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TECHNICAL MEMORANDUM NO. 1

City of Scottsdale Photo Enforcement Evaluation

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INTRODUCTION

This memo outlines the background, data methodologies, statistical analysis, and discusses the results for Phase I locations (activated after 2006) of the City of Scottsdale Photo Enforcement Evaluation.

The City of Scottsdale has been using photo enforcement technology since 1996 to reduce crashes related to red-light running at signalized intersections and speed-related crashes on arterial roadway segments. The ultimate goal is to improve safety by reducing injuries and death on city roads. The technology has been deployed in the City at three different time periods by the following three vendors:

- American Traffic Systems Wet Film Cameras – 1996-2001
- Redflex Digital cameras – 2002-2007
- ATS Digital cameras – 2007-2014

In March 2016, the Attorney General Opinion stated that third party contractors who operate photo radar and red light cameras must be licensed private investigators (**Appendix A**). This may make it difficult for Scottsdale and other Arizona municipalities to continue their photo enforcement programs. The results of this Photo Enforcement Evaluation will be used to inform decision making related to the City of Scottsdale Photo Enforcement Program.

SUMMARY

This Phase I analysis of enforcement cameras activated by ATS Digital Cameras in the City of Scottsdale during the years 2007 through 2014 indicate that there is a statistically significant reduction in the total numbers of crashes after activation of speed photo enforcement on segments and red-light photo enforcement at intersections, and may also be having a positive safety impact on nearby intersections.

STUDY LOCATIONS

This Phase I analysis evaluates locations of enforcement cameras activated by ATS Digital Cameras in the City of Scottsdale during the years 2007 through 2014.

Due to the infrequent, irregular nature of motor vehicle crashes and the multitude of factors which may influence roadway safety, this analysis makes use of a control group which serves to discount the influence of extraneous factors and helps to identify general trends in motor vehicle crashes apart from the effects which may be attributed to the implementation of photo enforcement. The control sites for the Phase I analysis were selected based on similar operating conditions to Phase I enforcement locations in the before and after period; including traffic control, lane configuration, and traffic volumes. One control location was selected for each enforcement location. A list of control locations used in this analysis and their respective Phase I enforcement locations are presented in **Table 1**.

Table 1 – Phase I Study Locations

Phase I	Enforcement Location	*Control Location*	Roadway Direction Enforced	Activation Date	Deactivation Date	Removal of Structure
Segments	120th & Shea	*Shea & Lakeview*	Eastbound (EB)	8/12/2007	NA	NA
	120th & Shea	*Shea & Lakeview*	Westbound (WB)	8/12/2007	NA	NA
	Pima & Hualapai	*Pima & Country Club*	Southbound (SB)	7/1/2007	NA	NA
	Pima & Hualapai	*Pima & Country Club*	Northbound (NB)	7/1/2007	NA	NA
	113th & Rio Verde	*Pima & Jomax*	WB	11/1/2013	NA	NA
	103rd & Dynamite	*Pima & Jomax*	EB	11/1/2013	NA	NA
Intersections	Scottsdale & McDowell	*Thompson Peak & FLW*	EB to NB Left-Turn (LT)	7/1/2007	NA	NA
	Scottsdale & McDowell	*Thompson Peak & FLW*	EB	7/1/2007	NA	NA
	Scottsdale & McDowell	*Thompson Peak & FLW*	SB	1/6/2014	NA	NA
	Scottsdale & Frank Lloyd Wright (FLW)	*Scottsdale & Greenway*	NB	8/18/2007	NA	NA
	Hayden & Indian School	*Scottsdale & Indian School*	SB to EB LT	8/15/2007	6/30/2010	unknown
	Hayden & Indian School	*Scottsdale & Indian School*	SB	8/15/2007	6/30/2010	unknown
	Scottsdale & Thomas	*Indian School & Goldwater*	NB to WB LT	3/1/2009	NA	NA
	Scottsdale & Thomas	*Indian School & Goldwater*	NB	8/12/2007	NA	NA
	Scottsdale & Cactus	*Scottsdale & Thunderbird*	NB	8/17/2007	12/16/2013	unknown
	Scotttsdale & Shea	*Scottsdale & Camelback*	SB to EB LT	10/1/2008	4/1/2013	unknown
	Scotttsdale & Shea	*Scottsdale & Camelback*	SB	8/13/2007	NA	NA
	90th & Shea	*FLW & Shea*	EB to NB LT	8/1/2008	4/1/2013	unknown
	90th & Shea	*FLW & Shea*	EB	8/12/2007	not in service	NA
	Hayden & McDowell	*Camelback & Goldwater*	EB	7/1/2010	12/16/2013	unknown
	Hayden & Thomas	*Pima & Chaparral*	EB	11/7/2013	NA	NA
	FLW & Greenway Hayden Loop	*FLW & Thompson Peak*	EB	11/15/2013	NA	NA
	FLW & Cactus	*114th & Shea*	SB	1/1/2014	NA	NA
	Hayden & Chaparral	*Hayden & Camelback*	NB	12/16/2014	NA	NA

