PCSs. Though statistically insignificant, there was a 13 percent decrease in the mean number of pedestrian–motor-vehicle crashes after the installation of PCSs and a 21 percent decrease in the mean number of all crashes after the installation of PCSs. Based on their analysis, the authors concluded that no negative consequences were observed after the installation of PCSs at the signalized intersections.

Camden et al., Richmond et al., and Kapoor and Magesan used PCS data from Toronto, ON, to conduct their crash-based evaluations.[12–14] Camden et al. used a total of 1,965 treated signalized intersections.[12] They found that PCS installation had no statistically significant effect on pedestrian–motor-vehicle crashes. The authors also did not find any evidence to suggest a correlation between PCSs and collisions by age, injury severity, or location. However, the two later studies conducted by Richmond et al. and Kapoor and Magesan found that PCSs led to an increase in collisions.[13,14] Richmond et al. observed a combined total of 9,262 pedestrian–motor-vehicle collisions at 1,965 treated signalized intersections.[13] Their analysis showed a statistically significant increase of 26 percent in the rate of pedestrian–motor-vehicle collisions after PCS installation. Similarly, Kapoor and Magesan also found that the installation of PCSs resulted in an approximately 5 percent increase in citywide collisions per month.[14] Their analysis also showed different effects for collisions involving pedestrians and those involving automobiles only. The authors found that PCSs reduced the number of pedestrians struck by automobiles; however, they increased the number of collisions between automobiles. They also found that PCSs caused fewer minor injuries among pedestrians for every pedestrian on the road and more RE crashes among cars for every car on the road.[14]

In summary, some studies indicated a decrease in crashes due to PCSs, whereas other studies concluded that PCSs led to an increase in crashes. The reported safety effects ranged from a 70 percent reduction found by Van Houten et al. in Detroit, MI, to a 26 percent increase found by Richmond et al. in Toronto, ON.[10,13] It is clear that a well-designed evaluation with a large sample of sites from multiple cities would provide useful information to practitioners on the effectiveness of this treatment.

CHAPTER 2. OBJECTIVE

This research examined the safety impacts of PCSs using data from Philadelphia, PA, and Charlotte, NC. The objective was to estimate the safety effectiveness of this strategy, as measured by crash frequency. The primary target crash type was PED crashes. However, changes in pedestrian signals could change driver behavior and affect the propensity for RE and ANG crashes. Because of this, the evaluation included the following crash types:

- Total intersection crashes.
- Intersection KABC crashes.
- Intersection RE crashes.
- Intersection ANG crashes.
- Intersection PED crashes.

In performing the evaluation, the project team recognized that not all agencies report crashes in the same way, especially property damage only (PDO) crashes. For this reason, it was important to include reference and comparison sites from the same agency so that any differences in crash reporting were accounted for in the analysis.

In addition to determining the overall safety effect of the treatment(s), a further objective was to address whether the safety effect was different depending on the type of intersection (i.e., three-leg versus four-leg signalized intersections).

The evaluation of overall effectiveness included the consideration of the installation costs and crash savings in terms of the B/C ratio.

CHAPTER 3. STUDY DESIGN

When planning a before–after safety evaluation study, it is vital to ensure that enough data are included to statistically detect the expected change in safety. Even though those designing the study do not know the expected change in safety during the planning stage, it is still possible to make a rough determination of how many sites are required based on the best available information about the expected change in safety. Alternatively, one could estimate the statistically detectable change in safety for the number of available sites. For a detailed explanation of sample size considerations as well as estimation methods, see chapter 9 of *Observational Before–After Studies in Road Safety*.[15] The sample size analysis cases presented in this chapter address the sample size required to statistically detect an expected change in safety.

SAMPLE SIZE REQUIRED TO DETECT AN EXPECTED CHANGE IN SAFETY

For this analysis, the project team assumed that the study used a conventional before–after study format with comparison group design, since available sample size estimation methods are based on this assumption. The sample size estimates from this method would be conservative in that the empirical Bayes (EB) methodology proposed would likely require fewer sites. To facilitate the analysis, the project team also assumed that the number of comparison sites was equal to the number of treatment sites, which, again, is a conservative assumption.

Because many agencies now introduce PCSs as a systemwide treatment, the possibility of bias due to regression to the mean was minimal. For this reason, for the sample size calculations, the before-period crash data from the treated sites were used. Table 2 provides the crash-rate (i.e., number of crashes per year) assumptions used.

Table 2. Before-period crash-rate assumptions.

Crash Type	Charlotte, NC Three-Leg Intersection	Charlotte, NC Four-Leg Intersection	Philadelphia, PA Three-Leg Intersection	Philadelphia, PA Four-Leg Intersection
Total	7.69	10.75	1.92	2.46
KABC	2.15	2.92	1.53	2.17
RE	3.60	4.34	0.57	0.49
ANG	0.64	1.35	0.39	0.65
PED	0.04	0.14	0.34	0.83

Table 3 provides estimates of the required number of before- and after-period intersection years for statistical significance at both the 95 and 90 percent confidence levels.

Table 3. Minimum required before-period intersection years for 95 and 90 percent confidences.

Crash Type	Expected Percent Reduction in Crashes	95 Percent Confidence Charlotte Three-Leg Intersection	95 Percent Confidence Charlotte Four-Leg Intersection	95 Percent Confidence Philadelphia Three-Leg Intersection	95 Percent Confidence Philadelphia Four-Leg Intersection	90 Percent Confidence Charlotte Three-Leg Intersection	90 Percent Confidence Charlotte Four-Leg Intersection	90 Percent Confidence Philadelphia Three-Leg Intersection	90 Percent Confidence Philadelphia Four-Leg Intersection
Total	10	164	117	656	464	116	83	512	362
Total	20	34	24	135	96	24	17	106	75
Total	30	12	9	48	34	9	6	38	27
Total	40	5	4	21	15	4	3	17	12
KABC	10	586	432	824	582	414	305	581	410
KABC	20	121	89	170	121	86	63	120	85
KABC	30	43	32	61	43	31	23	43	30
KABC	40	19	14	27	19	13	10	19	13
RE	10	350	290	2,211	1,561	247	205	2,571	1,816
RE	20	72	60	456	325	51	43	531	378
RE	30	26	21	163	116	18	15	190	135
RE	40	11	9	72	51	8	7	84	59
ANG	10	1,969	933	3,231	2,282	1,391	659	1,938	1,369
ANG	20	406	193	667	474	289	137	400	285
ANG	30	145	69	238	169	103	49	143	102
ANG	40	64	30	105	74	45	21	63	45
PED	10	31,500	9,000	3,706	2,618	22,250	6,357	1,518	1,072
PED	20	6,500	1,857	765	544	4,625	1,321	313	223
PED	30	2,325	664	274	194	1,650	471	112	80
PED	40	1,025	293	121	85	725	207	49	35

The minimum sample indicates the level for which a study seems worthwhile; that is, it is feasible to detect with this level of confidence the largest effect that one may reasonably expect based on current knowledge about the strategy. The project team based these sample size calculations on the methodology in Hauer and on specific assumptions regarding the number of crashes per intersection per year and years of available data.(15) Intersection years are the number of intersections where a strategy is in effect multiplied by the number of years of data before or after implementation. For example, if a strategy was in effect at 10 intersections, and data are available for 4 yr since implementation, then a total of 40 intersection years of after-period data are available for the study.

