Safety Effectiveness of the HAWK Pedestrian Crossing Treatment

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Turner-Fairbank Highway Research Center
6300 Georgetown Pike
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FOREWORD

The Federal Highway Administration (FHWA) Pedestrian and Bicycle Safety Research Program's overall goal is to increase pedestrian and bicycle safety and mobility. From better and safer crosswalks, sidewalks, and pedestrian technologies to growing educational and safety programs, the program strives to make it safer and easier for pedestrians, bicyclists, and drivers to share roadways in the future.

This study was part of a larger FHWA study to quantify the effectiveness of engineering countermeasures in improving safety and operations for pedestrians and bicyclists. The project focused on existing and new engineering countermeasures for pedestrians and bicyclists that have not yet been comprehensively evaluated in terms of effectiveness. This effort involved data collection and analysis to determine whether these countermeasures reduced fatalities and injuries or increased appropriate driving behaviors. In this study, the safety effectiveness of the High intensity Activated crossWalK (HAWK) pedestrian beacon was evaluated using a before-after empirical Bayes (EB) approach.

This report will interest engineers, planners, and other practitioners who have an interest in implementing pedestrian and bicycle treatments, as well as city, State, and local authorities who have a shared responsibility for public safety.

Monique R. Evans
Director, Office of Safety
Research and Development

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16. Abstract
The High intensity Activated crossWalK (HAWK) is a pedestrian-activated beacon located on the roadside and on mast arms over major approaches to an intersection. It was created in Tucson, AZ, and at the time of this study, it was used at more than 60 locations throughout the city. The HAWK head consists of two red lenses over a single yellow lens. It displays a red indication to drivers when activated, which creates a gap for pedestrians to use to cross a major roadway. A before-after study of the safety performance of the HAWK was conducted. The evaluations used an empirical Bayes (EB) method to compare the crash prediction for the after period if the treatment had not been applied to the observed crash frequency for the after period with the treatment installed.

To develop the datasets used in this evaluation, crashes were counted if they occurred within the study period, typically 3 years before the HAWK installation and 3 years after the HAWK installation or up to the limit of the available crash data for the after period. Two crash datasets were created. The first dataset included intersecting street name (ISN) crashes, which were all crashes with the same intersecting street names that matched the intersections used in the study. The second dataset included intersection-related (IR) crashes, which were only those ISN crashes that had "yes" for the intersection-related code. The crash types that were examined included total, severe, and pedestrian crashes. From the evaluation that considered data for 21 HAWK sites (treatment sites) and 102 unsignalized intersections (reference group), the following changes in crashes were found after the HAWK was installed: a 29 percent reduction in total crashes (statistically significant), a 15 percent reduction in severe crashes (not statistically significant), and a 69 percent reduction in pedestrian crashes (statistically significant).

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SI* (MODERN METRIC) CONVERSION FACTORS

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 1000 L shall be shown in m^3			
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		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 (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	$candela/m^2$	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the 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
ADT	Average daily traffic
EB	Empirical Bayes
FHWA	Federal Highway Administration
GEE	Generalized estimating equation
HAWK	High intensity Activated crossWalK
IR	Intersection-related
ISN	Intersecting street name
MEP	Million entering pedestrians
MEV&P	Million entering vehicles and pedestrians
MOTORV	Noncontact recreational vehicle
MUTCD	*Manual on Uniform Traffic Control Devices*
NCM	Noncontact motorcycle
NCNM	Noncontact nonmotorcycle
SPF	Safety performance function
SWOPP	Sideswipe opposite direction
SWSAME	Sideswipe same direction

Symbols

$\hat{\theta}$	Estimated index of effectiveness
$\hat{\pi}$	Predicted number of crashes in after period had HAWK not been installed
$\beta_0,, \beta_1, \beta_2,\ldots, \beta_k$	Regression coefficients
C_i	Adjustment factors
$\exp\left(\hat{\beta}_{period}\right)$	An estimate of the general trend including the change in extraneous factors between the before and after periods
$E\left(\kappa_i\right)$	Expected number of crashes
μ_i	Expected number of crashes at intersection *i* per unit time interval
I	Total number of intersections or sites
i	i^{th} intersection or site

k	Estimated dispersion parameter of the negative binomial regression model
K_i	Total crash counts during the before period at site *i*
L	Number of crashes observed during the after period
L_i	Total crash count during the after period at site *i*
ln	log
M_i	Estimate of the expected number of crashes
$r_{d,i}$	Adjustment factor for the duration of the study period
$r_{T,i}$	Adjustment factor for differences in traffic volumes and general time trend (if any exists)
w_i	Weight
$X_{1i}, \ldots, X_{ki}$	Predictors corresponding to the characteristics of intersection *i*

CHAPTER 1. INTRODUCTION

BACKGROUND

The city of Tucson, AZ, developed the High intensity Activated crossWalK (HAWK) pedestrian crossing beacon in the late 1990s to assist in pedestrian crossings, especially for major arterials at minor street intersections.[1] The purpose of a HAWK is to stop vehicles to allow pedestrians to cross the roadway and then permit drivers to proceed as soon as the pedestrians have passed. This application provides a pedestrian crossing without signal control for the side street because signal control on the side street can encourage unwanted additional traffic through the neighborhood. Figure 1 shows an example of the current head configuration for the HAWK.

Figure 1. Photo. Example of a HAWK head.

The HAWK head consists of two red lenses over a single yellow lens. The heads are located both on a mast arm over the roadway and on the roadside. Figure 2 shows a HAWK at an intersection.

Figure 2. Photo. Example of a HAWK treatment in Tucson, AZ.

A typical HAWK includes the following:

- An overhead red-yellow-red beacon (similar to an emergency vehicle beacon) facing both directions of the major street. Supplementing the beacons are signs labeled "CROSSWALK STOP ON RED" and "PEDESTRIAN CROSSING," which indicate that the location is associated with a pedestrian crosswalk.

- STOP sign(s) on the minor street.

- A marked crosswalk on only one major street approach.

- A pedestrian pushbutton with a supplemental educational plaque.

- Pedestrian signal indications with a pedestrian interval countdown display.

Figure 3 provides the phase sequence for a HAWK. The unit is dark until it is activated by a pedestrian. When pedestrians want to cross the street, they press a button that activates the warning flashing yellow on the major street. After a set amount of time, the indication changes to a solid yellow light to inform drivers to prepare to stop. The device then displays a dual solid red light for drivers on the major street and a walking person symbol (symbolizing WALK) for the pedestrians. The beacon then displays an alternating flashing red light, and pedestrians are shown a flashing upraised hand (symbolizing DONT WALK) with a countdown display advising them of the time

left to cross. During the alternating flashing red operation, drivers can proceed after coming to a full stop and checking that pedestrians have already crossed their lane of travel.

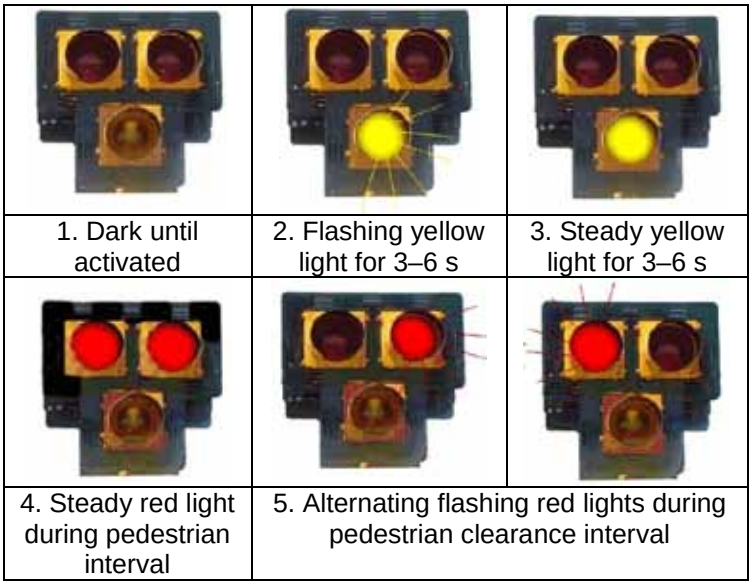

Figure 3. Chart. Example of phase sequence for a HAWK.[2]

Swartz discusses how the timing for the HAWK phases is selected in Tucson, AZ.[3] The flashing yellow light typically lasts for 3 s. The duration of the solid yellow light is equal to the yellow change interval for a standard traffic signal. The solid red light that is displayed to drivers is the same as the walk indication, which is 7–10 s long. A longer walk indication is implemented at locations with older, disabled, and/or young users. The width of the crossing affects the duration of the flashing red operation. The city has been using an interval of 4 ft/s for timing the HAWK crossing based on the *Manual on Uniform Traffic Control Devices* (MUTCD).[4] City officials are moving to 3.5 ft/s in anticipation of changes to the MUTCD. All new HAWKs are being implemented with countdown pedestrian heads.

The alternating flashing red operation allows vehicles to stop for the actual time period that is necessary for pedestrians to cross. Drivers can proceed with a stop-and-go operation during the flashing red phase if a pedestrian walks faster than the assumed walking speed and clears the lanes or roadway. If pedestrians need more time, then the drivers remain stopped. The ability to balance the needs of the pedestrians and the delay of the drivers is a valuable component of the HAWK treatment. Extensive red-light time when pedestrians no longer need it to cross safely can encourage violations.

Public outreach was extensive during the early years of the HAWK operation. Concerns have been expressed regarding confusion that may result from the dark beacon display, as some drivers may interpret it as a power outage. However, anecdotal experiences in Tucson, AZ, have indicated that the dark display does not create such a problem.

Another concern is in regards to drivers not stopping at the crosswalk during the flashing red operation. In some cases, once the queue began to disperse, drivers behind the lead vehicle continued through the intersection rather than coming to a complete stop at the head of the

queue. This concern is an education and enforcement issue. Officials in Tucson, AZ, have indicated that they have received complaints that drivers were traveling through the flashing red lights without stopping (a second time) at the stop bar. The Tucson Police Department has conducted targeted enforcement at HAWKs in response to this complaint.

STUDY APPROACH

The objective of the research effort was to evaluate the safety effectiveness of HAWKs. The safety benefits of the HAWK treatment were determined by reviewing crash data before and after HAWKs were installed. The before-after evaluation used an empirical Bayes (EB) method that considered nearby intersections without the HAWK treatment as reference sites to develop safety performance functions (SPFs). EB uses a crash prediction for the after period assuming the treatment has not been applied and compares this predicted value to the observed crash frequency for the after period with the treatment installed.[5]

2009 MUTCD

Following its completion but prior to the publication of this Federal Highway Administration (FHWA) study, the 2009 edition of the MUTCD was released.[6] The 2009 MUTCD includes information on the pedestrian hybrid beacon, which is similar to the HAWK. Chapter 4F of the 2009 MUTCD has information on the following:

- The application of pedestrian hybrid beacons.
- The design of pedestrian hybrid beacons.
- The operation of pedestrian hybrid beacons.

Section 2B.52 (and figure 2B-27) of the 2009 MUTCD has details on the sign to be used with the pedestrian hybrid beacon.[6]

The pedestrian hybrid beacons described in the 2009 MUTCD differ from the HAWKs included in this safety study in the following ways:[6]

- Section 4F.02 of the 2009 MUTCD, has the following guidance statement:
  "When an engineering study finds that installation of a pedestrian hybrid beacon is justified, then:
  A. The pedestrian hybrid beacon should be installed at least 100 feet from side streets or driveways that are controlled by STOP or YIELD signs."

  All 21 HAWKs included in this safety study were located either at a minor intersection (where the minor street was controlled by a STOP sign) or at a major driveway (where the driveway was controlled by a STOP sign).

- The 2009 MUTCD includes an R10-23 sign with the symbolic red circle and a white background for the CROSSWALK section of the sign (see figure 4). The signs typically used at the HAWK locations in Tucson, AZ, do not have the symbolic red circle, and the CROSSWALK background is yellow (see figure 5).

Figure 4. Photo. R10-23 sign from the 2009 MUTCD.[6]

Figure 5. Photo. Typical signs used at HAWK crossings in Tucson, AZ.

CHAPTER 2. LITERATURE REVIEW

A 2006 Transit Cooperative Research Program/National Cooperative Highway Research Program project used driver compliance (yielding or stopping where required) as the primary measure of effectiveness for evaluating engineering treatments at unsignalized roadway crossings.[(2)] Driver compliance data were collected at 42 study sites that included 9 different types of pedestrian crossing treatments. In addition to collecting driver yielding behavior for general population pedestrians, the data collection personnel also staged street crossings to ensure consistency among all sites as well as adequate sample sizes. The study found that the type of crossing treatment did have an impact on driver compliance. Treatments showing a red indication to the driver had a significantly higher compliance rate (both statistically and practically) than devices that did not show a red indication. These red signal or beacon devices, which included midblock signals, half signals, and HAWKs, had compliance rates greater than 95 percent, as shown in figure 6. Nearly all of the red signal or beacon treatments that were evaluated were used on busy, high-speed arterial streets. Pedestrian crossing flags and in-street crossing signs were also effective in prompting driver yielding, achieving 65 and 87 percent compliance, respectively. However, most of these crossing treatments were installed on lower-volume, two-lane roadways.