SAFETY IMPACT EVALUATION

Crash data and information about each study location was obtained from the City of Scottsdale's Traffic Engineering Division. The number of collisions in the five years before implementation of photo enforcement were analyzed against the five years after activation, in 12-month periods. In situations where the camera was installed less than five years prior to this report, the length of before data was identified to match the length of after data (i.e. if a camera was installed in 2013, then three years before and three years after were analyzed).

This study examines five crash categories by manner of collision: angle, left-turn, rear-end, sideswipe, and total crashes. Furthermore, the manner of collision is broken down by two violation categories: 1) all violations and 2) "speed too fast for conditions", "exceeded lawful speed", and "disregard traffic signal". For segment locations, "disregard traffic signal" is not applicable. Crashes of all injury severity were considered.

For the 13 enforced through movements at intersections, only crashes involving a unit number one vehicle from the enforced approach direction were analyzed. According to the 10th Edition of *Arizona's Crash Report Forms Instruction Manual* published by the Arizona Department of Transportation, "Traffic Unit #1 is the vehicle … that caused the collision or was most at fault". Therefore, the crashes analyzed for the 13 enforced through movements at intersections were those that may have been preventable due to change in driver behavior caused by the presence of photo enforcement.

Motor vehicle crash data, in tabular form, does not contain information regarding the lane position of the motor vehicles prior to the collision. For example, it cannot be determined from the crash data if a rear-end collision occurred in a through lane or turn lane. This level of detail can only be obtained from original crash reports and narratives, which were not reviewed as part of this study. Additionally, law enforcement may misunderstand crash type designations involving left-turning vehicles (e.g., angle versus left-turn). These occurrences made it difficult to isolate crashes involving vehicles from the enforced left-turn movement. Therefore, for the five locations and time periods of active enforced left-turn movements at intersections, all crashes involving at least one vehicle (i.e., vehicle unit number one or two) from the enforced approach direction were analyzed in the before and after condition to be more inclusive.

The crash categories analyzed for enforced segment locations and respective control locations include:

- All crashes
- Rear-end crashes
- All crashes related to "Speed Too Fast for Conditions" and "Exceeded Lawful Speed"
- Rear-end crashes related to "Speed Too Fast for Conditions" and "Exceeded Lawful Speed"

The crash categories analyzed for enforced intersection locations and respective control locations include:

- All crashes of the enforced approach
- Rear-end crashes of the enforced approach
- Angle crashes of the enforced approach
- Left-turn crashes of the enforced approach

- All crashes related to “Speed Too Fast for Conditions” and “Exceeded Lawful Speed” and “Disregarded Traffic Signal”
- Rear-end crashes related to “Speed Too Fast for Conditions” and “Exceeded Lawful Speed” and “Disregarded Traffic Signal”
- Angle crashes related to “Speed Too Fast for Conditions” and “Exceeded Lawful Speed” and “Disregarded Traffic Signal”
- Left-turn crashes related to “Speed Too Fast for Conditions” and “Exceeded Lawful Speed” and “Disregarded Traffic Signal”

Appendix B summarizes the before and after data for each Phase I location. Each location is accompanied by aerial photography, location details, analysis details, and collision data with corresponding graphs. Historical traffic volumes and current signal timing data are also provided. Each aerial photograph, one for before and one for after, was captured from Google Earth for dates as close as possible to the dates of photo enforcement activation and deactivation. In the case that photo enforcement is still active, the photo is the most recent Google Earth imagery available.