IMPLICATION FOR STUDY

Because PED crashes were the primary focus of this treatment, it is important to consider the required intersection years for the change in PED crashes. As the number of PED crashes were much lower than the number of total crashes, the number of intersection years needed to statistically detect an expected change in safety of a certain percentage were much higher for PED crashes compared to total crashes. The following list shows the number of before-period intersection years that were available in Philadelphia, PA, and Charlotte, NC, for three-leg and four-leg intersections:

- Philadelphia, PA, three-leg intersections = 112 intersection years.
- Philadelphia, PA, four-leg intersections = 458 intersection years.
- Charlotte, NC, three-leg intersections = 185 intersection years.
- Charlotte, NC, four-leg intersections = 390 intersection years.

Comparing these numbers with the required intersection years from the PED crash types in table 3, it is clear that the reduction in PED crashes would have to be 30 or 40 percent to be statistically detectable (especially at the 95 percent confidence level) if each city and intersection type (i.e., by leg) is considered separately. This is especially true for Charlotte, NC, where the rate of PED crashes was much lower compared to Philadelphia, PA (table 2). However, by combining the information for the two cities and intersection types, it will be more likely to statistically detect smaller reductions in crashes, with even smaller reductions detectable when the EB methodology is used. By combining the cities and intersection types, a total of 1,145 intersection years became available, and the average PED crash rate (based on a weighted average of the PED crash rate for the two cities and two intersection types) was calculated as 0.42. Based on these numbers, it is estimated that a 14 percent reduction in PED crashes could be statistically detected at a 90 percent confidence level, and a 16 percent reduction in PED crashes could be detected at a 95 percent confidence level.

CHAPTER 4. METHODOLOGY

This chapter presents the methodology that was used in this safety evaluation. The methodology is considered rigorous in that it accounts for regression to the mean using a reference group of similar but untreated sites. In the process, safety performance functions (SPFs) were used to address the following issues:

- Overcoming the difficulties of using crash rates in normalizing for volume differences between the before and after periods.
- Accounting for time trends.
- Reducing the level of uncertainty in the estimates of safety effect.
- Properly accounting for differences in crash experience and reporting practice in amalgamating data and results from diverse jurisdictions.

The methodology also provides a foundation for developing guidelines for estimating the likely safety consequences of a contemplated strategy. In the EB approach, the estimated change in safety for a given crash type at a site is shown in the equation in figure 2.

$$\Delta\ Safety = \lambda - \pi$$

Figure 2. Equation. Estimated change in safety.

Where:

λ = expected number of crashes that would have occurred in the after period without the strategy.
π = number of reported crashes in the after period.

In estimating λ, researchers typically use SPFs to explicitly account for the effects of regression to the mean and changes in traffic volume, relating different types of crashes to traffic flow and other relevant factors for each jurisdiction based on untreated or reference sites. However, since regression to the mean is unlikely with the PCSs for estimating SPFs, the project team used data from the before period of the treated sites along with the data from the complete study period of the reference sites. The project team calibrated annual SPF multipliers to account for temporal effects on safety, such as variation in weather, demography, and crash reporting.

In the EB procedure, the SPF was first used to estimate the number of crashes expected in each year of the before period. The sum of these annual estimates from a SPF in the before period at a strategy site (P) was then combined with the number of crashes at a strategy site in the before period (x) to obtain an EB estimate of the expected number of crashes at a strategy site in the before period (m), which was calculated using the equation in figure 3.

$$m = w(P) + (1 - w)(x)$$

Figure 3. Equation. EB estimate of the expected number of crashes.

Where w (EB weight) was estimated from the mean and variance of the SPF estimate using the equation in figure 4.

$$w = \frac{1}{1 + kP}$$

Figure 4. Equation. EB weight.

Where k is the constant for a given model and was estimated from the SPF calibration.

In estimating the SPF, a negative binomial distributed error structure was assumed, with k being the overdispersion parameter of this distribution.

A factor was then applied to m to account for the length of the after period and differences in traffic volumes between the before and after periods. This factor is the sum of the annual SPF predictions for the after period divided by P. The result, after applying this factor, was an estimate of λ, which is the expected number of crashes that would have occurred in the after period without the strategy at a strategy site. The procedure also produced an estimate of the variance of λ.

The sum of the expected number of crashes that would have occurred in the after period without the strategy (λ_{sum}) was obtained and compared with the sum of the number of crashes observed during the after period (π_{sum}) in that strategy group (where π is the number of crashes observed during the after period at a particular strategy site). The variance of λ was also summed over all sites in the strategy group.

The index of effectiveness (θ) was estimated using the equation in figure 5.

$$\theta = \frac{\pi_{sum} / \lambda_{sum}}{1 + \left(Var(\lambda_{sum}) / \lambda_{sum}^2 \right)}$$

Figure 5. Equation. Index of effectiveness.

The standard deviation of θ is given by the equation in figure 6.

$$StDev(\theta) = \sqrt{\frac{\theta^2 \left(\frac{Var(\pi_{sum})}{\pi_{sum}^2} + \frac{Var(\lambda_{sum})}{\lambda_{sum}^2} \right)}{\left(1 + \frac{Var(\lambda_{sum})}{\lambda_{sum}^2} \right)^2}}$$

Figure 6. Equation. Standard deviation of index of effectiveness.

The percent change in crashes was calculated as 100 ($1 - \theta$); thus, a value of $\theta = 0.70$ with a standard deviation of 0.12 indicates a 30 percent reduction in crashes with a standard deviation of 12 percent.

CHAPTER 5. DATA COLLECTION

The project team compiled data from Philadelphia, PA, Charlotte, NC, and two additional cities. Only the data from Philadelphia, PA, and Charlotte, NC were used in the evaluation. The first section of this chapter provides the summary data from Philadelphia, PA, and Charlotte, NC. The second section provides further discussion of the data from the unused cities.

PHILADELPHIA, PA

Data from Philadelphia, PA, were provided on intersections where the city had installed PCSs as part of the beginning of its citywide conversion of standard pedestrian signals to PCSs. The following sections describe how the project team collected installation, roadway, volume, and crash data for these sites.

Identification of Treatment and Reference Sites

The city of Philadelphia, PA, had installed PCSs at many intersections throughout the city. The installations used in this study mainly took place in the central area of the city because they were the earliest installations and therefore had more data available in the after period. The project team began with a list of about 500 intersections where PCSs had been installed prior to 2012 and for which the installation date was known. Installation began in 2008 and ended in 2011. The project team selected a 2012 cutoff date to ensure that treatment sites would have sufficient after data. The project team conducted a visual inspection of all sites from online aerial images and excluded sites with substantial changes (e.g., road widening and intersection reconstruction). The reference sites were identified by starting with a citywide inventory of signalized intersections and removing those where PCSs had been installed. The project team identified and retained only those treatment and reference sites within 1,500 ft of a point where the city had collected a count of pedestrians.