Based on the findings from the driver compliance study, the research team recommended the addition of red signal or beacon devices to the engineer's toolbox for pedestrian crossings.[(2)] The study results indicated that only the devices that showed a red indication were effective at prompting high levels of driver compliance on high-volume, high-speed streets. However, at the time of the study, only a traffic signal was recognized in the MUTCD, and the pedestrian signal warrant was difficult to meet.[(4)] Thus, engineers were unable to easily employ those traffic control devices that appear to be most effective for pedestrians on wide, high-speed streets. The Signal Technical Committee of the National Committee of Uniform Traffic Control Devices, along with representatives of the research team, developed language for the inclusion of the HAWK pedestrian beacon in the proposed revision to the MUTCD.[(7)]

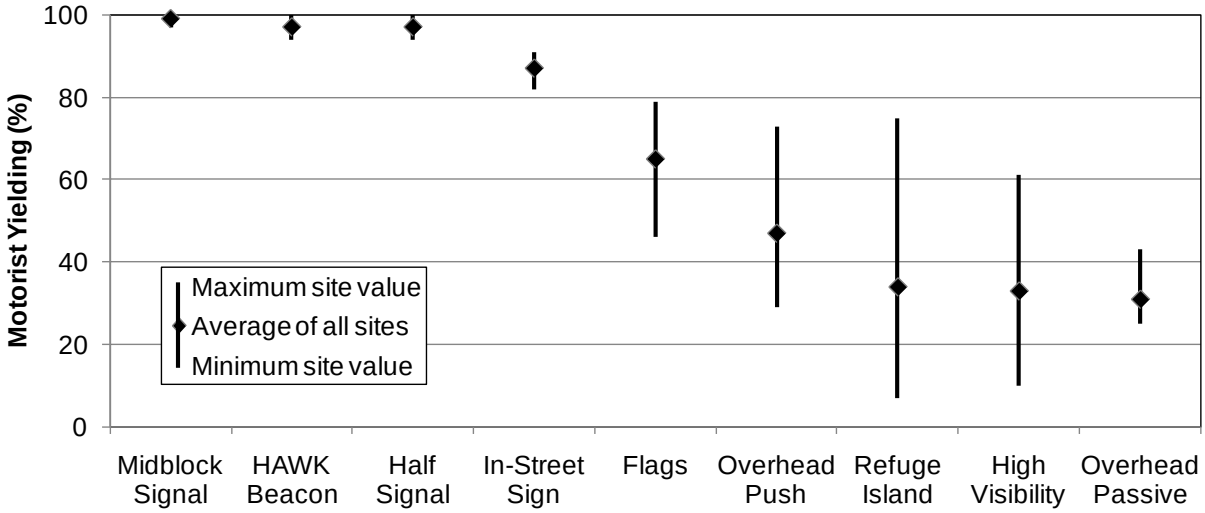

Figure 6. Graph. Driver yielding.[(2)]

In June 2006, Nassi and Barton reported that Tucson, AZ, had over 60 HAWKs, had not experienced a high occurrence of crashes at these locations, and had no pedestrian fatalities at any of the locations.[1] The report indicated that there had been only nine pedestrian accidents over a 5-year period at the HAWK locations. The breakdown of pedestrian accidents is as follows:

- 2002: One accident.
- 2003: Four accidents.
- 2004: Zero accidents.
- 2005: Two accidents.
- 2006: Two accidents (through December).[1]

While research has demonstrated that driver compliance is high for the HAWK and that there has been a positive safety experience in Tucson, AZ, a comprehensive study of the safety performance of the HAWK has not been conducted. As a result, this current study was created.

CHAPTER 3. DATA COLLECTION

SITE SELECTION AND GEOMETRIC DATA

The city of Tucson, AZ, provided the research team with a list of all HAWKs that were installed or planned. Sites that were planned or installed less than 18 months prior to this study were not evaluated. The head configuration for the HAWKs was initially similar to a vertical traffic signal. Because of criticisms that such a configuration appears to be a malfunctioning traffic signal when dark, officials in Tucson revised the head configuration to the current "Mickey Mouse ears" arrangement (see figure 1) in an effort to develop a unique configuration that would be associated with special types of crossings. Only sites where the current head configuration was newly installed (21 locations) were included in the before-after study.

Crash evaluations benefit when a set of similar sites without the treatment of interest (referred to as the reference group) are identified. When selecting these sites, the goal is that they are as similar as possible to the sites with the HAWK treatment without actually having the treatment. They should be located near the treated sites and have similar volumes, numbers of lanes, numbers and types of turn bays, medians, etc. These sites allow the evaluations to account for possible (or potential) regression-to-the-mean bias as well as traffic, weather, road-user behavior, citywide public relations campaigns, vehicle fleet, and other factors that change over time.

The city of Tucson, AZ, maintains a map center that provides online access to geographic information system maps and databases.[8] The Web site includes aerial photographs along with selected roadway characteristics and a tool for measuring distance. The roadway characteristics that were used to select reference sites included traffic signal locations, STOP sign locations, speed limit, bus routes, and bike treatment.

Potential Reference Groups

Care must be taken in selecting an appropriate reference group because the safety effectiveness estimate might change significantly depending on what reference group is used, as observed by Persaud and Lyon.[9] In the current study, researchers considered two potential reference groups—reference group 1 and reference group 2—and derived the safety effectiveness estimate for HAWK sites using each reference group.

Reference Group 1

After each HAWK site was located, unsignalized and signalized intersections were identified near the HAWK crossing, typically within 0.25 mi of the HAWK. These sites had at least one roadway in common with the HAWK location. Preferably, the sites had a similar number of approaches (e.g., three-leg intersection or four-leg intersection), and that goal was generally met for unsignalized intersections. A similar number of approaches could not be met for signalized intersections because most of the signalized intersections near the HAWKs had four-leg configurations. For the unsignalized intersections, the reference sites had a similar number of lanes on each approach (e.g., if the minor approach to the HAWK was a two-lane, undivided roadway, then the reference location also should have been a two-lane, undivided roadway). The preference was to find two unsignalized intersections and two signalized intersections for each

HAWK. Because in some cases suitable reference sites were not available, the dataset included approximately 3.4 reference sites for each HAWK site. The distribution of key variables for each intersection group is provided in table 1.

Table 1. Distribution of intersection characteristics for HAWKs and reference group 1.

Variable	Value	Number of Intersections (Percent of Total)		
		HAWK	**Signalized**	**Unsignalized**
Major cross section	Four-lane undivided or with two-way left-turn lane	12 (57)	22 (61)	22 (63)
	Four-lane divided	1 (5)	2 (6)	1 (3)
	Six-lane divided	8 (38)	12 (33)	12 (34)
Major speed limit (mi/h)	30	1 (5)	5 (14)	2 (6)
	35	9 (43)	12 (33)	16 (46)
	40	11 (52)	19 (53)	17 (49)
Refuge island on major	No	12 (57)	21 (58)	22 (63)
	Yes	9 (43)	15 (42)	13 (37)
Intersection type	Four-leg	12 (57)	35 (97)	17 (49)
	Three-leg	9 (43)	1 (3)	18 (52)
Total		21	36	35
Variable		**Average After Volume (Standard Deviation)**		
Major road (vehicles/day)		39,771 (9,673)	38,803 (8,592)	39,626 (9,966)
Minor road (vehicles/day)		711 (434)	25,480 (16,044)	594 (871)
Pedestrians (pedestrians/day)		405 (447)	657 (622)	180 (239)

Reference Group 2

Due to concerns with using signalized intersections as part of the reference group, a second reference group was developed. Reference group 2 consisted of 102 unsignalized intersections typically located within 2 mi of the HAWKs. The distribution of key variables for each intersection group is listed in table 2.

Table 2. Distribution of intersection characteristics for HAWKs and reference group 2.

Variable	Value	Number of Intersections (Percent of Total)	
		HAWK	**Unsignalized**
Number of lanes on major cross section	Two	0 (0)	2 (2)
	Four	13 (63)	57 (56)
	Six	8 (38)	43 (42)
Major speed limit (mi/h)	30	1 (5)	11 (11)
	35	9 (43)	41 (40)
	40	11 (52)	50 (49)
Refuge island on major	No	12 (57)	52 (51)
	Yes	9 (43)	50 (49)
Intersection type	Four-leg	12 (57)	48 (47)
	Three-leg	9 (43)	54 (53)
Total		21	102
Variable		**Average After Volume (Standard Deviation)**	
Major road (vehicles/day)		39,771 (9,673)	37,961 (12,396)
Minor road (vehicles/day)		711 (434)	741 (793)
Pedestrians (pedestrians/day)		405 (447)	185 (212)

TRAFFIC COUNTS

Several sources were used to obtain traffic counts. Traffic counts (or historical maps) were made available on the Web for selected intersections or segments by the city of Tucson, AZ, and the Pima Association of Governments.[10, 11] The Pima Association of Governments also provided historical counts upon request. Traffic maps and counts between 1996 and 2007 were reviewed. Relevant count information (count value and year of count) was transferred from the list of counts or traffic maps into the geometric database for each major street and minor road approach for all intersections when available. Vehicle counts from existing sources were identified for most of the major streets of the intersections.

None of the existing sources had available pedestrian counts. Therefore, 2-h pedestrian counts were collected during spring 2008 and spring 2009. The city of Tucson, AZ, provided 24-h video surveillance of five HAWK sites; however, one of the sites was eliminated due to a gap in the video tape. From the tapes, the number of pedestrians crossing for each hour was counted for the remaining sites, and the distribution was used to adjust the 2-h pedestrian counts into 24-h pedestrian counts. The 24-h volumes were also adjusted for seasonal variability. *Traffic Volumes Map* provided information on monthly variations, noting that winter visitors and college students contribute to higher volumes during the spring.[11] Converting the counts made in March 2008 and March 2009 to average annual daily traffic (AADT) counts (pedestrians and/or minor road vehicles) required multiplying the 24-h March volumes by 87 percent. The March counts were higher than the average annual values.

The 2-h pedestrian counts were gathered at all HAWK intersections except for those sites with 24-h counts. The 2-h pedestrian counts were also gathered at all reference intersections. When the minor road volume for an intersection was not available from existing counts, the minor road approach volume was also counted.

The available volumes were averaged for the relevant study period to generate the AADT (vehicle or pedestrian) for each study period for a site. If the available volumes were for a different time period than the period being used for the crashes, a 2 percent growth rate was assumed. For example, if counts were available for 2004 and 2005 but the crash data covered 2003, 2004, and 2005, the volume for 2003 was estimated as being 98 percent of the 2004 volume.

STUDY PERIODS

For the before-after study, the goal was to have 36 months of before data and 36 months of after data. The before period was set at 36 months and reflected month 38 to month 2 prior to the installation date of the HAWK. The 2-month period prior to the installation date was assumed for construction. The after period was set as beginning 2 months following the installation of the HAWK until 36 months later or December 31, 2007, which was the limit of crash data available. The 2-month period following the installation of the HAWK was assumed to be a learning period for the treatment. Therefore, a site with an installation date of December 31, 2002, would have the before-after analysis periods as follows:

- Before period: November 1, 1999–October 31, 2002.
- Installation period: November 1, 2002–December 31, 2002.
- Learning period: January 1, 2003–February 28, 2003.
- After period: March 1, 2003–February 28, 2006.

The number of months in the after period for the 21 HAWK sites varied depending when the HAWK was installed. Table 3 lists the number of months in the after period for the 21 sites.

The shortest after period was 19.5 months. The majority of the sites had a 32-month or greater after period, with more than 80 percent of the sites having at least a 28-month after period. Note that each reference site had the same number of days in its after period as its matched HAWK site.

Table 3. After study period length.

Number of Days in After Period	Number of Months in After Period	Number of HAWKs	Percentage of HAWKs with After Study Period Less than or Equal to Column 1 Value	Percentage of HAWKs with After Study Period Greater than or Equal to Column 1 Value
595	19.5	1	5	100
630	20.7	1	10	95
637	20.9	1	14	90
790	25.9	1	19	86
866	28.4	1	24	81
888	29.1	1	29	76
904	29.6	1	33	71
988	32.4	4	52	67
1,030	33.8	1	57	48
1,095	35.9	9	100	43
Total		21		

CRASH DATA

Crash data were supplied by the city of Tucson, AZ. Street names were used to match the crashes with the geometric database. Because different spellings could be present for a street name (e.g., St. Mary's, St Marys, Saint Mary's, etc.), the research team manually searched the datasets to verify that consistent spelling was used in both the crash dataset and the geometric dataset. A check was also performed with the street names reversed to ensure that all crashes associated with an intersection were identified. For example, crashes for Oak and Pine along with crashes for Pine and Oak (reverse order) were identified.

A review of the crash dataset revealed that some of the crashes were coded to a block address, with most associated with an intersection. Identifying all crashes associated with an intersection should capture the crashes that could be influenced by the intersection's traffic control; however, it may also capture crashes that occurred near the intersection that would not have been influenced by the intersection's traffic control. The Arizona traffic accident report form includes a space to record the distance from an intersection (measured or approximate). The distance could provide an appreciation of whether the crash should be associated with the intersection. The information, however, was not available to the research team. Another variable that can provide insight into whether the crash may be related to the intersection's traffic control is the variable "intersection-related" (IR). The permitted responses for the IR field were "yes," "no," or blank, and about ⅓ of the crashes had this field blank. A comparison of the number of IR crashes for the intersections reviewed in a previous study indicated that the IR variable may be too restrictive.[(1)] Therefore, both the crash dataset that included all crashes identified when the intersecting street names (ISNs) matched and the smaller crash dataset that reduced the data to

only those with “yes” for the IR code were used in the evaluations. Descriptions of the crash datasets used in this study are as follows:

- ISN crashes: identified by matching the street names for the intersection.
- IR crashes: identified as those crashes in the ISN crash dataset with “yes” for the IR code.

Different types of crashes from each of the crash datasets were used in the evaluations. The types of crashes are as follows:

- Total crashes: included all identified crashes.
- Severe crashes: included all crashes with an injury severity code of possible injury, nonincapacitating injury, incapacitating injury, or fatal injury.
- Pedestrian crashes: included all crashes with the manner of collision coded as pedestrian.

CHAPTER 4. OBSERVATIONS

BEFORE-AFTER CRASH DATA

Table 4 summarizes the number of crashes by control type for the before-after study periods for both the dataset where the crashes were matched by ISNs and the smaller dataset that only included IR crashes. For all crashes and specific crash types of interest, the rates were calculated with the number of entering vehicles and pedestrians.