TEST METHODOLOGIES

Lee Engineering performed the Wilcoxon Signed-Rank test to evaluate the effectiveness of the photo enforcement cameras on safety at the enforcement locations. This test examined if there was a significant decrease in crashes after activation of enforcement. This statistical methodology was also performed on the control locations for identical time periods.

The number of crashes decreased in the after periods of both the enforcement and control locations so a second test, Mann-Whitney U, was performed to determine if the crash reductions for each group were significantly different. In other words, this test was used to confirm whether the safety improvement was a direct effect of the photo enforcement implementation or if the enforced locations were not significantly different than the control locations.

The following sections describe details about the statistical tests, underlying assumptions, and the test hypotheses (both null and alternative hypotheses).

WILCOXON SIGNED-RANK TEST

The Wilcoxon Signed-Rank test compares two sample groups by pairing observations. An advantage of using the signed-rank test is that it does not require the data to be normally distributed, which is beneficial when the sample size is relatively small. Further, literature suggests that Wilcoxon Signed-Rank test is a powerful means of statistical comparison when investigating any change from one time point to another and, therefore, was utilized to evaluate any reduction in crashes for before and after time periods at the photo enforcement and control locations of this study.

The Wilcoxon Signed-Rank test can be performed as either a one-tailed or two-tailed test. The two-tailed test checks whether or not the mean differences of two population groups are zero or non-zero, whereas the one-tailed test checks whether or not one mean is larger than the other. Since this analysis is

comparing the difference in mean values, a one-tailed test was performed on the crash data for both enforcement and control locations using the before and after crash data as sample pair data.

For this study, a one-tailed Wilcoxon Signed-Rank test was performed for the following test hypotheses:

H_o: The mean difference in crashes before and after photo enforcement activation is zero.

H_a: The mean difference in crashes before photo enforcement activation is higher than after activation.

To perform this analysis, the null hypothesis, H_o, is tested by comparing the estimated W statistic (|W|) from the sample group to standard W values ($W_{critical}$) for a one-tailed test from a Wilcoxon W statistic table.

Pairing for the test was achieved in two ways; first by comparing the average number of crashes per year before to the average number of crashes per year after from equivalent time periods, and second, by comparing the most recent twelve-month period before with the most recent twelve-month period after, and so on for each twelve-month period of data analyzed at each location. Illustrations of these pairing techniques are displayed in **Figure 1** and **Figure 2**, respectively.

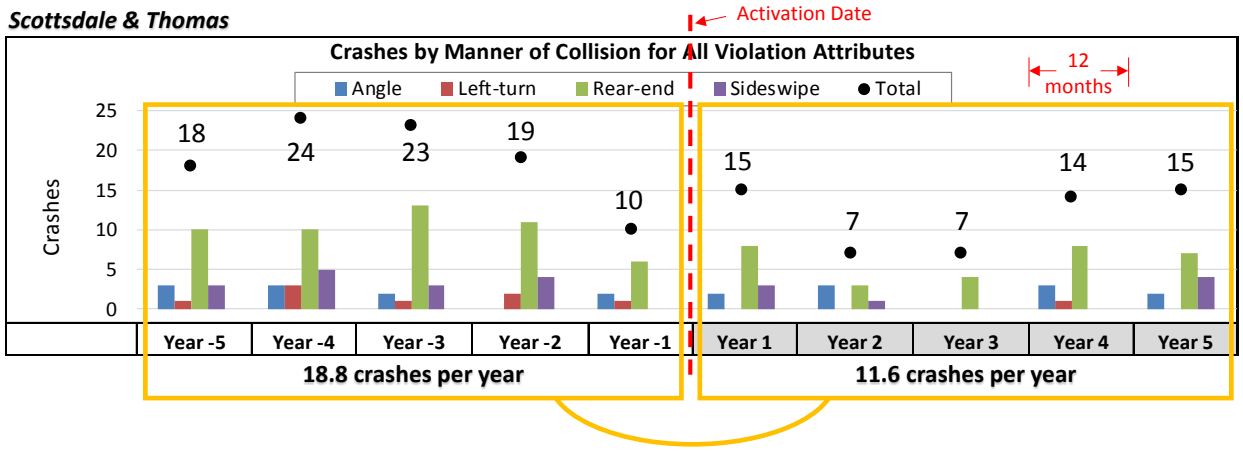

Figure 1 – Illustration of the pairing technique that compares the average number of crashes per year before to the average number of crashes per year after from equivalent time periods