Intersection Characteristics

The project team obtained roadway data[2] in a spatial format. These spatial files contained information on the characteristics of the street segments. They linked the study sites to these spatial data files to append data to each site about its number of intersection legs and traffic volume by street.

Pedestrian Volume Data

The primary source for pedestrian volume data was the counts collected by the Delaware Valley Regional Planning Commission (DVRPC).[(16)] These data were collected using passive infrared sensors that collected pedestrian counts continuously for a 1-week duration (as recommended by FHWA's *Traffic Monitoring Guide*).[(17)] DVRPC adjusted these raw counts using two factors similar to the process used for vehicle traffic. The first factor corrected for the seasonality effect. DVRPC has begun to implement permanent stations to provide the data to derive these factors; however, they had not been active for an entire year, so at the time of data collection, DVRPC

[2]Unpublished data acquired directly from the city of Philadelphia.

used the seasonal correction factors that had been developed for vehicle traffic. The second factor corrected for the detection error of the sensor technology, which was shown to undercount due to occlusion (pedestrians walking exactly side by side) and young children who were too short to be detected.

Given the focus of this evaluation on pedestrian safety, the project team believed that it was critical to account for pedestrian exposure at the treatment and reference sites. The existing pedestrian counts as collected by DVRPC were available at various locations throughout the city. However, not many of the treatment and reference sites had pedestrian counts available directly adjacent to the intersection, either for one or both streets of the intersection. One possibility was to drop all study sites without directly adjacent pedestrian counts for both streets. However, this would have reduced the sample size too greatly to continue to conduct the evaluation in Philadelphia, PA. Instead, the project team used a broader measure of pedestrian activity based on zones.

The zone-based methodology included dividing the city into small zones and using known pedestrian counts within each zone to calculate a measurement of the general pedestrian activity within the zone. Each zone contained one or more existing pedestrian counts (figure 7). The counts within a zone were averaged to calculate the pedestrian volume for an average street within the zone.

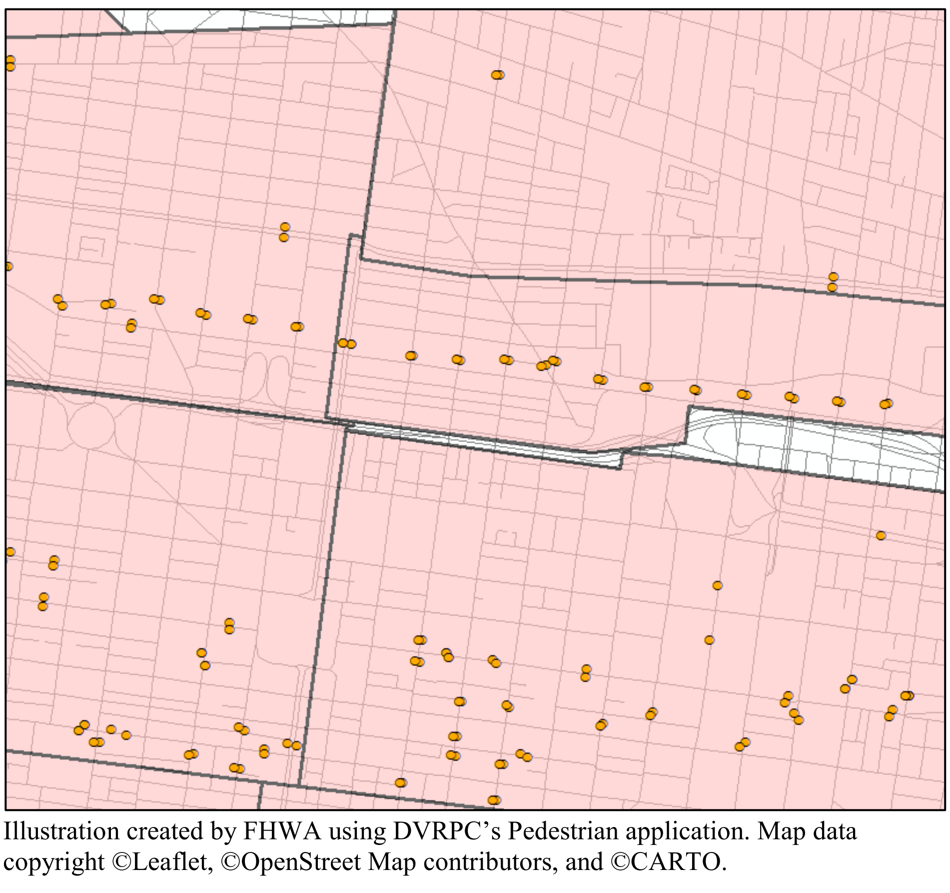

Illustration created by FHWA using DVRPC's Pedestrian application. Map data copyright ©Leaflet, ©OpenStreet Map contributors, and ©CARTO.

Figure 7. Illustration. Example pedestrian activity zones with pedestrian counts.[16]

The pedestrian count zones were delineated by the project team based on a combination of factors, including preexisting Philadelphia, PA, zoning, street characteristics, and existing pedestrian count values. The goal was to divide the city into zones in which the level of pedestrian activity could be assumed to be relatively similar. The project team used a map from the Philadelphia City Planning Zoning Commission as the primary basis for the zone delineation.(18) This zoning information was made available through OpenDataPhilly in spatial format.(19) In addition to these preexisting zones, the project team also considered the nature of the street network and the presence and location of existing pedestrian counts in determining boundaries for pedestrian count zones throughout the entire study area. This ensured that locations with widely disparate levels of pedestrian volumes (as indicated by the existing counts) were not being combined into the same zone. For certain areas of the city, the project team used other resources to more accurately delineate similar zones, such as in the Center City District, which contains the highest concentration of study sites and pedestrian counts. In this area, the project team also used "Walk! Philadelphia" Streetscape Improvement Project districts to delineate pedestrian count zones.(20) In other areas of the city, they also referred to a resource describing Philadelphia neighborhoods to assist in delineating zones.(21)

Each treatment or reference site that did not have a nearby pedestrian count was assigned the average pedestrian volume per street from the zone in which it was located. To make sure that sites were not assigned pedestrian volumes that were too far away (thus not applicable), the project team required that eligible sites be located within 1,500 ft of an existing pedestrian count. Generally, each intersection site was assigned a pedestrian volume primarily based on its proximity to an existing pedestrian count, but the zone-level pedestrian counts were used when an existing pedestrian count was not available for one or both streets of the study intersection.

Vehicle Volume Data

The project team acquired annual data[3] on vehicle traffic volume from 2009 to 2015 in spatial format. The annual average daily traffic (AADT) values were stored as attributes on the roadway line network. These values were joined to the study sites based on spatial proximity. Volume data were available for the major street of the study sites but rarely for the minor road.