The HAWK was installed to assist pedestrians in crossing the roadway; therefore, installing the device should have a notable impact on pedestrian crashes. The rates shown for pedestrian crashes in table 4 were calculated using both the number of vehicles and number of pedestrians entering the intersection and only the number of pedestrians entering the intersection. The pedestrian crashes per million entering pedestrians (pedestrian crashes/MEP) rate is not commonly used in crash evaluations; however, it was calculated to provide an appreciation of the relationship between pedestrian crashes and pedestrian usage by control type. Because vehicle counts were so much larger than pedestrian counts at an intersection, the crash rate that included vehicle exposure may mask the effects on pedestrian crashes. The crash rate that included both vehicles and pedestrians is expressed as crashes per million entering vehicles and pedestrians (crashes/MEV&P).

Using ISN crashes, the HAWK sites experienced a decrease of about 17 percent in the total crash rate after the installation of the beacon. The 102 unsignalized intersections experienced a 3 percent increase in total crash rate. When IR crashes were used, the HAWK sites experienced a larger decrease in their crash rate. IR crash rates also showed a reduction at unsignalized intersections.

Table 4. Crash data for before-after study by groups.

Treatment Group	Measure	ISN Crashes			IR Crashes		
		Before	After	Percent Change	Before	After	Percent Change
HAWK sites (21)	Frequency	11.0	9.2	-17	5.0	3.3	-34
	Total crashes/MEV&P	0.748	0.618	-17	0.341	0.223	-35
	Severe crashes/MEV&P	0.265	0.210	-21	0.138	0.094	-32
	Pedestrian crashes/MEV&P	0.029	0.005	-83	0.017	0.002	-86
	Pedestrian crashes/MEP	3.081	0.511	-83	1.826	0.255	-86
Reference group 1: signalized intersections (36)	Frequency	44.9	41.9	-7	19.6	16.8	-14
	Total crashes/MEV&P	1.953	1.788	-8	0.854	0.716	-16
	Severe crashes/MEV&P	0.549	0.503	-8	0.294	0.241	-18
	Pedestrian crashes/MEV&P	0.020	0.016	-23	0.010	0.008	-16
	Pedestrian crashes/MEP	2.051	1.546	-25	1.025	0.839	-18
Reference group 1: unsignalized intersections (35)	Frequency	4.2	4.3	3	1.6	1.3	-17
	Total crashes/MEV&P	0.285	0.292	2	0.108	0.090	-17
	Severe crashes/MEV&P	0.098	0.088	-10	0.043	0.038	-10
	Pedestrian crashes/MEV&P	0.006	0.009	52	0.003	0.004	42
	Pedestrian crashes/MEP	1.383	2.078	50	0.615	0.866	41
Reference group 2: unsignalized intersections (102)	Frequency	5.9	6.1	3	2.4	2.1	-9
	Total crashes/MEV&P	0.418	0.430	3	0.166	0.150	-9
	Severe crashes/MEV&P	0.140	0.141	0	0.060	0.056	-6
	Pedestrian crashes/MEV&P	0.006	0.011	93	0.001	0.003	143
	Pedestrian crashes/MEP	1.233	2.297	86	0.257	0.602	134

Crashes/MEV&P = Type of given crash (total, severe, or pedestrian crashes) per million entering vehicles and pedestrians.
Pedestrian crashes/MEP = Pedestrian crashes per million entering pedestrians.
Note: Frequency is expressed as the average annual number of total crashes for a site with the given intersection control and study period.

The HAWK sites experienced an 83 percent reduction in the pedestrian crash rate after installation. The 102 unsignalized intersections experienced a 93 percent increase in pedestrian ISN crashes/MEV&P. When IR crashes were used, the trends were the same.

As seen in table 4, HAWK sites had crash rates that were higher than unsignalized intersections. The HAWK locations were associated with a slightly greater number of crashes/MEV&P as compared to the nearby unsignalized intersections in both the before and after periods. This observation does not imply that if the HAWK were removed, the crash rate for a given intersection would be similar to the crash rate identified for the neighboring unsignalized intersections. The crash rate at the HAWK sites prior to installation also exceeded the crash rate for nearby unsignalized intersections (the IR crash rate when the intersections were unsignalized and before the HAWK was installed was 0.341 crashes/MEV&P, while that of the nearby unsignalized intersections was 0.166 crashes/MEV&P). Therefore, conditions at the HAWK sites

before the treatments were installed were generating crashes in greater numbers than the unsignalized intersections. This indicates that those intersections were associated with conditions that resulted in a higher number of crashes. Addressing those conditions by installing a HAWK appeared to result in a decrease in total crashes and pedestrian crashes. Chapter 5 of this report provides the statistical evaluations of these observations.

OTHER CRASH CHARACTERISTICS

The installation of the HAWK could also cause changes in the types of crashes occurring. Within the Tucson, AZ, crash database, the following manner-of-collision choices are available (officers can check only one):

- Angle.
- Backing.
- Bicycle.
- Fixed object.
- Head-on.
- Left turn.
- Noncontact recreational vehicle (MOTORV).
- Noncontact motorcycle (NCM).
- Noncontact nonmotorcycle (NCNM).
- Other.
- Pedestrian.
- Rear-end.
- Right turn.
- Sideswipe opposite direction (SWOPP).
- Sideswipe same direction (SWSAME).
- Single vehicle.
- U-turn.

The number of crashes by manner of collision is listed in table 5. Figure 7 and figure 8 show plots of the distributions. To make figure 7 and figure 8 more understandable, the following

manners of collision were summed to create the grouped category: backing, fixed object, head-on, MOTORV, NCM, NCNM, other, SWOPP, and U-turn.

The manner-of-collision variable was not checked in approximately 20 percent of the ISN crashes, and those crashes were not included in the generated distributions shown in table 5, figure 7, and figure 8. For each of the IR crashes, a manner of collision was selected by an officer.

Rear-end is the most common crash type for all types of intersection control, representing between 40 and 60 percent of the crashes for a given type of traffic control at the intersection. After rear-end, the most common crash types were left-turn and angle.

The dataset shows rear-end as the most common manner of collision for the HAWK intersections in both the before and after periods (illustrated in figure 7 and figure 8). The distribution of IR crashes at the HAWK sites before the HAWK was installed included rear-end (55 percent), angle (13 percent), left-turn (15 percent), and pedestrian (5 percent) crashes. After the installation, the greatest changes in the distribution of crash type were an increase in angle crashes to 19 percent and a decrease in pedestrian crashes to 1 percent.

Table 5. Number and percent of crashes by manner of collision.

Manner of Collision	Before HAWK (21 Sites)		After HAWK (21 Sites)		Signalized (36 Sites)		Unsignalized (102 Sites)	
	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
ISN Crashes								
Angle	58	9	53	13	1,069	15	395	13
Backing	10	2	6	1	69	1	52	2
Bicycle	13	2	7	2	76	1	34	1
Fixed	8	1	1	0	42	1	40	1
Head-on	3	0	0	0	50	1	32	1
Left turn	57	9	35	8	1,188	17	438	14
MOTORV	2	0	0	0	2	0	2	0
NCM	1	0	0	0	16	0	6	0
NCNM	1	0	0	0	9	0	5	0
Other	15	2	6	1	86	1	58	2
Pedestrian	27	4	4	1	85	1	66	2
Rear-end	382	60	245	59	3,345	47	1,481	47
Right turn	14	2	7	2	206	3	114	4
Single	19	3	20	5	195	3	142	5
SWOPP	1	0	1	0	41	1	16	1
SWSAME	29	5	27	6	543	8	235	7
U-turn	2	0	6	1	52	1	37	1
Blank	53	NI	90	NI	1,789	NI	357	NI
Total	695	100	508	100	8,863	100	3,510	100
IR Crashes								
Angle	40	13	35	19	694	19	248	19
Backing	0	0	1	1	33	1	9	1
Bicycle	8	3	2	1	42	1	23	2
Fixed	2	1	0	0	13	0	14	1
Head-on	1	0	0	0	35	1	10	1
Left turn	46	15	25	14	889	24	318	24
NCM	1	0	0	0	7	0	1	0
NCNM	1	0	0	0	1	0	3	0
Other	5	2	2	1	29	1	18	1
Pedestrian	16	5	2	1	44	1	16	1
Rear-end	175	55	98	54	1,515	41	458	35
Right turn	6	2	4	2	96	3	74	6
Single	7	2	4	2	78	2	33	3
SWOPP	0	0	1	1	27	1	8	1
SWSAME	7	2	6	3	187	5	57	4
U-turn	2	1	3	2	36	1	23	2
Total	317	100	183	100	3,726	100	1,313	100

Note: *Blank* indicates that the manner of collision was not provided for crash; *NI* indicates condition was not included in calculation of percent distribution.

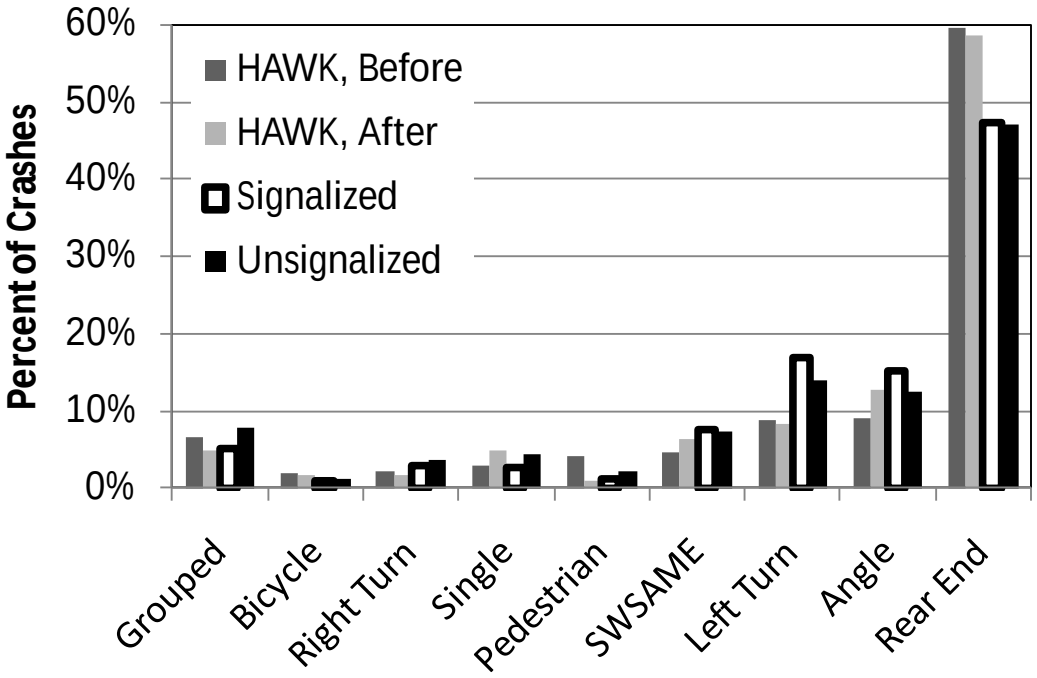

Figure 7. Graph. Distribution of manner of collision by control for ISN crashes.

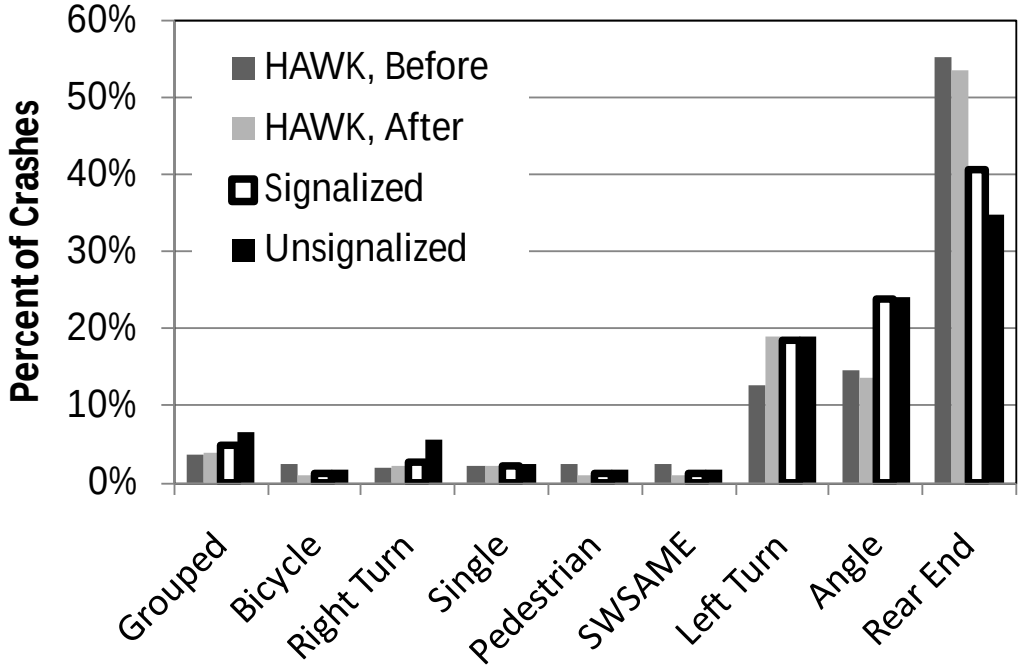

Figure 8. Graph. Distribution of manner of collision by control for IR crashes.

CHAPTER 5. BEFORE-AFTER EVALUATION

This chapter presents the results from safety evaluations of the HAWK. To evaluate the effectiveness of the HAWK, a before-after evaluation using the EB approach was used.

BEFORE-AFTER CRASH DATA

The treated sites included 21 intersections with the HAWK installed during the study period. Reference group 1 included 71 intersections (36 signalized and 35 unsignalized), and reference group 2 included 102 unsignalized intersections. The following crash types were examined in this study:

- Total crashes.
- Severe crashes.
- Pedestrian crashes.

Table 6 summarizes the total number of each type of crash by site type for the before and after study periods. Additional crash statistics are provided in table 4.

As can be observed from table 6, crashes decreased from before to after at both treatment and reference sites, which implies that the decrease at the treatment sites was not caused solely by installation of HAWKs. Other variables and extraneous factors that might have contributed to the observed decreases in crashes include AADT, changes in weather, vehicle mix, driver behavior, crash reporting practices, etc. To account for the effects of those variables in crash reduction as well as potential regression-to-the-mean bias, the EB approach was employed to identify the safety effectiveness of the HAWK.