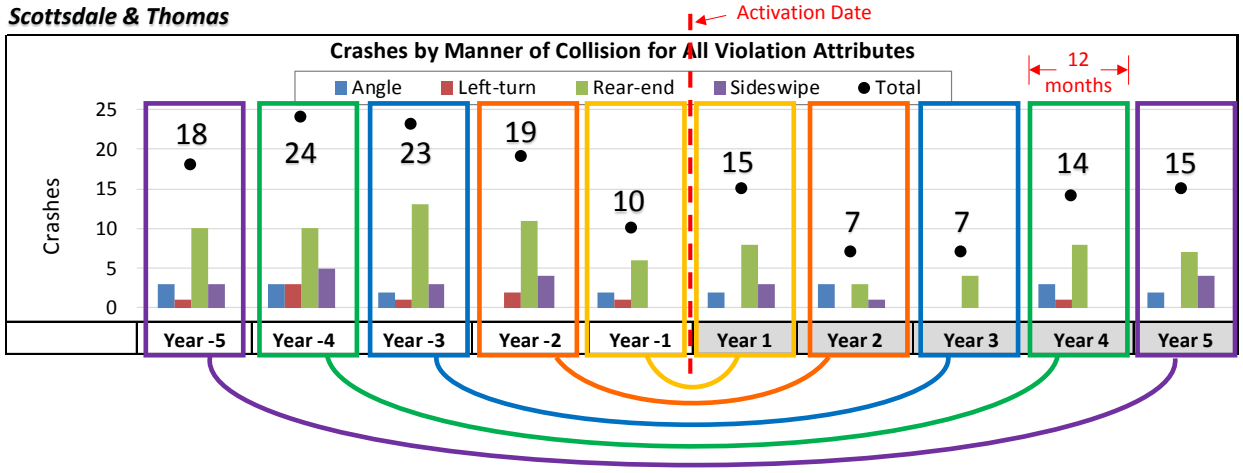

Figure 2 – Illustration of the pairing technique that compares the most recent twelve-month period before with the most recent twelve-month period after, and so on for each twelve-month period of data analyzed at each location

MANN-WHITNEY U TEST

The Mann-Whitney U test is a non-parametric test of a null hypothesis which states the probability distributions of two continuous scale variables are the same for two independent populations. This test was first proposed by Wilcoxon with the prerequisite stating the test was to have two sample population groups of the same size. Therefore, the test is sensitive to the differences in means between two populations. Mann and Whitney introduced an equivalent statistic that can compare unequal and equal population sizes. This statistical analysis is more appropriate for examining whether the means of two population groups are the same or statistically different. An advantage of using this test is that it does not require the data to be normally distributed.

The Mann-Whitney U test can also be performed as either a one-tailed or two-tailed test. The two-tailed test indicates whether the means of two population groups are the same or different, whereas the one-tailed test indicates whether one mean is larger than the other. Since the previous test (Wilcoxon Signed-Rank) in this study provides an examination of whether there is any significant safety improvement at the enforced segment, intersection, and respective control locations; the Mann-Whitney U test was selected to determine if there is a significant difference between the crash reduction at the enforcement locations and control locations.

For this study a one-tailed Mann-Whitney U test was performed with the following test hypotheses:

H_o: The means of crashes for both the camera and control locations are the same.

H_a: The mean of crashes for control locations is higher than the mean of enforcement locations.

To perform this analysis, the null hypothesis, H_o, is tested by comparing the estimated U statistic with the calculated U value at different confidence levels.

PHASE I CRASH ANALYSIS FOR 2007-2016 STUDY LOCATIONS

The analysis methods utilized to examine Phase I study locations identified if there is a statistical difference in the number of crashes before and after photo enforcement activation. **Figure 3** shows an example of the statistical analysis procedure for rear-end crashes at enforced intersection locations. This particular example is testing the reduction between the sample means for rear-end crashes from the before and after time periods. The conclusion is that there is a significant reduction in the means at a 95% confidence level. The Wilcoxon Signed-Rank test only considers paired samples that have an absolute difference other than zero. Therefore, in the example, the first two locations are not considered in the Signed-Rank Test. The complete statistical analysis for the Phase I intersections, segments, and their respective control locations can be found in **Appendix C**.