Crash Data

The project team acquired crash data for all treatment and reference sites from the Pennsylvania Department of Transportation's (PennDOT's) Bureau of Maintenance and Operations. The crash data covered the period from 2008 to 2013. Crashes were associated to the study sites via spatial proximity using a 200-ft radius. The project team removed crashes that occurred in parking lots or were related to driveways.

Treatment Cost Data

The project team did not receive information on the cost to install the PCSs.

[3]Unpublished data acquired directly from PennDOT.

CHARLOTTE, NC

Data were provided from Charlotte, NC, on intersections where the city had installed PCSs. The following sections describe how the project team collected installation, roadway, volume, and crash data for these sites.

Identification of Treatment and Reference Sites

The city of Charlotte, NC, installs PCSs on a regular basis throughout the city and has done so for years. The low cost of converting a pedestrian signal to a PCS typically means that it is not tracked in a central database (i.e., the date of change is not recorded). However, as part of a 2009 Federal stimulus spending package, the city converted over 100 signalized intersections to PCSs, meaning that the installation year was known for these intersections.[4] The project team obtained from the city this list of intersections, which served as the preliminary group of treatment sites.

The project team obtained and reviewed signal-timing plans to determine if there had been any changes during the study period and to verify the presence and installation date of the PCSs. Sites were eliminated from this group if there was a known significant change that occurred during the study period.

The ideal reference group for this evaluation would have been signalized intersections with non-PCS pedestrian signals. However, the project team acquired a signal inventory from the city and determined that there was an insufficient number of this type of intersection; almost all signalized intersections with pedestrian signals were equipped with PCSs. Thus, the project team compiled a list of signalized intersections without pedestrian signals, and these sites served as the comparison group.

Intersection Characteristics

The project team acquired roadway information data in spatial format from FHWA's Highway Safety Information System (HSIS) and used spatial analysis to join these data to the study sites.(22) Data included site-level characteristics, such as number of legs, number of lanes per street, and whether the roadway was divided or undivided.

Pedestrian Volume Data

The project team obtained pedestrian counts from the city as a part of its database of intersection turning-movement counts. The data were stored in an easily accessed database and were available for the time periods before and after PCS installation. Sites that did not have pedestrian counts available were eliminated from the study.

Vehicle Volume Data

The city of Charlotte collects road-segment volumes (e.g., tube counts) on a regular basis throughout the city. However, for many of the study sites, these segment volumes did not provide information about the volume of the minor street of the intersection. Thus, the project team used

[4]Unpublished data acquired directly from the city of Charlotte.

the vehicle volume information in the turning-movement count database to calculate entering volume for each study site. This provided volume data for all legs at each intersection.

Crash Data

The project team acquired crash data from FHWA's HSIS from 2004 to 2013.(22) Crashes were associated with the study intersections based on spatial proximity using a 200-ft radius. Crashes that were within 200 ft of two adjacent intersections were inspected to assign the crash to one intersection and avoid double counting of crashes.

Treatment Cost Data

The project team did not receive information on the cost to install the PCSs.

UNUSED CITIES

The project team also pursued data on PCS installations in two additional cities, but these cities were ultimately not used in the final analysis. Both cities had approximately 1,600 PCS installations at the time of the evaluation. Data were acquired from both cities; however, there were several factors that resulted in the two cities' sites not being included in the analysis, including the following:

- Unknown date of PCS installation.
- Installation date too early to allow for before data or too recent to allow for after data within the time range of reliable and available data.
- Lack of pedestrian volume counts nearby.
- Crash data reliability concerns.

The project team investigated several different options to resolve these issues but was unable to do so. Ultimately, these concerns were significant enough that the sites were not included in the study.

SUMMARY DATA

Table 4 through table 19 show the summary data from the treatment and reference sites in Philadelphia, PA, and Charlotte, NC. Data were available from 2008 to 2103 in Philadelphia, PA, and from 2004 to 2013 in Charlotte, NC. The rate of PED crashes (per year per intersection) was lower in Charlotte, NC, when compared to Philadelphia, PA. The pedestrian volume in Charlotte, NC, was also substantially lower than in Philadelphia, PA, where only major road traffic volumes were available. In Charlotte, NC, the project team used total intersection volumes because volumes could not be easily assigned to a particular leg of the intersection. Compared to Charlotte, NC, only a small percentage of PDO crashes in Philadelphia, PA, were available in the crash database.

Table 4. Summary of three-leg treatment intersections in Philadelphia, PA (47 intersections).

Variable	Min	Max	Sum	Mean	Standard Deviation
Major road AADT before (vehicles per day)	6,092	36,807	—	20,912	8,478
Major road AADT after (vehicles per day)	5,530	37,168	—	19,121	8,152
Annual average daily pedestrian volume before (pedestrians per day)	153	15,707	—	4,628	4,877
Annual average daily pedestrian volume after (pedestrians per day)	153	15,707	—	4,628	4,877
Years before	1	3	112	2.38	0.61
Years after	2	4	123	2.62	0.61
Total crashes per site year before	0	8.5	90.33	1.92	1.73
Total crashes per site year after	0	7	93.34	1.99	1.67
KABC crashes per site year before	0	6	72	1.53	1.35
KABC crashes per site year after	0	5.67	72.42	1.54	1.31
RE crashes per site year before	0	3.5	26.83	0.57	0.76
RE crashes per site year after	0	2.5	23.08	0.49	0.58
ANG crashes per site year before	0	3	18.17	0.39	0.6
ANG crashes per site year after	0	3.67	29.25	0.62	0.93
PED crashes per site year before	0	2.5	16.17	0.34	0.58
PED crashes per site year after	0	1.67	13.67	0.29	0.38

—No data available.
Min = minimum; Max = maximum.

Table 5. Summary of four-leg treatment intersections in Philadelphia, PA (171 intersections).

Variable	Min	Max	Sum	Mean	Standard Deviation
Major road AADT before (vehicles per day)	5,565	36,807	—	17,653	6,024
Major road AADT after (vehicles per day)	5,014	37,168	—	16,028	5,938
Annual average daily pedestrian volume before (pedestrians per day)	203	32,500	—	7,176	6,399
Annual average daily pedestrian volume after (pedestrians per day)	203	32,500	—	7,176	6,399
Years before	1	3	458	2.68	0.57
Years after	2	4	397	2.32	0.57
Total crashes per site year before	0	11	421	2.46	1.65
Total crashes per site year after	0	9	412	2.41	1.74
KABC crashes per site year before	0	9	371	2.17	1.5
KABC crashes per site year after	0	6.5	336	1.97	1.52
RE crashes per site year before	0	3.5	84	0.49	0.63
RE crashes per site year after	0	2.5	79	0.46	0.55
ANG crashes per site year before	0	3	111	0.65	0.61
ANG crashes per site year after	0	5.25	126	0.74	0.78
PED crashes per site year before	0	4	142	0.83	0.87
PED crashes per site year after	0	4.5	123	0.72	0.9

—No data available.
Min = minimum, Max = maximum.