Table 6. Number of crashes in before and after periods.

Type of Site	Type of Crash	Number of Crashes			
		ISN Crashes		IR Crashes	
		Before	After	Before	After
HAWKs	Total	695	508	317	183
	Severe	246	173	128	77
	Pedestrian	27	4	16	2
Reference group 1: signalized intersections (36)	Total	4,849	4,014	2,119	1,607
	Severe	1,362	1,129	729	540
	Pedestrian	50	35	25	19
Reference group 1: unsignalized intersections (35)	Total	438	394	167	121
	Severe	151	119	66	52
	Pedestrian	9	12	4	5
Reference group 2: unsignalized intersections (102)	Total	1,817	1,693	720	593
	Severe	610	555	260	221
	Pedestrian	24	42	5	11

EB PROCEDURE

The statistical method used to evaluate the effectiveness of the HAWK was a before-after evaluation using the EB method. The EB method can account for the effect of regression to the mean on evaluation results along with changes in traffic volume levels and general time trend (if any exists) in the accident frequencies. Details on the EB method are available elsewhere.[5, 12, 13] For the purpose of completeness, the steps of the EB procedure are as follows:

1. Develop an SPF, usually by adopting negative binomial regression models, and estimate the regression coefficients and a negative binomial dispersion parameter (k) using data from the reference group.

2. Estimate the expected number of crashes $E(\kappa_i)$ in the before period at each treatment site i as the (per-day) SPF prediction multiplied by the number of days in the before period.

3. Obtain an estimate of the expected number of crashes (M_i) before implementation of the HAWK at each treatment site by using the equation in figure 9, where K_i is the total crash count during the before period at site i and the weight w_i is given by the equation in figure 10. Within the weight equation, k is the estimated dispersion parameter of the negative binomial regression model developed in step 1. An estimated variance (var) of M_i is given by the equation in figure 11.

$$M_i = w_i E(\kappa_i) + (1 - w_i) K_i$$

Figure 9. Equation. Estimate of expected number of crashes during the before period.

$$w_i = \frac{1}{1 + kE(\kappa_i)}$$

Figure 10. Equation. Weight.

$$\hat{Var}(M_i) = (1 - w_i) M_i$$

Figure 11. Equation. Estimated variance of expected number of crashes during the before period.

4. Compute the adjustment factors to account for differences in traffic volumes (and general trend if any exists) and duration between the before and after periods. The adjustment factor for differences in traffic volumes (and general trends), $r_{T,i}$ is computed as the ratio of the per-day SPF prediction for the after period and that for the before period at each site. The adjustment factor for the duration of the study period ($r_{d,i}$) is computed as the ratio of the number of days for the after period and that for the before period at each site. Let C_i represent the adjustment factors. The equation for C_i is provided in figure 12.

$$C_i = r_{T,i} r_{d,i}$$

Figure 12. Equation. Adjustment factors.

5. Obtain the predicted crashes ($\hat{\pi}_i$) during the after period that would have occurred without implementing HAWK by the equation in figure 13. The estimated variance of $\hat{\pi}_i$ is given by the equation in figure 14.

$$\hat{\pi}_i = M_i C_i$$

Figure 13. Equation. Predicted crashes during the after period.

$$\hat{Var}\left(\hat{\pi}_i\right) = C_i^2 \hat{Var}\left(M_i\right) = C_i^2\left(1 - w_i\right) M_i$$

Figure 14. Equation. Estimated variance of predicted crashes during the after period.

6. Compute the sum of the predicted crashes over all sites in the treatment group by the equation in figure 15. Compute its estimated variance by the equation in figure 16 where *I* is the total number of sites in the treatment group, which is 21 in this study.

$$\hat{\pi} = \sum_{i=1}^{I} \hat{\pi}_i$$

Figure 15. Equation. Sum of predicted crashes.

$$\hat{Var}\left(\hat{\pi}\right) = \sum_{i=1}^{I} \hat{Var}\left(\hat{\pi}_i\right)$$

Figure 16. Equation. Estimated variance of sum of predicted number of crashes.

7. Compute the sum of the observed crashes over all sites in the treatment group using the equation in figure 17, where L_i is the total crash count during the after period at site *i*.

$$L = \sum_{i=1}^{I} L_i$$

Figure 17. Equation. Sum of observed crashes.

8. Estimate the index of effectiveness ($\theta = L/\pi$) for the HAWK by the equation in figure 18 and the percent change in the number of crashes by the equation in figure 19. If $\hat{\theta}$ is less than 1, then the HAWK has a positive effect on safety.

$$\hat{\theta} = \frac{L}{\hat{\pi}\left(1 + \text{var}\left(\hat{\pi}\right)/\hat{\pi}^2\right)}$$

Figure 18. Equation. Estimated index of effectiveness.

$$\text{Percent change in number of crashes} = 100\left(1 - \hat{\theta}\right)$$

Figure 19. Equation. Percent change in number of crashes.

9. Compute the estimated variance and standard error of the estimated index of effectiveness. The estimated variance and standard error of the estimated index of effectiveness are given by figure 20 and figure 21, respectively.

$$\hat{Var}\left(\hat{\theta}\right) = \hat{\theta}^2 \frac{\left(1/L + \hat{Var}\left(\hat{\pi}\right)/\hat{\pi}^2\right)}{\left(1 + \hat{Var}\left(\hat{\pi}\right)/\hat{\pi}^2\right)^2}$$

Figure 20. Equation. Estimated variance of estimated index of effectiveness.

$$s.e.\left(\hat{\theta}\right) = \sqrt{\hat{Var}\left(\hat{\theta}\right)}$$

Figure 21. Equation. Standard error of estimated index of effectiveness.

10. Construct the confidence interval by adding and subtracting $z_{\alpha/2} \times s.e.\left(\hat{\theta}\right)$ from $\hat{\theta}$ where $z_{\alpha/2}$ is the *z* critical value corresponding to a predetermined confidence level $(1 - \alpha) \times 100$ percent. Different confidence levels and the corresponding *z* critical values are as follows:

    - 95 percent confidence level ($\alpha = 0.05$) $z_{\alpha/2} = z_{0.025} = 1.96$.
    - 90 percent ($\alpha = 0.1$) $z_{\alpha/2} = z_{0.05} = 1.645$.
    - 85 percent ($\alpha = 0.15$) $z_{\alpha/2} = z_{0.075} = 1.44$.

If the confidence interval does not contain the value 1, then a significant effect at the $(1 - \alpha) \times 100$ percent level has been observed.

SPF DEVELOPMENT

As presented previously, the first step in the before-after EB method is to develop and calibrate an SPF using data from a reference group. Reference group 1 included both signalized (36) and unsignalized (35) intersections, and reference group 2 consisted of 102 unsignalized intersections. Within the SPF, the log of the number of days was included as an offset variable (the SPFs were developed for the expected number of crashes per day).

SPF development first involved determining which predictor variables should be used in the model, how variables should be grouped, and what model form should be used. The major street and minor road average daily traffic (ADT) values are often the key variables in developing SPFs for intersections. In addition, pedestrian volumes are likely to play an important role in pedestrian crashes. Typically, using the log of the sum of entering vehicles and pedestrians (or the log of the entering vehicles and the log of pedestrian volumes) as predictors seemed to be most appropriate for the data. Other combinations of ADT values, such as separating the vehicle volumes by major and minor approaches or using the ratio of major to minor approach volume, were considered during model development.

To account for additional intersection-to-intersection variability other than that caused by the differences in traffic volumes and pedestrian volumes, intersection type, median refuge presence, number of lanes, and major street speed limit were also considered in the SPF predictions. Other variables, such as parking on the minor road, were considered but were eliminated because most sites had the same characteristic. Variables were eliminated if the corresponding coefficient was not significant at $\alpha = 0.2$ and had a counterintuitive sign at the same time.

For the SPF predictions in EB analysis, it is typical to adopt negative binomial regression models. The general form of the expected number of crashes in a negative binomial regression model is shown in figure 22. After exploring various negative binomial regression model forms with different predictors, the best model for the different types of crashes was identified.

$$\mu_i = \exp\left(\beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \cdots + \beta_k X_{ki}\right)$$

Figure 22. Equation. General form for expected number of crashes.

Where:

μ_i = The expected number of crashes at intersection *i* per unit time interval (1 day).
$X_{1i}, \ldots, X_{ki}$ = The predictors corresponding to the characteristics of *i*.
$\beta_0, \beta_1, \beta_2, \ldots, \beta_k$ = The regression coefficients.

In developing the SPFs, the crash counts at reference sites could be treated as aggregated data over the entire study period (including both the before and after periods) or as disaggregated data with two crash counts from each intersection, one for the before period and one for the after period. Aggregating the data can account for the correlations that might be present in the crash counts when the intersections are included twice (once for the before period and once for the after period) in estimating the SPFs. Disaggregating the data provides the opportunity to account for general time trend (if any exists) within the two periods.

Several SPFs were generated as part of the evaluations. The coefficients for models with potential are included in the appendix of this report. The tables presented in this section include the best model for the conditions based on the assessment of the research team.

Reference Group 1 Aggregate Data

Initial efforts used aggregated data from reference group 1. Results for models identified by the research team are included in the appendix. Table 7 and table 8 present the best SPFs for total, severe, and pedestrian ISN and IR crashes when using aggregated data. The tables also provide the corresponding EB safety effectiveness estimates. Higher percent reductions were found for IR total crashes (29 percent) as compared to ISN total crashes (15 percent). For pedestrian crashes, a 57 percent reduction (statistically significant) in ISN crashes and a 56 percent reduction (not statistically significant) in IR crashes were found. For severe crashes, an 11 percent reduction in ISN crashes and an 18 percent reduction in IR crashes were found, although those results were not statistically significant at the 95 percent confidence levels.

Although the 95 percent confidence level was used throughout this report, a selection of prespecified confidence levels may vary with researchers or with the problem. The statistical

significance may also vary depending on what confidence level is chosen. It needs to be noted that the statistically insignificant results at the 95 percent confidence level for severe crashes may still be important. The statistically insignificant 11 percent reduction in crashes could have been due to the lack of power resulting from a small sample size or due to chance. The size of the sample for severe crashes as well as for IR pedestrian crashes was a concern. For ISN pedestrian crashes, a statistically significant reduction in crashes was achieved despite a small sample size due to a huge effect size (57 percent). For IR crashes, the sample size was even smaller than that for the ISN crashes, which led to a statistically insignificant result, although the effect size (56 percent) was about the same as that for the ISN crashes. For severe crashes, the effect size was much smaller (11 and 18 percent, although still practically significant) than those for pedestrian crashes, and a much larger sample will be required to achieve statistical significance. It is possible that with a larger sample, the effect of the HAWK on severe crashes may become significant at the 95 percent confidence level.

While there has been a case where a HAWK replaced a signal, in most cases, the HAWK was installed at a previously unsignalized intersection. Therefore, an alternative reference group that only contains unsignalized intersections was developed.

Table 7. Estimate of regression coefficients of SPFs for ISN crashes using reference group 1.

Variable	Total Crashes Coefficient Estimate (*p*-Value)	Severe Crashes Coefficient Estimate (*p*-Value)	Pedestrian Crashes Coefficient Estimate (*p*-Value)
SPF Results			
Intercept	-34.3200 (< 0.0001)	-32.2219 (< 0.0001)	-26.5372 (< 0.0001)
Intersection type (three-leg = 1, four-leg = 0)	-0.9932 (< 0.0001)	-0.9557 (< 0.0001)	-0.8826 (0.0137)
Major street speed limit (mi/h)	0.0951 (0.0016)	0.1110 (0.0003)	0.1048 (0.0031)
Median refuge present	-0.7478 (0.0003)	-0.6998 (0.0012)	-0.4731 (0.0545)
LnVeh&Ped	2.6005 (< 0.0001)	—	1.4433 (0.0002)
LnVeh	—	2.1704 (< 0.0001)	—
LnPed	—	0.1390 (0.0834)	—
Dispersion	0.4452	0.4235	0.0588
Pearson chi-square/degree of freedom	0.9702	1.0360	1.1428
EB Results			
L, Number of crashes observed during the after period	508	173	4
$\hat{\rho}$, Predicted number of crashes during after period had the HAWK not been installed	594.744	192.979	9.35410
$\hat{q}$, Estimated index of effectiveness	0.853	0.893	0.426
$se(\hat{q})$, Standard error of $\hat{q}$	0.050	0.086	0.214
$100(1-\hat{q})$, Percent reduction in the number of crashes (i.e., crash reduction)	15	11	57
Results are statistically significant at 95 percent confidence level	Yes	No	Yes

LnVeh&Ped = Ln(entering vehicles and pedestrians).
LnVeh = Ln(entering vehicles).
LnPed = Ln(entering pedestrians).
— Indicates that the variable was not included in model.

Table 8. Estimate of regression coefficients of SPFs for IR crashes using reference group 1.

Variable	Total Crashes Coefficient Estimate (*p*-Value)	Severe Crashes Coefficient Estimate (*p*-Value)	Pedestrian Crashes Coefficient Estimate (*p*-Value)
SPF Results			
Intercept	-34.2206 (< 0.0001)	-32.9071 (< 0.0001)	-31.9455 (< 0.0001)
Intersection type (three-leg = 1, four-leg = 0)	-1.2010 (< 0.0001)	-1.1455 (< 0.0001)	-0.8626 (0.1096)
Major street speed limit (mi/h)	0.0889 (0.0080)	0.1057 (0.0031)	0.1313 (0.0173)
Median refuge present	-0.5582 (0.0172)	-0.5465 (0.0277)	-0.1824 (0.6126)
LnVeh&Ped	2.5262 (< 0.0001)	2.2558 (< 0.0001)	1.7660 (0.0028)
LnVeh	—	—	—
LnPed	—	—	—
Dispersion	0.5276	0.5425	0.1978
Pearson chi-square/degree of freedom	0.9983	1.0243	1.2738
EB Results			
L, Number of crashes observed during the after period	183	77	2
$\hat{\rho}$, Predicted number of crashes during after period had the HAWK not been installed	256.501	93.5850	4.49476
$\hat{q}$, Estimated index of effectiveness	0.711	0.817	0.439
$se(\hat{q})$, Standard error of $\hat{q}$	0.065	0.114	0.311
$100(1-\hat{q})$, Percent reduction in the number of crashes (i.e., crash reduction)	29	18	56
Results are statistically significant at 95 percent confidence level	Yes	No	No

LnVeh&Ped = Ln(entering vehicles and pedestrians).
LnVeh = Ln(entering vehicles).
LnPed = Ln(entering pedestrians).
— Indicates that the variable was not included in model.