Phase I Enforcement Locations	Average Number of Crashes Per Year		Sign	Absolute Difference	Rank	Signed-Rank
	Before	After				
Scottsdale & McDowell Eastbound	7.00	7.00	0	0.00		
Scottsdale & McDowell Southbound	6.33	6.33	0	0.00		
Hayden & Thomas Eastbound	9.67	9.33	-1	0.33	1	-1
Hayden & McDowell Eastbound	5.50	4.75	-1	0.75	2	-2
Frank Lloyd Wright & Cactus Southbound	3.00	2.00	-1	1.00	3	-3
90th & Shea Eastbound	16.00	14.80	-1	1.20	4	-4
Hayden & Chaparral Northbound	3.50	2.00	-1	1.50	5	-5
Hayden & Indian School Southbound	4.33	2.33	-1	2.00	6	-6
Scottsdale & Cactus Northbound	6.60	4.40	-1	2.20	7.5	-7.5
Scottsdale & Frank Lloyd Wright Northbound	11.00	8.80	-1	2.20	7.5	-7.5
Scottsdale & Shea Southbound	8.00	5.60	-1	2.40	9	-9
Scottsdale & Thomas Northbound	10.00	6.00	-1	4.00	10	-10
Frank Lloyd Wright & Greenway Hayden Loop Eastbound	11.33	5.67	-1	5.67	11	-11

Wilcoxon Signed-Rank Test			
n = 11		**|W| =**	66
conf. level = 0.05		**$W_{Critical}$ =**	13.000
$|W| > W_{critical}$ = True		**Significant Difference**	
Reject Null Hypothesis and conclude that the after mean is statistically significantly smaller @ 95% confidence level.			

Figure 3 - Statistical Analysis Example for Phase I Intersection Locations for Rear-End Crashes

PHASE I SEGMENT LOCATIONS

Phase I Enforced Segments

There were six segments with photo enforcement implementation in this Phase I segment analysis. The average number of crashes annually is shown in **Table 2.** There is an overall 37% reduction in crashes from the before to after period. Each location decreased in crashes except Pima and Hualapai southbound, which maintained the same average number of crashes before and after photo enforcement activation.

Table 2 – Before and After Crash Differences for Phase I Enforced Segments

Enforcement Location	Average number of crashes per year		Difference
	Before	After	
Pima and Hualapai (550' south) Southbound	0.80	0.80	0.00
Pima and Hualapai (550' south) Northbound	0.80	0.60	-0.20
103rd and Dynamite (250' east) Eastbound	0.67	0.33	-0.33
120th and Shea (800' east) Westbound	1.20	0.60	-0.60
120th and Shea (800' east) Eastbound	4.00	3.00	-1.00
113th and Rio Verde (300' east) Westbound	1.00	0.00	-1.00

Table 3 shows the statistical analysis results for Phase I enforced segment locations when comparing the average number of crashes per year before to the average number of crashes per year after from equivalent time periods. Within the table is the before and after average number of crashes, the difference in those averages, and the results of Wilcoxon Signed-Rank test. Both the samples of all crashes and rear-end crashes, regardless of violation, have statistically significant different means at a 95% confidence level. All crashes reduced by 37% and rear-end crashes reduced by 51%. For the other two tests, all crashes related to speed violations and rear-end crashes related to speed violations, there was not enough data for the Wilcoxon Signed-Rank test to be performed. This is due to multiple locations having identical before and after crash averages, therefore eliminating them from the analysis and decreasing the sample size.

Table 3 – Statistical Analysis Results for Phase I Enforced Segments (Average Crashes per Year)

Type of crashes	Sum of Average Number of Crashes per Year for 6 Phase I Segment Enforcement Locations			Statistical Significance in Different Means
	Before	After	Difference	
All crashes	8.47	5.33	-3.13	Yes
Rear-end crashes	5.33	2.60	-2.73	Yes
All crashes related to speed violations	5.13	1.93	-3.20	N/A^
Rear-end crashes related to speed violations	3.60	1.93	-1.67	N/A^

^ *Sample size too small to conduct Wilcoxon Signed Rank Test*

Table 4 shows the statistical analysis results for Phase I enforced segment locations when comparing each twelve-month period before and after. Within the table is the sum of crashes in the before and after periods, the difference, and the results of Wilcoxon Signed-Rank test. Each analysis has a statistically significant reduction in mean at a 95% confidence level. All crashes reduced by 33%; rear-end crashes reduced by 50%; all crashes related to speed violations reduced by 65%; and rear-end crashes related to speed violations reduced by 53%.