Table 6. Summary of three-leg treatment intersections in Charlotte, NC (37 intersections).

Variable	Min	Max	Sum	Mean	Standard Deviation
Intersection AADT before (vehicles per day)	13,794	53,489	—	30,933	8,150
Intersection AADT after (vehicles per day)	12,713	51,179	—	30,745	8,287
Annual average daily pedestrian volume before (pedestrians per day)	5	379	—	78	89
Annual average daily pedestrian volume after (pedestrians per day)	8	562	—	91	120
Years before	5	5	185	5	0
Years after	4	4	148	4	0
Total crashes per site year before	2.2	20	284	7.69	3.41
Total crashes per site year after	1	13.5	213	5.74	3.03
KABC crashes per site year before	0.2	6.2	80	2.15	1.16
KABC crashes per site year after	0.25	4.25	77	2.07	1.23
RE crashes per site year before	0.2	11	133	3.60	2.1
RE crashes per site year after	0	5.75	90	2.42	1.54
ANG crashes per site year before	0	2.8	24	0.64	0.54
ANG crashes per site year after	0	3.75	30	0.80	0.87
PED crashes per site year before	0	0.6	2	0.04	0.13
PED crashes per site year after	0	0.75	4	0.10	0.22

—No data available.
Min = minimum; Max = maximum.

Table 7. Summary of four-leg treatment intersections in Charlotte, NC (78 intersections).

Variable	Min	Max	Sum	Mean	Standard Deviation
Intersection AADT before (vehicles per day)	11,695	64,407	—	30,525	11,382
Intersection AADT after (vehicles per day)	12,370	67,366	—	30,647	12,085
Annual average daily pedestrian volume before (pedestrians per day)	10	392	—	112	91
Annual average daily pedestrian volume after (pedestrians per day)	11	482	—	127	108
Years before	5	5	390	5	0
Years after	4	4	312	4	0
Total crashes per site year before	0	39.6	838.2	10.75	7.47
Total crashes per site year after	0	35	601	7.71	5.79
KABC crashes per site year before	0	10.6	227.4	2.92	2.09
KABC crashes per site year after	0	14.75	235.25	3.02	2.5
RE crashes per site year before	0	22.4	338.4	4.34	3.91
RE crashes per site year after	0	12.25	232	2.97	2.68
ANG crashes per site year before	0	4.8	105.2	1.35	0.99
ANG crashes per site year after	0	8.5	105.5	1.35	1.23
PED crashes per site year before	0	1	11	0.14	0.19
PED crashes per site year after	0	1.25	12.25	0.16	0.24

—No data available.
Min = minimum; Max = maximum.

Table 8. Summary of three-leg reference intersections in Philadelphia, PA (45 intersections).

Variable	Min	Max	Sum	Mean	Standard Deviation
Major road AADT (vehicles per day)	3,877	33,037	—	14,260	6,910
Annual average daily pedestrian volume (pedestrians per day)	153	15,707	—	2,792	3,946
Years	8	8	360	8	0
Total crashes per site year	0.17	2.67	52	1.14	0.68
KABC crashes per site year	0	2	40	0.88	0.54
RE crashes per site year	0	1.17	16	0.36	0.33
ANG crashes per site year	0	1	12	0.27	0.26
PED crashes per site year	0	1	9	0.2	0.23

—No data available.
Min = minimum; Max = maximum.

Table 9. Summary of four-leg reference intersections in Philadelphia, PA (552 intersections).

Variable	Min	Max	Sum	Mean	Standard Deviation
Major road AADT (vehicles per day)	1,111	38,538	—	9,854	5,260
Annual average daily pedestrian volume (pedestrians per day)	203	28,900	—	6,178	6,251
Years	8	8	4,416	8	0
Total crashes per site year	0	6.67	713	1.29	0.88
KABC crashes per site year	0	5.33	589	1.07	0.76
RE crashes per site year	0	1.5	112	0.2	0.24
ANG crashes per site year	0	3.5	283	0.51	0.47
PED crashes per site year	0	2.17	174	0.32	0.35

—No data available.
Min = minimum; Max = maximum.

Table 10. Summary of three-leg reference intersections in Charlotte, NC (54 intersections).

Variable	Min	Max	Sum	Mean	Standard Deviation
Intersection AADT (vehicles per day)	12,374	52,858	—	26,443	8,267
Annual average daily pedestrian volume (pedestrians per day)	3	818	—	51	120
Years	10	10	540	10	0
Total crashes per site year	0	16	296.3	5.49	3.93
KABC crashes per site year	0	5.2	99.9	1.85	1.36
RE crashes per site year	0	10.2	151.5	2.81	2.44
ANG crashes per site year	0	1.8	27.6	0.51	0.45
PED crashes per site year	0	0.4	2	0.04	0.08

—No data available.
Min = minimum, Max = maximum.

Table 11. Summary of four-leg reference intersections in Charlotte, NC (82 intersections).

Variable	Min	Max	Sum	Mean	Standard Deviation
Intersection AADT (vehicles per day)	11,225	70,257	—	30,828	12,762
Annual average daily pedestrian volume (pedestrians per day)	1	255	—	36	44
Years	10	10	820	10	0
Total crashes per site year	0.4	29.4	742	9.05	6.12
KABC crashes per site year	0.2	10.1	258.2	3.15	2.2
RE crashes per site year	0.1	19.1	356.7	4.35	3.98
ANG crashes per site year	0	3.8	98.2	1.2	0.81
PED crashes per site year	0	0.3	4.2	0.05	0.08

—No data available.
Min = minimum; Max = maximum.

Table 12. Number of intersections by maximum number of lanes pedestrians must cross on the major road (after accounting for refuge islands) for reference and treatment intersections in Charlotte, NC.

Number of Lanes	Treatment Three-Leg Intersection	Treatment Four-Leg Intersection	Treatment Intersection Total	Reference Three-Leg Intersection	Reference Four-Leg Intersection	Reference Intersection Total
1–2	9	14	23	24	33	57
3–4	25	48	73	27	43	70
5–7	3	16	19	3	6	9

Table 13. Number of intersections by maximum number of lanes pedestrians must cross on the minor road (after accounting for refuge islands) for reference and treatment intersections in Charlotte, NC.

Number of Lanes	Treatment Three-Leg Intersection	Treatment Four-Leg Intersection	Treatment Intersection Total	Reference Three-Leg Intersection	Reference Four-Leg Intersection	Reference Intersection Total
1–2	24	40	64	43	60	103
3–5	13	38	51	11	22	33

Note: Information on the site characteristics presented in this table was not available in Philadelphia, PA.

Table 14. Number of intersections by type of major road division for reference and treatment intersections in Charlotte, NC.