Reference Group 2 Aggregate Data

The results for reference group 2 with an aggregated data approach are shown in table 9 and table 10. These tables present the best SPFs for total, severe, and pedestrian ISN and IR crashes, along with the corresponding EB safety effectiveness estimates. Results for other models identified by the research team for reference group 2 are included in the appendix.

It can be observed from a comparison of table 7 through table 10 that the safety effectiveness estimates ($\hat{q}$) from both reference groups are close, while the coefficients of SPFs calibrated based on reference group 1 are somewhat different from those calibrated using reference group 2. For total crashes, similar results were obtained between the two reference groups—about a 14 percent reduction in ISN crashes and a 29 percent reduction in IR crashes, both being statistically significant at the 95 percent confidence level. The results for pedestrian crashes were fairly similar—about a 59 percent reduction (statistically significant) in ISN crashes and about a 51 percent reduction (not statistically significant) in IR crashes. The results for severe crashes were also similar; an 11 and 18 percent reduction were found for ISN crashes and IR crashes, respectively, although the results were not statistically significant at the 95 percent level. Note again that statistically insignificant results may still be important, and with a larger sample, those results may become significant at the 95 percent confidence level.

Table 9. Estimate of regression coefficients of SPFs for ISN crashes using reference group 2.

Variable	Total Crashes Coefficient Estimate (*p*-Value)	Severe Crashes Coefficient Estimate (*p*-Value)	Pedestrian Crashes Coefficient Estimate (*p*-Value)
SPF Results			
Intercept	-16.8197 (< 0.0001)	-17.7484 (< 0.0001)	-16.8225 (0.0004)
Intersection type (three-leg = 1, four-leg = 0)	-0.3732 (0.0116)	-0.3586 (0.0370)	-0.0292 (0.9207)
Major street speed limit (mi/h)	0.0673 (0.0062)	0.0860 (0.0031)	0.0248 (0.6263)
LnVeh&Ped	0.9827 (< 0.0001)	0.8990 (0.0003)	—
LnVeh	—	—	0.6518 (0.1787)
LnPed	—	—	0.1999 (0.1186)
Dispersion	0.4592	0.5560	0.2712
Pearson chi-square/degree of freedom	1.1011	1.0367	1.0967
EB Results			
L, Number of crashes observed during the after period	508	173	4
$\hat{p}$, Predicted number of crashes during after period had the HAWK not been installed	588.646	198.106	9.71056
$\hat{q}$, Estimated index of effectiveness	0.862	0.870	0.408
$se(\hat{q})$, Standard error of $\hat{q}$	0.050	0.084	0.206
$100(1-\hat{q})$, Percent reduction in the number of crashes (i.e., crash reduction)	14	13	59
Results are statistically significant at 95 percent confidence level	Yes	No	Yes

LnVeh&Ped = Ln(entering vehicles and pedestrians).
LnVeh = Ln(entering vehicles).
LnPed = Ln(entering pedestrians).
— Indicates that the variable was not included in model.

Table 10. Estimate of regression coefficients of SPFs for IR crashes using reference group 2.

Variable	Total Crashes Coefficient Estimate (*p*-Value)	Severe Crashes Coefficient Estimate (*p*-Value)	Pedestrian Crashes Coefficient Estimate (*p*-Value)
SPF Results			
Intercept	-18.5272 (< 0.0001)	-18.3149 (< 0.0001)	-25.4693 (0.0222)
Intersection type (three-leg = 1, four-leg = 0)	-0.6012 (0.0012)	-0.5635 (0.0050)	-0.3600 (0.5457)
Major street speed limit (mi/h)	0.0917 (0.0025)	0.1128 (0.0012)	0.0497 (0.6429)
LnVeh&Ped	0.9740 (0.0003)	—	—
LnVeh	—	0.7829 (0.0087)	—
LnPed	—	—	0.3056 (0.2692)
LnMajor	—	—	1.1741 (0.2829)
LnMinor	—	—	0.0692 (0.8003)
Dispersion	0.6461	0.6297	1.2769
Pearson chi-square/degree of freedom	1.1445	1.0049	0.9878
EB Results			
L, Number of crashes observed during the after period	183	77	2
$\hat{\rho}$, Predicted number of crashes during after period had the HAWK not been installed	256.423	90.0872	3.94071
$\hat{q}$, Estimated index of effectiveness	0.712	0.849	0.490
$se(\hat{q})$, Standard error of $\hat{q}$	0.065	0.118	0.347
$100(1-\hat{q})$, Percent reduction in the number of crashes (i.e., crash reduction)	29	15	51
$\hat{\rho}$, Predicted number of crashes during after period had the HAWK not been installed	Yes	No	No

LnVeh&Ped = Ln(entering vehicles and pedestrians).
LnVeh = Ln(entering vehicles).
LnPed = Ln(entering pedestrians).
LnMajor = Ln(entering vehicles from major approaches).
LnMinor = Ln(entering vehicles from minor approaches).
— Indicates that the variable was not included in model.

Reference Group 2 Disaggregate Data

SPFs may also be developed based on disaggregated crash count data between before and after periods at reference sites. In that case, each intersection is represented twice in the dataset, and the general time trend between the before and after periods may be estimated by specifying "Period" as a dummy variable. Because the crash counts from the same intersection are likely to be correlated, it is desirable to use the generalized estimating equation (GEE) approach in estimating the SPF coefficients to incorporate this potential correlation.

Table 11 and table 12 present the summary of the SPFs estimated by GEE for total, severe, and pedestrian ISN and IR crashes based on the before and after crash counts from reference group 2. Note that the period indicator is "0" for the before period and "1" for the after period. The after period SPF multiplier, obtained by taking the exponential of the estimated coefficient of period ($\hat{\beta}_{period}$), exp ($\hat{\beta}_{period}$), can be considered as an estimate of the general trend including the change in extraneous factors between the before and after periods. Hauer notes that a disaggregate crash count approach (a multivariate model approach based on disaggregated data in time) can serve a dual purpose of being an SPF and a comparison group (to estimate the general trend).[5] For this approach, the ratio of the per-day SPF prediction for the after period and that for the before period ($r_{tf,i}$) described in step 4 of the EB procedure in this chapter play a role of adjusting for differences in both traffic volumes and general trends between the before and after periods.

The EB safety effectiveness estimates are also given below the corresponding SPFs with the period indicator included in table 11 and table 12. Results were similar for ISN and IR crashes. Both total and pedestrian crash reductions (19 and 23 percent for total and 69 and 65 percent for pedestrian) were significant at the 95 percent confidence level. Although severe crashes showed reductions (14 and 8 percent), the changes were not statistically significant at the 95 percent confidence level.

Table 11. Estimate of regression coefficients of SPFs with the period indicator obtained by GEE for ISN crashes using reference group 2.

Variable	Total Crashes Coefficient Estimate (*p*-Value)	Severe Crashes Coefficient Estimate (*p*-Value)	Pedestrian Crashes Coefficient Estimate (*p*-Value)
SPF Results			
Intercept	-16.5961 (< 0.0001)	-17.5186 (< 0.0001)	-17.5699 (< 0.0001)
Period (after = 1, before = 0)	0.0613 (0.1639)	0.0080 (0.8923)	0.6444 (0.0103)
Intersection type (three-leg = 1, four-leg = 0)	-0.3665 (0.0313)	-0.3434 (0.0729)	—
Major street speed limit (mi/h)	0.0653 (0.0409)	0.0832 (0.0125)	—
LnVeh&Ped	0.9655 (0.0003)	0.8858 (0.0042)	—
LnVeh	—	—	0.7673 (0.0347)
LnPed	—	—	0.2203 (0.0402)
Dispersion	0.4720	0.5709	0.2205
Pearson chi-square/degree of freedom	1.0757	0.9802	1.0513
EB Results			
L, Number of crashes observed during the after period	508	173	4
$\hat{p}$, Predicted number of crashes during after period had the HAWK not been installed	624.517	199.818	12.8256
$\hat{q}$, Estimated index of effectiveness	0.812	0.863	0.309
$se(\hat{q})$, Standard error of $\hat{q}$	0.047	0.084	0.156
$100(1-\hat{q})$, Percent reduction in the number of crashes (i.e., crash reduction)	19	14	69
Results are statistically significant at 95 percent confidence level	Yes	No	Yes

— Indicates that the variable was not included in model.
LnVeh&Ped = Ln(entering vehicles and pedestrians).
LnVeh = Ln(entering vehicles).
LnPed = Ln(entering pedestrians).

Table 12. Estimate of regression coefficients of SPFs with the period indicator obtained by GEE for IR crashes using reference group 2.

Variable	Total Crashes Coefficient Estimate (*p*-Value)	Severe Crashes Coefficient Estimate (*p*-Value)	Pedestrian Crashes Coefficient Estimate (*p*-Value)
SPF Results			
Intercept	-17.9300 (< 0.0001)	-17.9507 (< 0.0001)	-27.2540 (0.0048)
Period (after = 1, before = 0)	-0.0870 (0.2651)	-0.1117 (0.2582)	0.8232 (0.0222)
Intersection type (three-leg = 1, four-leg = 0)	-0.5831 (0.0017)	-0.5374 (0.0064)	—
Major street speed limit (mi/h)	0.0905 (0.0227)	0.1125 (0.0016)	—
LnVeh&Ped	0.9247 (0.0006)	0.7522 (0.0180)	—
LnVeh	—	—	1.4937 (0.0506)
LnPed	—	—	0.3066 (0.1202)
Dispersion	0.6628	0.6829	1.2431
Pearson chi-square/degree of freedom	1.1767	0.9708	1.0946
EB Results			
L, Number of crashes observed during the after period	183	77	2
$\hat{\rho}$, Predicted number of crashes during after period had the HAWK not been installed	237.043	83.0204	5.51422
$\hat{q}$, Estimated index of effectiveness	0.770	0.921	0.351
$se(\hat{q})$, Standard error of $\hat{q}$	0.071	0.128	0.248
$100(1-\hat{q})$, Percent reduction in the number of crashes (i.e., crash reduction)	23	8	65
Results are statistically significant at 95 percent confidence level	Yes	No	Yes

— Indicates that the variable was not included in model.
LnVeh&Ped = Ln(entering vehicles and pedestrians).
LnVeh = Ln(entering vehicles).
LnPed = Ln(entering pedestrians).

In comparing the results obtained from aggregated and disaggregated data, the conclusions did not change significantly, although the magnitude of crash reduction was slightly changed by inclusion of consideration of general time trends.

Comparison of SPFs

The appendix includes other SPFs identified in this study. The SPFs selected within each evaluation approach are provided in table 7 through table 12. Although the magnitude of the safety effectiveness estimate varies to some extent as different predictors are included in the SPFs, the results did not seem to change materially. Table 13 summarizes the percent reduction from the different approaches used in evaluating the HAWK.

The results for total crashes were similar regardless of the approach used to evaluate the data. The reduction was about 16 percent for ISN crashes (14–19 percent) and 27 percent for IR crashes (23–29 percent), all significant at a 95 percent confidence level.

Table 13. Summary of results.

Reference Group (Aggregation)	Percent Reduction (Significant at the 95 Percent Confidence Level)		
	Total Crashes	Severe Crashes	Pedestrian Crashes
ISN Crashes			
1 (aggregated)	15 (Yes)	11 (No)	57 (Yes)
2 (aggregated)	14 (Yes)	13 (No)	59 (Yes)
2 (disaggregated)	19 (Yes)	14 (No)	69 (Yes)
IR Crashes			
1 (aggregated)	29 (Yes)	18 (No)	56 (No)
2 (aggregated)	29 (Yes)	15 (No)	51 (No)
2 (disaggregated)	23 (Yes)	8 (No)	65 (Yes)

For pedestrian crashes, the results were fairly similar, with the disaggregate approach resulting in higher reductions (69 percent) than the aggregate approaches (51–59 percent). While the number of total crashes was either decreasing or had only a small increase over the time period studied, the number of pedestrian crashes had large increases, as can be seen for unsignalized intersections in table 4. The effects of the time trend are better considered in the SPFs developed based on disaggregate data, which contributed to the higher percent reduction found for pedestrian crashes.

Severe crash results were not statistically significant at the 95 percent confidence level. The smaller sample size along with the smaller influence the HAWK has on reducing severe crashes (as compared to pedestrian crashes) probably affected the results.

Although the safety effectiveness estimate does not change significantly depending on which reference group is used (which is desirable), reference group 2 was chosen as the more appropriate reference group since in most cases, the HAWK was installed at a previously unsignalized intersection. There has not been a clear guideline in the literature on when to include the period indicator in the SPFs. Harwood et al. and Persaud et al. did not consider it, while Persaud and Lyon suggest including it.[12, 13, 9] The decision of whether to include the period indicator in the SPFs could be made based on some objective criterion such as the corresponding *p*-value (the significance of the term) as in the case of other predictors. If a stringent criterion such that the corresponding *p*-value is less than or equal to 0.05 is used as a

basis for the inclusion in the SPF, only the period indicator for pedestrian ISN crashes ($p = 0.0106$) and pedestrian IR crashes ($p = 0.0222$) can be retained in the model. In variable selection, however, it is typical to use a less stringent criterion such as including the variable if the corresponding *p*-value is less than or equal to 0.2, as mentioned earlier. Under such a criterion, the period indicator for total ISN crashes ($p = 0.1639$) can also be retained in the model.

FINDINGS

The preferred SPFs for total, severe, and pedestrian ISN and IR crashes (considering the goodness of fit, interpretability of models, and significance of the coefficients, especially the period indicator) are listed in table 14 and table 15.