Table 4 – Statistical Analysis Results for Phase I Enforced Segments (Crashes Year by Year)

Type of crashes	Sum of Crashes for 6 Phase I Segment Enforcement Locations			Statistical Significance in Different Means
	Before	After	Difference	
All crashes	39.00	26.00	-13.00	Yes
Rear-end crashes	26.00	13.00	-13.00	Yes
All crashes related to speed violations	26.00	9.00	-17.00	Yes
Rear-end crashes related to speed violations	19.00	9.00	-10.00	Yes

Phase I Control Segments

The analysis was conducted for six similar control segment locations that did not have photo enforcement installed. **Table 5** shows the statistical analysis results for Phase I control segment locations when comparing the average number of crashes per year before to the average number of crashes per year after from equivalent time periods. There was not enough data to perform the Wilcoxon Signed-Rank test.

Table 5 – Statistical Analysis Results for Phase I Control Segments (Average Crashes per Year)

Type of crashes	Sum of Average Number of Crashes per Year for 6 Phase I Segment *Control* Locations			Statistical Significance in Different
	Before	After	Difference	
All crashes	2.20	2.13	-0.07	N/A^
Rear-end crashes	0.80	1.13	0.33	N/A^
All crashes related to speed violations	0.80	1.13	0.33	N/A^
Rear-end crashes related to speed violations	0.80	0.93	0.13	N/A^

^ *Sample size too small to conduct Wilcoxon Signed Rank Test*

Table 6 shows the statistical analysis results for Phase I control segment locations when comparing each twelve-month period before and after. Within the table is the sum of crashes in the before and after periods, the difference, and the results of Wilcoxon Signed-Rank test. Two tests have a statistically significant increase in mean at a 95% confidence level. Rear-end crashes increased by 25% and all crashes related to speed violations increased by 25%.

Enforced segment locations are activated based on historical collision patterns and law enforcement observation. Overall, control segments experienced 66% fewer crashes (22 versus 65) than the enforced segment locations, indicating appropriate site selection because the current enforced segment locations have the highest potential for safety improvement.

Table 6 – Statistical Analysis Results for Phase I Control Segments (Crashes Year by Year)

Type of crashes	Sum of Crashes for 6 Phase I Segment Control Locations			Statistical Significance in Different Means
	Before	After	Difference	
All crashes	11.00	10.00	-1.00	No
Rear-end crashes	4.00	5.00	1.00	Yes
All crashes related to speed violations	4.00	5.00	1.00	Yes
Rear-end crashes related to speed violations	4.00	4.00	0.00	No

PHASE I INTERSECTION LOCATIONS

Phase I Enforced Intersections

Thirteen intersection through movements with photo enforcement implemented were analyzed in this Phase I analysis. Only crashes involving a unit number one vehicle (at fault) from the enforced approach direction were analyzed. The average number of crashes annually for each enforced intersection location is shown in **Table 7**. Crashes reduced 24% from the before to after period. Each location decreased in crashes except Hayden and McDowell eastbound, which has an increase in 1.75 crashes per year from before to after photo enforcement activation.

Table 7 – Before and After Crash Differences for Phase I Enforced Intersections

Enforcement Location	Average number of crashes per year		Difference
	Before	After	
Hayden & McDowell Eastbound	7.25	9.00	1.75
Scottsdale & McDowell Southbound	9.67	9.33	-0.33
Scottsdale & McDowell Eastbound	13.00	12.00	-1.00
Hayden & Chaparral Northbound	5.50	4.00	-1.50
90th & Shea Eastbound	24.60	22.80	-1.80
Frank Lloyd Wright & Cactus Southbound	6.00	3.33	-2.67
Scottsdale & Frank Lloyd Wright Northbound	15.60	12.60	-3.00
Scottsdale & Shea Southbound	12.20	8.80	-3.40
Scottsdale & Cactus Northbound	11.00	7.00	-4.00
Hayden & Thomas Eastbound	19.33	15.00	-4.33
Hayden & Indian School Southbound	12.33	6.67	-5.67
Frank Lloyd Wright & Greenway Hayden Loop Eastbound	13.67	6.67	-7.00
Scottsdale & Thomas Northbound	18.80	11.60	-7.20