Type of Major Road Division	Treatment Three-Leg Intersection	Treatment Four-Leg Intersection	Treatment Intersection Total	Reference Three-Leg Intersection	Reference Four-Leg Intersection	Reference Total Intersection
Divided	18	28	46	17	22	39
Divided on one side	4	19	23	14	17	31
Undivided	15	31	46	23	43	66

Note: Information on the site characteristics presented in this table was not available in Philadelphia, PA.

Table 15. Number of intersections by type of minor road division for reference and treatment intersections in Charlotte, NC.

Type of Minor Road Division	Treatment Three-Leg Intersection	Treatment Four-Leg Intersection	Treatment Intersection Total	Reference Three-Leg Intersection	Reference Four-Leg Intersection	Reference Total Intersection
Divided	8	11	19	14	9	23
Divided on one side	2	15	17	2	10	12
Undivided	27	52	79	38	63	101

Note: Information on the site characteristics presented in this table was not available in Philadelphia, PA.

Table 16. Number of intersections by speed limit of major road for reference and treatment intersections in Charlotte, NC.

Speed Limit (mi/h)	Treatment Three-leg Intersection	Treatment Four-Leg Intersection	Treatment Intersection Total	Reference Three-Leg Intersection	Reference Four-Leg Intersection	Reference Intersection Total
25–35	20	47	67	19	20	39
40–55	17	31	48	35	62	97

Table 17. Number of intersections by speed limit of minor road for reference and treatment intersections in Charlotte, NC.

Speed Limit (mi/h)	Treatment Three-Leg Intersection	Treatment Four-Leg Intersection	Treatment Intersection Total	Reference Three-Leg Intersection	Reference Four-Leg Intersection	Reference Intersection Total
25–35	35	70	105	46	60	106
40–55	2	8	10	8	22	30

Note: Information on the site characteristics presented in this table was not available in Philadelphia, PA.

Table 18. Number of intersections by maximum number of lanes for major road for reference and treatment intersections in Charlotte, NC.

Number of Lanes	Treatment Three-Leg Intersection	Treatment Four-Leg Intersection	Treatment Intersection Total	Reference Three-Leg Intersection	Reference Four-Leg Intersection	Reference Intersection Total
2–3	0	5	5	13	25	38
4	24	39	63	31	41	72
5–7	13	34	47	10	16	26

Note: Information on the site characteristics presented in this table was not available in Philadelphia, PA.

Table 19. Number of intersections by maximum number of lanes for minor road for treatment and reference intersections in Charlotte, NC.

Number of Lanes	Treatment Three-Leg Intersection	Treatment Four-Leg Intersection	Treatment Intersection Total	Reference Three-Leg Intersection	Reference Four-Leg Intersection	Reference Intersection Total
1–2	23	32	55	37	54	91
3–6	14	46	60	17	28	45

Note: Information on the site characteristics presented in this table was not available in Philadelphia, PA.

CHAPTER 6. DEVELOPMENT OF SPFS

This chapter presents the SPFs that the project team estimated. Generalized linear modeling was used to estimate model coefficients assuming a negative binomial error distribution, which is consistent with the state of research in developing these models. As previously discussed in chapter 4, the before data from the treatment group were used in combination with the reference group data for estimating the SPFs. Data from three-leg and four-leg intersections in Charlotte, NC, and Philadelphia, PA, were used for estimating SPFs. The independent variables included the following:

- Major road AADT.
- Minor road AADT.
- Intersection level AADT.
- Pedestrian traffic volume.
- Number of legs (three or four; this is a categorical variable).
- Maximum number of through lanes on the major road.
- Maximum number of through lanes on the minor road.
- Maximum number of lanes for the pedestrians to cross in any crossing maneuver on the major road considering the presence of refuge islands.
- Maximum number of lanes for the pedestrians to cross in any crossing maneuver on the minor road considering the presence of refuge islands.
- Major road divisions (i.e., divided on both sides, divided on one side, or undivided).
- Minor road divisions (i.e., divided on both sides, divided on one side, or undivided).
- Speed limit on the major road.
- Speed limit on the minor road.
- Indicator variable whether the observation was before data from the treatment group or from the reference group. The primary purpose of this variable was to account for the differences in the characteristics of the treatment group and the reference group that were not measured. The coefficients from this variable should not be used to infer the safety effect of the treatment (i.e., PCSs).

The variables are included in a log-linear form, as shown in the equation in figure 8.

$$Y = \exp(a_0 + a_1X_1 + a_2X_2 + \dots a_nX_n)$$

Figure 8. Equation. Functional form for SPF.

Where:

Y = predicted value from the SPF.
a_0 = intercept.
X_1 through X_n = independent variables.
a_1 through a_n = coefficients for independent variables X_1 through X_n.

The project team estimated separate SPFs for total, KABC, RE, ANG, and PED crashes. In Charlotte, NC, SPFs for PED crashes could not be reliably estimated, and the predictions for PED crashes were estimated by multiplying the predictions from the total crash model with the proportion of PED crashes.

After estimating the SPFs, the project team estimated annual SPF multipliers, as discussed in chapter 4 of this report. Table 20 and table 21 show the SPFs for Philadelphia, PA, and Charlotte, NC, respectively.

Table 20. SPFs for Philadelphia, PA.

Parameter	Total	KABC	RE	ANG	PED
Intercept	–3.0611 (0.9292)	–4.6368 (0.4594)	–8.3833 (0.8509)	–5.5733 (0.5474)	–4.4932 (0.7790)
ln(major road AADT)	0.3204 (0.1115)	0.4934 (0.0467)	0.8689 (0.0797)	0.4614 (0.0554)	0.3128 (0.0792)
Major road AADT/1,000	0.0180 (0.0093)	—	—	—	—
ln(pedestrian volume)	—	—	–0.1235 (0.0326)	—	0.0424 (0.0055)
Pedestrian volume/1,000	—	—	—	–0.0150 (0.0051)	—
Four-leg intersection	0.3526 (0.0738)	0.3946 (0.0783)	—	0.7758 (0.1207)	0.5396 (0.1367)
Three-leg intersection	—	—	—	—	—
Before period of treatment group	0.1502 (0.0285)	0.1964 (0.0299)	0.1810 (0.0478)	—	0.3349 (0.0484)
Reference group	—	—	—	—	—
k	0.2225 (0.0185)	0.2436 (0.0211)	0.3035 (0.0580)	0.3303 (0.0375)	0.5047 (0.0581)

—Reference level for categorical variables.
Note: Standard error is in parentheses.

Table 21. SPFs for Charlotte, NC.