The results from the EB analyses based on the final SPFs applied on ISN crashes are given in table 14. The key findings are as follows:

- A 19 percent reduction in total crashes was achieved, which was statistically significant at the 95 percent confidence level.
- A 69 percent reduction in pedestrian crashes was achieved, which was statistically significant at the 95 percent confidence level.
- A 13 percent reduction in severe crashes was achieved, which was not statistically significant at the 95 percent confidence level.

Table 15 summarizes the results from the EB analyses applied on IR crashes. The key findings after the installation of a HAWK are as follows:

- A 29 percent reduction in total crashes was achieved, which was statistically significant at the 95 percent confidence level.
- A 65 percent reduction in pedestrian crashes was achieved, which was statistically significant at the 95 percent confidence level.
- A 15 percent reduction in severe crashes was achieved, which was not statistically significant at the 95 percent confidence level.

Table 14. ISN crashes results.

Variable	Total Crashes Coefficient Estimate (*p*-Value)	Severe Crashes Coefficient Estimate (*p*-Value)	Pedestrian Crashes Coefficient Estimate (*p*-Value)
SPF Results			
Intercept	-16.5961 (< 0.0001)	-17.7484 (< 0.0001)	-17.5699 (< 0.0001)
Period (after = 1, before = 0)	0.0613 (0.1639)	—	0.6444 (0.0103)
Intersection type (three-leg = 1, four-leg = 0)	-0.3665 (0.0313)	-0.3586 (0.0370)	—
Major street speed limit (mi/h)	0.0653 (0.0409)	0.0860 (0.0031)	—
LnVeh&Ped	0.9655 (0.0003)	0.8990 (0.0003)	—
LnVeh	—	—	0.7673 (0.0347)
LnPed	—	—	0.2203 (0.0402)
Dispersion	0.4720	0.5560	0.2205
Pearson chi-square/degree of freedom	1.0757	1.0367	1.0513
EB Results			
L, Number of crashes observed during the after period	508	173	4
$\hat{\rho}$, Predicted number of crashes during after period had the HAWK not been installed	624.517	198.106	12.8256
$\hat{q}$, Estimated index of effectiveness	0.812	0.870	0.309
$se(\hat{q})$, Standard error of $\hat{q}$	0.047	0.084	0.156
$100(1-\hat{q})$, Percent reduction in the number of crashes (i.e., crash reduction)	19	13	69
Results are statistically significant at 95 percent confidence level	Yes	No	Yes

— Indicates that the variable was not included in model.
LnVeh&Ped = Ln(entering vehicles and pedestrians).
LnVeh = Ln(entering vehicles).
LnPed = Ln(entering pedestrians).

Table 15. IR crashes results.

Variable	Total Crashes Coefficient Estimate (*p*-Value)	Severe Crashes Coefficient Estimate (*p*-Value)	Pedestrian Crashes Coefficient Estimate (*p*-Value)
SPF Results			
Intercept	-18.5272 (< 0.0001)	-18.3149 (< 0.0001)	-27.2540 (0.0048)
Period (after = 1, before = 0)	—	—	0.8232 (0.0222)
Intersection type (three-leg = 1, four-leg = 0)	-0.6012 (0.0012)	-0.5635 (0.0050)	—
Major street speed limit (mi/h)	0.0917 (0.0025)	0.1128 (0.0012)	—
LnVeh&Ped	0.9740 (0.0003)	—	—
LnVeh	—	0.7829 (0.0087)	1.4937 (0.0506)
LnPed	—	—	0.3066 (0.1202)
Dispersion	0.6461	0.6297	1.2431
Pearson chi-square/degree of freedom	1.1445	1.0049	1.0946
EB Results			
L, Number of crashes observed during the after period	183	77	2
$\hat{\rho}$, Predicted number of crashes during after period had the HAWK not been installed	256.423	90.0872	5.51422
$\hat{q}$, Estimated index of effectiveness	0.712	0.849	0.351
$se(\hat{q})$, Standard error of $\hat{q}$	0.065	0.118	0.248
$100(1-\hat{q})$, Percent reduction in the number of crashes (i.e., crash reduction)	29	15	65
Results are statistically significant at 95 percent confidence level	Yes	No	Yes

— Indicates that the variable was not included in model.
LnVeh&Ped = Ln(entering vehicles and pedestrians).
LnVeh = Ln(entering vehicles).
LnPed = Ln(entering pedestrians).

A safety treatment at an intersection should influence the crash pattern occurring at the intersection. Crashes that occur a distance away from the intersection that are influenced by a specific intersection treatment would be a function of the type of treatment. For example, a left-turn prohibition could cause drivers to find a travel path through developments to achieve

their goal. They might use an upstream or downstream driveway located a distance away from the intersection. Those driveway turns made in response to the left-turn prohibition could result in a crash that may not be counted because it did not occur at the intersection.

A HAWK may also influence crashes occurring away from the intersection. Before the HAWK is installed, pedestrians might be crossing away from the intersection because no benefit is provided to the pedestrians to walk the extra distance to the pedestrian crossing (i.e., because there is no active traffic control device informing drivers of the crossing pedestrians). When the HAWK is installed, pedestrians benefit from the activated traffic control device and may be more willing to walk the extra distance. Simply, the HAWK may consolidate pedestrian crossings within an area that extends beyond the typical limits of an intersection. Therefore, the ISN crash evaluation in this study may be more representative of the change in pedestrian crashes as compared to IR crashes. While using the ISN evaluation results for pedestrians seems more reasonable for that type of crash, the IR crash evaluation results are probably more representative for total or severe crashes.

CHAPTER 6. SUMMARY, CONCLUSION, AND DISCUSSION

SUMMARY

The HAWK is a pedestrian-activated beacon located at the roadside and on mast arms over the major approaches to an intersection. It was created in Tucson, AZ, and at the time of this study, it was used at more than 60 locations throughout the city. The HAWK head consists of two red lenses over a single yellow lens. It appears red to drivers when activated and creates gaps during which pedestrians can cross the major street. It also transitions to a flashing red phase to allow vehicles to proceed as soon as the pedestrians have passed. Previous research found driver yielding percentages above 95 percent for the HAWK treatment even on major streets with multiple lanes or higher speeds. Because of the limited number of treatments with high yielding rates for major arterials, the FWHA sponsored this study to determine the safety benefits of the HAWK. It considered 21 intersections where a HAWK had been installed. Evaluation approaches considered included the following:

- Three types of crashes (total, severe, and pedestrian).
- Two methods for identifying crashes (ISN and IR).
- Two reference groups (reference group 1 with 36 signalized and 35 unsignalized intersections and reference group 2 with 102 unsignalized intersections).
- Two ways to combine the reference group before and after data (aggregated where each intersection is only included once and disaggregated where each intersection is included twice and a period indicator variable represents the before and after periods).

This report documents a study of the safety performance of HAWKs using a before-after EB method. The EB method permits the evaluations to account for possible regression-to-the-mean bias as well as traffic, weather, citywide public relations campaigns, and other factors that change over time. SPFs were developed using reference site data consisting of nearby intersections without the HAWK treatment. The crash prediction during the before period is calculated from SPFs and combined with the observed crash count for the before period by using a weighted average to control for regression-to-the-mean bias. This weighted average is adjusted for differences in duration and traffic volumes (and general time trend if any exists) between the before and after periods to lead to a crash prediction for the after period had the treatment not been applied. EB then compares this predicted value to the observed crash frequency for the after period with the treatment installed.

CONCLUSION

In conclusion, the before-after evaluation found the following:

- A 29 percent reduction in total crashes, which is statistically significant at the 95 percent confidence level.

- A 69 percent reduction in pedestrian crashes, which is statistically significant at the 95 percent confidence level.

- A 15 percent reduction in severe crashes, which is not statistically significant at the 95 percent confidence level.

DISCUSSION

Two crash datasets were used in the before-after evaluation. The initial dataset, ISN crashes, included all crashes coded with the same street names that matched the HAWK or unsignalized intersections used in the study. The second dataset, IR crashes, included only those ISN crashes that had "yes" for the intersection-related code. In theory, the IR crash dataset should represent those crashes that would be affected by the traffic control at the intersection. A closer review revealed that the IR code was not used in over ⅓ of the crashes; therefore, the IR crash dataset may have eliminated too many of the crashes. The ISN crash dataset, however, may include crashes that are not related to the intersection. Therefore, both datasets were considered. The IR crashes may initially appear to be the more representative group for evaluating the benefits of the HAWK. The ISN crash evaluation, however, may be more representative of the change in pedestrian crashes as compared to IR crashes since the HAWK could induce pedestrians to walk an additional distance to receive the benefit of an activated traffic control device.

HAWK intersections are associated with a slightly greater number of total crashes (0.223 crashes/MEV&P) as compared to nearby unsignalized intersections (0.150 crashes/MEV&P) (see table 4). This observation should not indicate that the removal of a HAWK from a location will result in a crash rate similar to the unsignalized intersection rate. Rather, the conditions and characteristics at these locations are associated with more crashes. The before crash rate for the HAWK sites (i.e., before the HAWKs were installed) was greater (0.341 crashes/MEV&P) than the crash rate identified for the unsignalized intersections for the same time period (0.166 crashes/MEV&P).

While the observed after crash rate is higher for total crashes at HAWKs as compared to nearby unsignalized intersections, the crash rate for total crashes at HAWK sites (0.223 crashes/MEV&P) is lower than the crash rate at signalized intersections (0.716 crashes/MEV&P). In addition, the pedestrian crash rates for HAWKs are lower than both the neighboring unsignalized intersections and the neighboring signalized intersections (see table 4). This difference is even more pronounced when only considering the number of entering pedestrians rather than both entering vehicles and pedestrians. The HAWK sites had 0.255 pedestrian crashes/MEP, while the unsignalized and signalized intersections had 0.602 and 0.839 pedestrian crashes/MEP, respectively.

The prime objective of a HAWK is to provide pedestrians with crossing opportunities. As such, a reduction in pedestrian crashes would be expected to be associated with the HAWK. The evaluation found a statistically significant reduction in pedestrian crashes for ISN (based on either aggregated or disaggregated data) and IR crashes (based on disaggregated data). The installation of the HAWK was also found to be associated with a statistically significant reduction in total crashes. The HAWK, however, just like any other warning traffic control device, may not work as well if overused. Also, such high crash reductions identified in this

study may not be achieved at future locations if the site has different characteristics, such as less pedestrian activity.

While this study demonstrated safety benefits for the HAWK, there are still several questions that need to be investigated. The sample sizes for pedestrian crashes and for severe crashes were a concern during the evaluations. For pedestrian crashes, a statistically significant reduction in crashes (at the 95 percent confidence level) was achieved in spite of a small sample size due to a large effect size (69 percent). For severe crashes, the effect size was much smaller (15 percent, although still practically significant) than that for pedestrian crashes, and a much larger sample will be required to achieve statistical significance. Further research with a larger sample should examine the effectiveness of HAWKs in reducing severe crashes. It is possible that with a larger sample size, the effect of HAWKs on severe crashes may become statistically significant at the 95 percent confidence level.

A preliminary review of crash type at the HAWK sites indicated a reduction in rear-end crashes, which is not typical when a higher level of control is implemented at an intersection. A potential reason for the reduction in rear-end crashes is that drivers behind the initial vehicle that has stopped for a crossing pedestrian can view the traffic control device without needing to see the pedestrian, who may be obscured by the lead vehicle. Additional research to investigate the changes in crash patterns at the HAWK sites should be considered. Other questions include the minimum spacing between a HAWK and a signal and the criteria that should be used to warrant the device, especially near a school.

APPENDIX: TABLES OF RESULTS

Several SPF alternatives were developed. The following tables summarize the coefficients along with the EB results. The SPF alternative selected for each evaluation approach is shown in the first column of the tables. Although the magnitude of the safety effectiveness estimate varies to some extent as different predictors are included in the SPFs, the results did not seem to change materially.

Table 16. Estimate of regression coefficients of SPFs for ISN total crashes using reference group 1.

Variable	Alternative I: Total Crashes Coefficient Estimate (*p*-Value)	Alternative II: Total Crashes Coefficient Estimate (*p*-Value)
	SPF Results	
Intercept	-34.3200 (< 0.0001)	-32.1004 (< 0.0001)
Intersection type (three-leg = 1, four-leg = 0)	-0.9932 (< 0.0001)	-0.9548 (< 0.0001)
Major street speed limit (mi/h)	0.0951 (0.0016)	0.0944 (0.0013)
Median refuge present	-0.7478 (0.0003)	-0.6844 (0.0009)
LnVeh&Ped	2.6005 (< 0.0001)	—
LnVeh	—	2.3080 (< 0.0001)
LnPed	—	0.1751 (0.0205)
Dispersion	0.4452	0.4192
Pearson chi-square/degree of freedom	0.9702	1.0125
	EB Results	
L, Number of crashes observed during the after period	508	508
$\hat{\rho}$, Predicted number of crashes during after period had the HAWK not been installed	594.744	601.915
$\hat{q}$, Estimated index of effectiveness	0.853	0.843
$se(\hat{q})$, Standard error of $\hat{q}$	0.050	0.049
$100(1-\hat{q})$, Percent reduction in the number of crashes (i.e., crash reduction)	15	16
Results are statistically significant at 95 percent confidence level	Yes	Yes

LnVeh&Ped = Ln(entering vehicles and pedestrians).
LnVeh = Ln(entering vehicles).
LnPed = Ln(entering pedestrians).
— Indicates that the variable was not included in model.

Table 17. Estimate of regression coefficients of SPFs for IR total crashes using reference group 1.

Variable	Alternative I: Total Crashes Coefficient Estimate (*p*-Value)	Alternative II: Total Crashes Coefficient Estimate (*p*-Value)
SPF Results		
Intercept	-34.2206 (< 0.0001)	-31.9988 (< 0.0001)
Intersection type (three-leg = 1, four-leg = 0)	-1.2010 (< 0.0001)	-1.1452 (< 0.0001)
Major street speed limit (mi/h)	0.0889 (0.0080)	0.0874 (0.0079)
Median refuge present	-0.5582 (0.0172)	-0.4851 (0.0370)
LnVeh&Ped	2.5262 (< 0.0001)	—
LnVeh	—	2.2308 (< 0.0001)
LnPed	—	0.1841 (0.0287)
Dispersion	0.5276	0.4965
Pearson chi-square/degree of freedom	0.9983	1.0572
EB Results		
L, Number of crashes observed during the after period	183	183
$\hat{\rho}$, Predicted number of crashes during after period had the HAWK not been installed	256.501	261.122
$\hat{q}$, Estimated index of effectiveness	0.711	0.699
$se(\hat{q})$, Standard error of $\hat{q}$	0.065	0.064
$100(1-\hat{q})$, Percent reduction in the number of crashes (i.e., crash reduction)	29	30
Results are statistically significant at 95 percent confidence level	Yes	Yes

LnVeh&Ped = Ln(entering vehicles and pedestrians).
LnVeh = Ln(entering vehicles).
LnPed = Ln(entering pedestrians).
— Indicates that the variable was not included in model.

Table 18. Estimate of regression coefficients of SPFs for ISN severe crashes using reference group 1.

Variable	Alternative I: Severe Crashes Coefficient Estimate (*p*-Value)	Alternative II: Severe Crashes Coefficient Estimate (*p*-Value)	Alternative III: Severe Crashes Coefficient Estimate (*p*-Value)
SPF Results			
Intercept	-32.2219 (< 0.0001)	-34.1361 (< 0.0001)	-34.1789 (< 0.0001)
Intersection type (three-leg = 1, four-leg = 0)	-0.9557 (< 0.0001)	-1.0020 (< 0.0001)	-1.0093 (< 0.0001)
Major street speed limit (mi/h)	0.1110 (0.0003)	0.1128 (0.0003)	0.1139 (0.0003)
Median refuge present	-0.6998 (0.0012)	-0.7657 (0.0004)	-0.7715 (0.0004)
LnVeh&Ped	—	2.4128 (< 0.0001)	—
LnVeh	2.1704 (< 0.0001)	—	2.4153 (< .0001)
LnPed	0.1390 (0.0834)	—	—
Dispersion	0.4235	0.4426	0.4463
Pearson chi-square/degree of freedom	1.0360	0.9955	0.9912
EB Results			
L, Number of crashes observed during the after period	173	173	173
$\hat{p}$, Predicted number of crashes during after period had the HAWK not been installed	192.979	188.366	188.025
$\hat{q}$, Estimated index of effectiveness	0.893	0.915	0.917
$se(\hat{q})$, Standard error of $\hat{q}$	0.086	0.089	0.089
$100(1-\hat{q})$, Percent reduction in the number of crashes (i.e., crash reduction)	11	9	8
Results are statistically significant at 95 percent confidence level	No	No	No

LnVeh&Ped = Ln(entering vehicles and pedestrians).
LnVeh = Ln(entering vehicles).
LnPed = Ln(entering pedestrians).
— Indicates that the variable was not included in model.

Table 19. Estimate of regression coefficients of SPFs for IR severe crashes using reference group 1.

Variable	Alternative I: Severe Crashes Coefficient Estimate (*p*-Value)	Alternative II: Severe Crashes Coefficient Estimate (*p*-Value)
SPF Results		
Intercept	-32.9071 (< 0.0001)	-31.0082 (< 0.0001)
Intersection type (three-leg = 1, four-leg = 0)	-1.1455 (< 0.0001)	-1.0969 (< 0.0001)
Major street speed limit (mi/h)	0.1057 (0.0031)	0.1040 (0.0033)
Median refuge present	-0.5465 (0.0277)	-0.4726 (0.0606)
LnVeh&Ped	2.2558 (< 0.0001)	—
LnVeh	—	2.0141 (< 0.0001)
LnPed	—	0.1385 (0.1344)
Dispersion	0.5425	0.5228
Pearson chi-square/degree of freedom	1.0243	1.0641
EB Results		
L, Number of crashes observed during the after period	77	77
$\hat{\rho}$, Predicted number of crashes during after period had the HAWK not been installed	93.5850	96.4656
$\hat{q}$, Estimated index of effectiveness	0.817	0.793
$se(\hat{q})$, Standard error of $\hat{q}$	0.114	0.110
$100(1-\hat{q})$, Percent reduction in the number of crashes (i.e., crash reduction)	18	21
Results are statistically significant at 95 percent confidence level	No	No

LnVeh&Ped = Ln(entering vehicles and pedestrians).
LnVeh = Ln(entering vehicles).
LnPed = Ln(entering pedestrians).
— Indicates that the variable was not included in model.

Table 20. Estimate of regression coefficients of SPFs for ISN and IR pedestrian crashes using reference group 1.

Variable	Alternative I: ISN Pedestrian Crashes Coefficient Estimate (*p*-Value)	Alternative II: IR Pedestrian Crashes Coefficient Estimate (*p*-Value)
SPF Results		
Intercept	-26.5372 (< 0.0001)	-31.9455 (< 0.0001)
Intersection Type (three-leg = 1, four-leg = 0)	-0.8826 (0.0137)	-0.8626 (0.1096)
Major street speed limit (mi/h)	0.1048 (0.0031)	0.1313 (0.0173)
Median refuge present	-0.4731 (0.0545)	-0.1824 (0.6126)
LnVeh&Ped	1.4433 (0.0002)	1.7660 (0.0028)
LnVeh	—	—
LnPed	—	—
Dispersion	0.0588	0.1978
Pearson chi-square/degree of freedom	1.1428	1.2738
EB Results		
L, Number of crashes observed during the after period	4	2
$\hat{\rho}$, Predicted number of crashes during after period had the HAWK not been installed	9.35410	4.49476
$\hat{q}$, Estimated index of effectiveness	0.426	0.439
$se(\hat{q})$, Standard error of $\hat{q}$	0.214	0.311
$100(1-\hat{q})$, Percent reduction in the number of crashes (i.e., crash reduction)	57	56
Results are statistically significant at 95 percent confidence level	Yes	No

LnVeh&Ped = Ln(entering vehicles and pedestrians).
LnVeh = Ln(entering vehicles).
LnPed = Ln(entering pedestrians).
— Indicates that the variable was not included in model.

Table 21. Estimate of regression coefficients of SPFs for ISN total crashes using reference group 2.

Variable	Alternative I: Total Crashes Coefficient Estimate (*p*-Value)	Alternative II: Total Crashes Coefficient Estimate (*p*-Value)
SPF Results		
Intercept	-16.8197 (< 0.0001)	-16.7870 (< 0.0001)
Intersection type (three-leg = 1, four-leg = 0)	-0.3732 (0.0116)	-0.3731 (0.0116)
Major street speed limit (mi/h)	0.0673 (0.0062)	0.0672 (0.0062)
LnVeh&Ped	0.9827 (< 0.0001)	—
LnVeh	—	0.9804 (< 0.0001)
LnPed	—	—
Dispersion	0.4592	0.4589
Pearson chi-square/degree of freedom	1.1011	1.0995
EB Results		
L, Number of crashes observed during the after period	508	508
$\hat{\rho}$, Predicted number of crashes during after period had the HAWK not been installed	588.646	588.054
$\hat{q}$, Estimated index of effectiveness	0.862	0.863
$se(\hat{q})$, Standard error of $\hat{q}$	0.050	0.050
$100(1-\hat{q})$, Percent reduction in the number of crashes (i.e., crash reduction)	14	14
Results are statistically significant at 95 percent confidence level	Yes	Yes

LnVeh&Ped = Ln(entering vehicles and pedestrians).
LnVeh = Ln(entering vehicles).
LnPed = Ln(entering pedestrians).
— Indicates that the variable was not included in model.

Table 22. Estimate of regression coefficients of SPFs for IR total crashes using reference group 2.

Variable	Alternative I: Total Crashes Coefficient Estimate (*p*-Value)	Alternative II: Total Crashes Coefficient Estimate (*p*-Value)
SPF Results		
Intercept	-18.5272 (< 0.0001)	-18.5557 (< 0.0001)
Intersection type (three-leg = 1, four-leg = 0)	-0.6012 (0.0012)	-0.6018 (0.0012)
Major street speed limit (mi/h)	0.0917 (0.0025)	0.0915 (0.0025)
LnVeh&Ped	0.9740 (0.0003)	—
LnVeh	—	0.9778 (0.0002)
LnPed	—	—
Dispersion	0.6461	0.6450
Pearson chi-square/degree of freedom	1.1445	1.1455
EB Results		
L, Number of crashes observed during the after period	183	183
$\hat{\rho}$, Predicted number of crashes during after period had the HAWK not been installed	256.423	256.071
$\hat{q}$, Estimated index of effectiveness	0.712	0.713
$se(\hat{q})$, Standard error of $\hat{q}$	0.065	0.065
$100(1-\hat{q})$, Percent reduction in the number of crashes (i.e., crash reduction)	29	29
Results are statistically significant at 95 percent confidence level	Yes	Yes

LnVeh&Ped = Ln(entering vehicles and pedestrians).
LnVeh = Ln(entering vehicles).
LnPed = Ln(entering pedestrians).
— Indicates that the variable was not included in model.

Table 23. Estimate of regression coefficients of SPFs for ISN severe crashes using reference group 2.

Variable	Alternative I: Severe Crashes Coefficient Estimate (*p*-Value)	Alternative II: Severe Crashes Coefficient Estimate (*p*-Value)
SPF Results		
Intercept	-17.7484 (< 0.0001)	-17.7487 (< 0.0001)
Intersection type (three-leg = 1, four-leg = 0)	-0.3586 (0.0370)	-0.3585 (0.0368)
Major street speed limit (mi/h)	0.0860 (0.0031)	0.0858 (0.0031)
LnVeh&Ped	0.8990 (0.0003)	—
LnVeh	—	0.9001 (0.0003)
LnPed	—	—
Dispersion	0.5560	0.5552
Pearson chi-square/degree of freedom	1.0367	1.0353
EB Results		
L, Number of crashes observed during the after period	173	173
$\hat{\rho}$, Predicted number of crashes during after period had the HAWK not been installed	198.106	197.805
$\hat{q}$, Estimated index of effectiveness	0.870	0.871
$se(\hat{q})$, Standard error of $\hat{q}$	0.084	0.084
$100(1-\hat{q})$, Percent reduction in the number of crashes (i.e., crash reduction)	13	13
Results are statistically significant at 95 percent confidence level	No	No

LnVeh&Ped = Ln(entering vehicles and pedestrians).
LnVeh = Ln(entering vehicles).
LnPed = Ln(entering pedestrians).
— Indicates that the variable was not included in model.

Table 24. Estimates of regression coefficients of SPFs for IR severe crashes using reference group 2.

Variable	Alternative I: Severe Crashes Coefficient Estimate (*p*-Value)	Alternative II: Severe Crashes Coefficient Estimate (*p*-Value)
SPF Results		
Intercept	-18.3149 (< 0.0001)	-18.2802 (< 0.0001)
Intersection type (three-leg = 1, four-leg = 0)	-0.5635 (0.0050)	-0.5633 (0.0051)
Major street speed limit (mi/h)	0.01128 (0.0012)	0.1130 (0.0012)
LnVeh&Ped	—	0.7785 (0.0094)
LnVeh	0.7829 (0.0087)	—
LnPed	—	—
Dispersion	0.6297	0.6305
Pearson chi-square/degree of freedom	1.0049	1.0056
EB Results		
L, Number of crashes observed during the after period	77	77
$\hat{\rho}$, Predicted number of crashes during after period had the HAWK not been installed	90.0872	90.2312
$\hat{q}$, Estimated index of effectiveness	0.849	0.848
$se(\hat{q})$, Standard error of $\hat{q}$	0.118	0.118
$100(1-\hat{q})$, Percent reduction in the number of crashes (i.e., crash reduction)	15	15
Results are statistically significant at 95 percent confidence level	No	No

LnVeh&Ped = Ln(entering vehicles and pedestrians).
LnVeh = Ln(entering vehicles).
LnPed = Ln(entering pedestrians).
— Indicates that the variable was not included in model.

Table 25. Estimate of regression coefficients of SPFs for ISN pedestrian crashes using reference group 2.

Variable	Alternative I: Pedestrian Crashes Coefficient Estimate (*p*-Value)	Alternative II: Pedestrian Crashes Coefficient Estimate (*p*-Value)	Alternative III: Pedestrian Crashes Coefficient Estimate (*p*-Value)	Alternative IV: Pedestrian Crashes Coefficient Estimate (*p*-Value)
SPF Results				
Intercept	-16.8225 (0.0004)	-16.3873 (0.0003)	-16.5834 (0.0003)	-16.9442 (0.0004)
Intersection type (three-leg = 1, four-leg = 0)	-0.0292 (0.9207)	-0.0719 (0.8093)	—	—
Major street speed limit (mi/h)	0.0248 (0.6263)	0.0317 (0.5388)	—	—
LnVeh&Ped	—	0.6791 (0.1516)	0.8059 (0.0622)	—
LnVeh	0.6518 (0.1787)	—	—	0.7527 (0.0893)
LnPed	0.1999 (0.1186)	—	—	0.1987 (0.1178)
Dispersion	0.2712	0.3516	0.3551	0.2716
Pearson chi-square/degree of freedom	1.0967	1.0113	0.9894	1.0816
EB Results				
L, Number of crashes observed during the after period	4	4	4	4
$\hat{\rho}$, Predicted number of crashes during after period had the HAWK not been installed	9.71056	8.76300	8.65617	9.60233
$\hat{q}$, Estimated index of effectiveness	0.408	0.451	0.457	0.412
$se(\hat{q})$, Standard error of $\hat{q}$	0.206	0.228	0.231	0.208
$100(1-\hat{q})$, Percent reduction in the number of crashes (i.e., crash reduction)	59	55	54	59
Results are statistically significant at 95 percent confidence level	Yes	Yes	Yes	Yes

— Indicates that the variable was not included in model.
LnVeh&Ped = Ln(entering vehicles and pedestrians).
LnVeh = Ln(entering vehicles).
LnPed = Ln(entering pedestrians).