Parameter	Total	KABC	RE	ANG
Intercept	0.0000 (0.0000)	−10.7884 (1.0144)	−15.9857 (1.1600)	−1.8147 (0.1903)
Total AADT/1,000	0.03780 (0.0030)	—	—	0.0228 (0.0040)
ln(total AADT)	—	1.0780 (0.0992)	1.6322 (0.1174)	—
ln(pedestrian volume)	0.1646 (0.0287)	0.1463 (0.0354)	0.1205 (0.0340)	0.1437 (0.0385)
Four-leg intersection	0.4280 (0.1410)	0.3247 (0.0748)	—	0.6963 (0.0983)
Three-leg intersection	0.1780 (0.1372)	—	—	—
Maximum number of lanes on minor road (3–6)	0.2424 (0.0681)	0.2104 (0.0760)	0.1891 (0.0758)	—
Maximum number of lanes on minor road (1–2)	—	—	—	—
Maximum number of lanes on major road (4)	—	—	−0.3493 (0.1127)	—
Maximum number or lanes on major road (5–7)	—	—	−0.4241 (0.1352)	—
Maximum number or lanes on major road (1–3)	—	—	—	—
Minor road divided on both sides	—	—	0.1773 (0.0958)	—
Minor road divided on one side	—	—	0.2500 (0.1149)	—
Minor road undivided	—	—	—	—
Major road speed limit of 40–55 mi/h	—	—	0.2278 (0.0782)	—
Major road speed limit of 25–35 mi/h	—	—	—	—
Minor road speed limit of 40–55 mi/h	—	—	0.1938 (0.0961)	—
Minor road speed limit (25–35 mi/h)	—	—	—	—
Maximum number of lanes for pedestrian crossing on major road (3–4)	−0.1560 (0.0733)	−0.1240 (0.0803)	—	—
Maximum number of lanes for pedestrian crossing on major road (5–7)	−0.4619 (0.1185)	−0.4884 (0.1334)	—	—
Maximum number of lanes for pedestrian crossing on major road (1–2)	—	—	—	—
Maximum number of lanes for pedestrian crossing on minor road (3–5)	—	—	—	—

Parameter	Total	KABC	RE	ANG
Maximum number of lanes for pedestrian crossing on minor road (1–2)	—	—	—	0.1911 (0.0966)
Before period of treatment group	—	−0.1910 (0.0823)	—	—
Reference group	—	—	—	—
k	0.2303 (0.0234)	0.2418 (0.0287)	0.2506 (0.0283)	0.3458 (0.0485)

—Reference level for categorical variables.
Note: SE is in parentheses. In Charlotte, NC, the predictions for PED crashes were estimated by multiplying the predictions from the total crash model with the proportion of PED crashes.

CHAPTER 7. BEFORE–AFTER EVALUATION RESULTS

This chapter provides the results of the before–after evaluation. The project team investigated the possibility of providing results for each city and number of legs separately. However, as discussed in chapter 3 of this report, in comparison to Philadelphia, PA, Charlotte, NC, had a smaller sample of treatment intersections (115 intersections compared to 218, respectively) and a lower rate of PED crashes. Hence, the project team decided to combine the results from Charlotte, NC, with those from Philadelphia, PA. Table 22 provides crash modification factors (CMFs) by crash type for the observed number of crashes in the after period with treatment, an EB estimate of the expected number of crashes in the after period without treatment, CMF, and the standard error (SE) of the CMF.

Table 22. Three-leg and four-leg intersection CMFs for PCSs.

Crash Type	Observed Number of Crashes in the After Period (With Treatment)	EB Estimate of Expected Number of Crashes in the After Period (Without Treatment)	CMF	SE of CMF
Total	4,499	4,885.8	0.921*	0.017
KABC	2,257	2,283.8	0.988	0.026
RE	1,542	1,761.3	0.875*	0.027
ANG	927	901.9	1.027	0.042
PED	397	434.9	0.912#	0.055

*CMF is statistically significant at the 95 percent confidence level.
#CMF is statistically significant at the 90 percent confidence level.

The project team also investigated the CMFs for three-leg and four-leg intersections separately. For PED crashes, the following CMFs were obtained:

- **Three-leg intersections:** CMF = 0.843 and SE of CMF = 0.132.
- **Four-leg intersections:** CMF = 0.922 and SE of CMF = 0.060.

These two CMFs were not statistically significant at the 90 or 95 percent confidence levels, and, based on a homogeneity test, neither were statistically different from each other at these confidence levels.(23) However, both indicated a reduction in crashes. For this reason, the project team combined the results for three-leg and four-leg intersections with the intent of obtaining a more stable CMF value with a lower SE that could be applied to either category of intersection (table 22).

The CMFs for total crashes (about an 8 percent reduction) and RE crashes (about a 12 percent reduction) were both statistically significant at the 95 percent confidence level. The CMF for PED crashes (about a 9 percent reduction) was statistically significant at the 90 percent confidence level, which may be regarded as a reasonable standard for such rare crash types.

CHAPTER 8. ECONOMIC ANALYSIS

The project team based the economic analysis on the estimated CMF values for total and KABC crashes. They conducted the economic analysis using the following steps:

1. Using the number of total and KABC crashes in the after period, the EB-expected number of total and KABC crashes in the after period, and the number of intersection years in the after period, the project team determined the change in PDO crashes per intersection year and the change in KABC crashes per intersection year. The expected benefit due to the PCSs was estimated as 0.03 KABC crashes per intersection per year and 0.37 PDO crashes per intersection per year.

2. The project team used the most recent FHWA mean comprehensive crash costs disaggregated by crash severity and location type as a base for the benefit calculations.(24) These costs were developed based on 2001 crash costs, and the unit cost (in 2001 U.S. dollars (USD)) for KABC and PDO crashes in urban areas was $91,917 and $7,068, respectively.(24) This was updated to 2016 USD by applying the ratio of the U.S. Department of Transportation (USDOT) 2016 value of a statistical life of $9.6 million to the 2001 value of $3.8 million.(25) Applying this ratio of 2.53 to the unit costs resulted in an aggregate 2016 unit cost of $232,211 for KABC crashes and $17,856 for PDO crashes. The expected annual benefit due to the fewer crashes after PCSs was $12,900. Based on the suggestions from USDOT, a sensitivity analysis was conducted to obtain a low and high value for the benefits and consequently a low and high value for the B/C ratios.(25)

3. The project team estimated the annualized cost of the treatment, as shown in the equation in figure 9.

$$\text{Annual Cost} = \frac{C \times R}{1 - (1 + R)^{-N}}$$

Figure 9. Equation. Annual cost.

Where:

C = treatment cost. The average cost of PCS installation was assumed to be $4,000 based on the two cities not included in the evaluation but that provided cost information.
R = discount rate (as a decimal); assumed to be 0.07.
N = expected service life (years); assumed to be 10 yr.

The annualized cost per year for PCS installation was $570.

4. The project team calculated the B/C ratio as the ratio of the annual crash savings to the annualized treatment cost. The B/C ratio was 23, with a low of 13 to a high of 32.

CHAPTER 9. SUMMARY AND CONCLUSIONS

The project team obtained geometric, traffic, and crash data from signalized intersections in Philadelphia, PA, and Charlotte, NC, to evaluate the safety effect of PCSs. A before–after EB analysis was performed using data from 115 treated intersections in Charlotte, NC, and 218 treated intersections in Philadelphia, PA. The evaluation also included 136 reference intersections in Charlotte, NC, and 597 reference intersections in Philadelphia, PA.

Table 1 showed the CMFs for the PCS treatment. The CMFs for total crashes (about an 8 percent reduction) and RE crashes (about a 12 percent reduction) were statistically significant at the 95 percent confidence level. The CMF for PED crashes (about a 9 percent reduction) was statistically significant at the 90 percent confidence level, which may be regarded as a reasonable standard for such rare crash types. The economic analysis revealed a B/C ratio of 23, with a low of 13 and a high of 32.

There were some limitations in the study. Minor road AADT data were not available in Philadelphia, PA, for most of the intersections and thus could not be used in estimating the SPFs. In addition, unlike Charlotte, NC, Philadelphia, PA, did not have specific pedestrian volume counts for most of its intersections, and the pedestrian volumes were estimated based on information on the pedestrian activity within a particular zone.

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REFERENCES

1. American Association of State Highway and Transportation Officials. (2003). *NCHRP Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan,* National Cooperative Highway Safety Research Program, Washington, DC. Available online: http://www.trb.org/Main/Blurbs/152868.aspx, last accessed February 16, 2018.

2. Federal Highway Administration. (2009). *Manual on Uniform Traffic Control Devices for Streets and Highways*, U.S. Department of Transportation, Washington, DC.

3. Pécheux, K., Bauer, J., and McLeod, P. (2009). *Pedestrian Safety and ITS-Based Countermeasures Program for Reducing Pedestrian Fatalities, Injury Conflicts, and Other Surrogate Measures Draft Zone/Area-Wide Evaluation Technical Memorandum*, Federal Highway Administration, Washington, DC.

4. American Association of State Highway and Transportation Officials. (2005). *AASHTO Strategic Highway Safety Plan*, American Association of State Highway and Transportation Officials, Washington, DC.

5. Markowitz, F., Sciortino, S., Fleck, J.L., and Yee. B.M. (2006). "Pedestrian Countdown Signals: Experience with an Extensive Pilot Installation." *ITE Journal*, *76*(1), pp. 43–48, Institute of Transportation Engineers, Washington, DC.

6. Leonard, J., Juckes, M., and Clement, B. (1999). "Behavioural Evaluation of Pedestrians and Motorists towards Pedestrian Countdown Signals." *Compendium of Papers, Institute of Transportation Engineers 2000*, Presented at District 6 Annual Meeting, San Diego, CA.

7. Zegeer, C. and Huang, H. (2000). *The Effects of Pedestrian Countdown Signals in Lake Buena Vista*, Florida Department of Transportation, Tallahassee, FL.

8. Eccles, K.A., Tao, R., and Mangum, B.C. (2004). *Evaluation of Pedestrian Countdown Signals in Montgomery County, Maryland*, Presented at the 83d Annual Meeting of the Transportation Research Board, Washington, DC.

9. Federal Highway Administration. (2008). *Pedestrian Safety: A Report to Congress*, U.S. Department of Transportation, Washington, DC.

10. Van Houten, R., LaPlante, J., and Gustafson, T. (2012). *Evaluating Pedestrian Safety Improvements,* Report-1585, Michigan Department of Transportation, Lansing, MI.

11. Srinivas, S.P., Desai, A., and Pulugurtha, N.M. (2010). "Are Pedestrian Countdown Signals Effective in Reducing Crashes?" *Traffic Injury Prevention*, *11*(6), pp. 632–641, Taylor &\ Francis, London, United Kingdom.

12. Camden, A., Buliung, R., Rothman, L., Macarthur C., and Howard, A. (2012). "The Impact of Pedestrian Countdown Signals on Pedestrian–Motor-vehicle Collisions: A Quasi-Experimental Study." *Injury Prevention*, *18*(4), pp. 210–215, BMJ Group, London, United Kingdom.

13. Richmond, S., Willan, A., Rothman, L., Camden, A., Buliung, R., Macarthur, C., and Howard, A. (2014). "The Impact of Pedestrian Countdown Signals on Pedestrian–Motor Vehicle Collisions: A Reanalysis of Data from a Quasi-Experimental Study." *Injury Prevention*, *20*(3), pp. 155–158, BMJ Group, London, United Kingdom.

14. Kapoor, S. and Magesan, A. (2014). "Paging Inspector Sands: The Costs of Public Information." *American Economic Journal: Economic Policy*, *6*(1), pp. 92–113, American Economic Association, Pittsburgh, PA.

15. Hauer, E. (1997). *Observational Before–After Studies in Road Safety*, Pergamon Press, Oxford, United Kingdom.

16. Delaware Valley Regional Planning Commission. (n.d.). "DVRPC Travel Monitoring Pedestrian and Bicycle Counts." (website) Philadelphia, PA. Available online: https://www.dvrpc.org/webmaps/pedbikecounts/, last accessed May 31, 2018.

17. Federal Highway Administration. (2016). *Traffic Monitoring Guide*, U.S. Department of Transportation, Washington, DC.

18. City of Philadelphia Department of Licenses and Inspection. (n.d.) "Zoning." (website) Philadelphia, PA. Available online: http://www.phila.gov/li/Pages/Zoning.aspx, last accessed May 30, 2018.

19. OpenDataPhilly. (n.d.) "Homepage." (website) Philadelphia, PA. Available online: www.opendataphilly.org, last accessed May 30, 2018.

20. Center City District. (n.d.). *Walk! Philadelphia*, Center City District, Philadelphia, PA. Available online: https://centercityphila.org/uploads/attachments/cityj10ay0039wzqd9k9osoafour-walkphila-infosheet.pdf, last accessed May 30, 2018.

21. Visit Philadelphia. (n.d.). "Philadelphia Neighborhoods." (website). Philadelphia, PA. Available online: http://www.visitphilly.com/philadelphia-neighborhoods, last accessed May 30, 2018.

22. Federal Highway Administration. (n.d.). "Highway Safety Information System." (website) U.S. Department of Transportation, Washington, DC, Available online: https://www.hsisinfo.org, last accessed April 22, 2019.

23. Carter, D., Srinivasan, R., Gross, F., Himes, S., Le, T., Persaud, B., Lyon, C., and Bonneson, J. (2017). *Guidance for the Development and Application of Crash Modification Factors*, Draft Final Report, Project 17-63, National Cooperative Highway Research Program, Washington, DC.

24. Council, F., Zaloshnja, E., Miller, T., and Persaud, B. (2005). *Crash Cost Estimates by Maximum Police-Reported Injury Severity Within Selected Crash Geometries*, Report No. FHWA-HRT-05-051, Federal Highway Administration, Washington, DC.

25. U.S. Department of Transportation Office of the Secretary of Transportation. (2016). *Guidance on Treatment of the Economic Value of a Statistical Life (VSL) in U.S. Department of Transportation Analyses—2016 Adjustment*, Memorandum, U.S. Department of Transportation, Washington, DC. Available online: https://www.transportation.gov/sites/dot.gov/files/docs/2016%20Revised%20Value%20of%20a%20Statistical%20Life%20Guidance.pdf, last accessed May 24, 2018.

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