Table 26. Estimate of regression coefficients of SPFs for IR pedestrian crashes using reference group 2 (page 1 of 2).

Variable	Alternative I: Pedestrian Crashes Coefficient Estimate (*p*-Value)	Alternative II: Pedestrian Crashes Coefficient Estimate (*p*-Value)	Alternative III: Pedestrian Crashes Coefficient Estimate (*p*-Value)
SPF Results			
Intercept	-25.4693 (0.0222)	-26.1717 (0.0243)	-24.0449 (0.0258)
Intersection type (three-leg = 1, four-leg = 0)	-0.3600 (0.5457)	-0.3681 (0.5335)	-0.4575 (0.4387)
Major street speed limit (mi/h)	0.0497 (0.6429)	0.0493 (0.6431)	0.0615 (0.5616)
LnVeh&Ped	—	—	1.1775 (0.2754)
LnVeh	—	1.2820 (0.2650)	—
LnPed	0.3056 (0.2692)	0.3026 (0.2800)	—
LnMajor	1.1741 (0.2829)	—	—
LnMinor	0.0692 (0.8003)	—	—
Dispersion	1.2769	1.2338	1.3763
Pearson chi-square/degree of freedom	0.9878	1.0279	0.9762
EB Results			
L, Number of crashes observed during the after period	2	2	2
$\hat{p}$, Predicted number of crashes during after period had the HAWK not been installed	3.94071	3.86283	3.30109
$\hat{q}$, Estimated index of effectiveness	0.490	0.500	0.585
$se(\hat{q})$, Standard error of $\hat{q}$	0.347	0.354	0.413
$100(1-\hat{q})$, Percent reduction in the number of crashes (i.e., crash reduction)	51	50	42
Results are statistically significant at 95 percent confidence level	No	No	No

LnVeh&Ped = Ln(entering vehicles and pedestrians).
LnVeh = Ln(entering vehicles).
LnPed = Ln(entering pedestrians).
LnMajor = Ln(entering vehicles from major approaches).
LnMinor = Ln(entering vehicles from minor approaches).
— Indicates that the variable was not included in model.

Table 27. Estimate of regression coefficients of SPFs for IR pedestrian crashes using reference group 2 (page 2 of 2).

Variable	Alternative IV: Pedestrian Crashes Coefficient Estimate (*p*-Value)	Alternative V: Pedestrian Crashes Coefficient Estimate (*p*-Value)
	SPF Results	
Intercept	-27.1040 (0.0213)	-24.7119 (0.0228)
Intersection type (three-leg = 1, four-leg = 0)	—	—
Major street speed limit (mi/h)	—	—
LnVeh&Ped	—	1.4370 (0.1589)
LnVeh	1.5182 (0.1582)	—
LnPed	0.3230 (0.2402)	—
Dispersion	1.2602	1.4822
Pearson chi-square/degree of freedom	0.9761	0.9160
	EB Results	
L, Number of crashes observed during the after period	2	2
$\hat{\rho}$, Predicted number of crashes during after period had the HAWK not been installed	3.81139	3.24767
$\hat{q}$, Estimated index of effectiveness	0.508	0.595
$se(\hat{q})$, Standard error of $\hat{q}$	0.359	0.420
$100(1-\hat{q})$, Percent reduction in the number of crashes (i.e., crash reduction)	49	41
Results are statistically significant at 95 percent confidence level	No	No

— Indicates that the variable was not included in model.
LnVeh&Ped = Ln(entering vehicles and pedestrians).
LnVeh = Ln(entering vehicles).
LnPed = Ln(entering pedestrians).

Table 28. Estimate of regression coefficients of SPFs for ISN total crashes using reference group 2 and the period indicator variable.

Variable	Alternative I: Total Crashes Coefficient Estimate (*p*-Value)	Alternative II: Total Crashes Coefficient Estimate (*p*-Value)
SPF Results		
Intercept	-16.5961 (< 0.0001)	-16.5632 (< 0.0001)
Period (after = 1, before = 0)	0.0613 (0.1639)	0.0617 (0.1606)
Intersection type (three-leg = 1, four-leg = 0)	-0.3665 (0.0313)	-0.3665 (0.0314)
Major street speed limit (mi/h)	0.0653 (0.0409)	0.0652 (0.0418)
LnVeh&Ped	0.9655 (0.0003)	—
LnVeh	—	0.9632 (0.0003)
LnPed	—	—
Dispersion	0.4720	0.4717
Pearson chi-square/degree of freedom	1.0757	1.0741
EB Results		
L, Number of crashes observed during the after period	508	508
$\hat{\rho}$, Predicted number of crashes during after period had the HAWK not been installed	624.517	624.163
$\hat{q}$, Estimated index of effectiveness	0.812	0.813
$se(\hat{q})$, Standard error of $\hat{q}$	0.047	0.047
$100(1-\hat{q})$, Percent reduction in the number of crashes (i.e., crash reduction)	19	19
Results are statistically significant at 95 percent confidence level	Yes	Yes

LnVeh&Ped = Ln(entering vehicles and pedestrians).
LnVeh = Ln(entering vehicles).
LnPed = Ln(entering pedestrians).
— Indicates that the variable was not included in model.

Table 29. Estimate of regression coefficients of SPFs for IR total crashes using reference group 2 and the period indicator variable.

Variable	Alternative I: Total Crashes Coefficient Estimate (*p*-Value)	Alternative II: Total Crashes Coefficient Estimate (*p*-Value)
SPF Results		
Intercept	-17.9300 (< 0.0001)	-17.9498 (< 0.0001)
Period (after = 1, before = 0)	-0.0870 (0.2651)	-0.0863 (0.2691)
Intersection type (three-leg = 1, four-leg = 0)	-0.5831 (0.0017)	-0.5834 (0.0017)
Major street speed limit (mi/h)	0.0905 (0.0227)	0.0903 (0.0233)
LnVeh&Ped	0.9247 (0.0006)	—
LnVeh	—	0.9277 (0.0005)
LnPed	—	—
Dispersion	0.6628	0.6619
Pearson chi-square/degree of freedom	1.1767	1.1777
EB Results		
L, Number of crashes observed during the after period	183	183
$\hat{\rho}$, Predicted number of crashes during after period had the HAWK not been installed	237.043	236.917
$\hat{q}$, Estimated index of effectiveness	0.770	0.770
$se(\hat{q})$, Standard error of $\hat{q}$	0.071	0.071
$100(1-\hat{q})$, Percent reduction in the number of crashes (i.e., crash reduction)	23	23
Results are statistically significant at 95 percent confidence level	Yes	Yes

LnVeh&Ped = Ln(entering vehicles and pedestrians).
LnVeh = Ln(entering vehicles).
LnPed = Ln(entering pedestrians).
— Indicates that the variable was not included in model.

Table 30. Estimate of regression coefficients of SPFs for ISN severe crashes using reference group 2 and the period indicator variable.

Variable	Alternative I: Severe Crashes Coefficient Estimate (*p*-Value)	Alternative II: Severe Crashes Coefficient Estimate (*p*-Value)
SPF Results		
Intercept	-17.5186 (< 0.0001)	-17.5169 (< 0.0001)
Period (after = 1, before = 0)	0.0080 (0.8923)	0.0085 (0.8851)
Intersection type (three-leg = 1, four-leg = 0)	-0.3434 (0.0729)	-0.3434 (0.0730)
Major street speed limit (mi/h)	0.0832 (0.0125)	0.0830 (0.0130)
LnVeh&Ped	0.8858 (0.0042)	—
LnVeh	—	0.8867 (0.0041)
LnPed	—	—
Dispersion	0.5709	0.5702
Pearson chi-square/degrees of freedom	0.9802	0.9791
EB Results		
L, Number of crashes observed during the after period	173	173
$\hat{\rho}$, Predicted number of crashes during after period had the HAWK not been installed	199.818	199.639
$\hat{q}$, Estimated index of effectiveness	0.863	0.863
$se(\hat{q})$, Standard error of $\hat{q}$	0.084	0.084
$100(1-\hat{q})$, Percent reduction in the number of crashes (i.e., crash reduction)	14	14
Results are statistically significant at 95 percent confidence level	No	No

LnVeh&Ped = Ln(entering vehicles and pedestrians).
LnVeh = Ln(entering vehicles).
LnPed = Ln(entering pedestrians).
— Indicates that the variable was not included in model.

Table 31. Estimate of regression coefficients of SPFs for IR severe crashes using reference group 2 and the period indicator variable.

Variable	Alternative I: Severe Crashes Coefficient Estimate (*p*-Value)	Alternative II: Severe Crashes Coefficient Estimate (*p*-Value)
SPF Results		
Intercept	-17.9507 (< 0.0001)	-17.9757 (< 0.0001)
Period (after = 1, before = 0)	-0.1117 (0.2582)	-0.1112 (0.2604)
Intersection type (three-leg = 1, four-leg = 0)	-0.5374 (0.0064)	-0.5375 (0.0064)
Major street speed limit (mi/h)	0.1125 (0.0016)	0.01123 (0.0017)
LnVeh&Ped	0.7522 (0.0180)	—
LnVeh	—	0.7556 (0.0174)
LnPed	—	—
Dispersion	0.6829	0.6822
Pearson chi-square/degree of freedom	0.9708	0.9700
EB Results		
L, Number of crashes observed during the after period	77	77
$\hat{\rho}$, Predicted number of crashes during after period had the HAWK not been installed	83.0204	82.9242
$\hat{q}$, Estimated index of effectiveness	0.921	0.922
$se(\hat{q})$, Standard error of $\hat{q}$	0.128	0.128
$100(1-\hat{q})$, Percent reduction in the number of crashes (i.e., crash reduction)	8	8
Results are statistically significant at 95 percent confidence level	No	No

LnVeh&Ped = Ln(entering vehicles and pedestrians).
LnVeh = Ln(entering vehicles).
LnPed = Ln(entering pedestrians).
— Indicates that the variable was not included in model.

Table 32. Estimate of regression coefficients of SPFs for ISN pedestrian crashes using reference group 2 and the period indicator variable.

Variable	Alternative I: Pedestrian Crashes Coefficient Estimate (*p*-Value)	Alternative II: Pedestrian Crashes Coefficient Estimate (*p*-Value)	Alternative III: Pedestrian Crashes Coefficient Estimate (*p*-Value)	Alternative IV: Pedestrian Crashes Coefficient Estimate (*p*-Value)
SPF Results				
Intercept	-17.5699 (< 0.0001)	-17.3841 (< 0.0001)	-16.2619 (< 0.0001)	-17.3941 (< 0.0001)
Period (after = 1, before = 0)	0.6444 (0.0103)	0.6408 (0.0106)	0.6582 (0.0091)	0.6406 (0.0106)
Intersection type (three-leg = 1, four-leg = 0)	—	—	—	0.0088 (0.9738)
Major street speed limit (mi/h)	—	0.0232 (0.6216)	—	0.0227 (0.6348)
LnVeh&Ped	—	—	0.7408 (0.0258)	—
LnVeh	0.7673 (0.0347)	0.6683 (0.1087)	—	0.6709 (0.1144)
LnPed	0.2203 (0.0402)	0.2191 (0.0417)	—	0.2196 (0.0367)
Dispersion	0.2205	0.2189	0.3158	0.2180
Pearson chi-square/degree of freedom	1.0513	1.0462	1.0160	1.0524
EB Results				
L, Number of crashes observed during the after period	4	4	4	4
$\hat{\rho}$, Predicted number of crashes during after period had the HAWK not been installed	12.8256	12.8646	11.6274	12.8896
$\hat{q}$, Estimated index of effectiveness	0.309	0.308	0.340	0.308
$se(\hat{q})$, Standard error of $\hat{q}$	0.156	0.155	0.172	0.155
$100(1-\hat{q})$, Percent reduction in the number of crashes (i.e., crash reduction)	69	69	66	69
Results are statistically significant at 95 percent confidence level	Yes	Yes	Yes	Yes

— Indicates that the variable was not included in model.
LnVeh&Ped = Ln(entering vehicles and pedestrians).
LnVeh = Ln(entering vehicles).
LnPed = Ln(entering pedestrians).

Table 33. Estimate of regression coefficients of SPFs for IR pedestrian crashes using reference group 2 and the period indicator variable.

Variable	Alternative I: Pedestrian Crashes Coefficient Estimate (*p*-Value)	Alternative II: Pedestrian Crashes Coefficient Estimate (*p*-Value)	Alternative III: Pedestrian Crashes Coefficient Estimate (*p*-Value)
SPF Results			
Intercept	-27.2540 (0.0048)	-26.2689 (0.0152)	-24.7331 (0.0031)
Period (after = 1, before = 0)	0.8232 (0.0222)	0.8392 (0.1295)	0.8641 (0.0252)
Intersection type (three-leg = 1, four-leg = 0)	—	-0.4000 (0.5594)	—
Major street speed limit (mi/h)	—	0.0496 (0.6633)	—
LnVeh&Ped	—	—	1.3912 (0.0553)
LnVeh	1.4937 (0.0506)	1.2530 (0.2246)	—
LnPed	0.3066 (0.1202)	0.2842 (0.1639)	—
Dispersion	1.2431	1.3086	1.6436
Pearson chi-square/degree of freedom	1.0946	1.0133	1.0530
EB Results			
L, Number of crashes observed during the after period	2	2	2
$\hat{\pi}$, Predicted number of crashes during after period had the HAWK not been installed	5.51422	6.03609	5.12614
$\hat{\theta}$, Estimated index of effectiveness	0.351	0.320	0.376
$se\left(\hat{\theta}\right)$, Standard error of $\hat{\theta}$	0.248	0.228	0.266
$100\left(1-\hat{\theta}\right)$, Percent reduction in the number of crashes (i.e., crash reduction)	65	68	62
Results are statistically significant at 95 percent confidence level	Yes	Yes	Yes

— Indicates that the variable was not included in model.
LnVeh&Ped = Ln(entering vehicles and pedestrians).
LnVeh = Ln(entering vehicles).
LnPed = Ln(entering pedestrians).

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