Table 8 displays the statistical analysis results for Phase I intersection enforcement locations of through movements when comparing the average number of crashes per year before to the average number of crashes per year after from equivalent time periods. With the exception of right-angle crashes, each analysis has a statistically significant reduction in mean at a 95% confidence level. All crashes reduced by 24%; rear-end crashes reduced by 23%; left-turn crashes reduced by 61%; all crashes related to speed and signal violations reduced by 35%; rear-end crashes related to speed and signal violations reduced by 30%; right-angle crashes related to speed and signal violations reduced by 50%; and left-turn crashes related to speed and signal violations reduced by 56%.

Table 9 displays the statistical analysis results for Phase I intersection enforcement locations of through movements when comparing each twelve-month period before and after. With the exception of right-angle crashes, each analysis has a statistically significant reduction in mean at a 95% confidence level. All crashes reduced by 23%; rear-end crashes reduced by 22%; left-turn crashes reduced by 61%; all crashes related to speed and signal violations reduced by 33%; rear-end crashes related to speed and signal violations reduced by 28%; right-angle crashes related to speed and signal violations reduced by 46%; and left-turn crashes related to speed and signal violations reduced by 59%.

Table 8 – Statistical Analysis Results for Phase I Enforced Intersections (Average Crashes per Year)

Type of crashes	Sum of Average Number of Crashes per Year for 13 Phase I Intersection Enforcement Locations			Statistical Significance in Different Means
	Before	After	Difference	
All crashes	168.95	128.80	-40.15	Yes
Rear-end crashes	102.27	79.02	-23.25	Yes
Right-angle crashes	18.12	18.78	0.67	No
Left-turn crashes	17.70	6.83	-10.87	Yes
All crashes related to speed and signal violations	85.97	56.18	-29.78	Yes
Rear-end crashes related to speed and signal violations	69.27	48.42	-20.85	Yes
Right-angle crashes related to speed and signal violations	6.93	3.45	-3.48	Yes
Left-turn crashes related to speed and signal violations	4.33	1.90	-2.43	Yes

Table 9 – Statistical Analysis Results for Phase I Enforced Intersections (Crashes Year by Year)

Type of crashes	Sum of Crashes for 13 Phase I Intersection Enforcement Locations			Statistical Significance in Different Means
	Before	After	Difference	
All crashes	699.00	541.00	-158.00	Yes
Rear-end crashes	426.00	333.00	-93.00	Yes
Right-angle crashes	69.00	80.00	11.00	No
Left-turn crashes	69.00	27.00	-42.00	Yes
All crashes related to speed and signal violations	352.00	236.00	-116.00	Yes
Rear-end crashes related to speed and signal violations	285.00	205.00	-80.00	Yes
Right-angle crashes related to speed and signal violations	26.00	14.00	-12.00	Yes
Left-turn crashes related to speed and signal violations	17.00	7.00	-10.00	Yes

Phase I Control Intersections

Table 10 displays the statistical analysis results for Phase I intersection control locations when comparing the average number of crashes per year before to the average number of crashes per year after from equivalent time periods. All crashes, right-angle crashes, and right-angle crashes related to speed and signal violations do not have a statistically significant reduction in mean at a 95% confidence level. Rear-end crashes reduced by 9%; left-turn crashes reduced by 45%; all crashes related to speed and signal violations reduced by 25%; rear-end crashes related to speed and signal violations reduced by 19%; and left-turn crashes related to speed and signal violations reduced by 23%.

Table 10 – Statistical Analysis Results for Phase I Control Intersections (Average Crashes per Year)

Type of crashes	Sum of Average Number of Crashes per Year for 13 Phase I intersection *control* locations			Statistical Significance in Different Means
	Before	After	Difference	
All crashes	70.83	66.95	-3.88	No
Rear-end crashes	33.83	30.95	-2.88	Yes
Right-angle crashes	9.42	10.65	1.23	No
Left-turn crashes	15.10	8.37	-6.73	Yes
All crashes related to speed and signal violations	29.45	22.10	-7.35	Yes
Rear-end crashes related to speed and signal violations	19.75	15.92	-3.83	Yes
Right-angle crashes related to speed and signal violations	3.38	3.25	-0.13	N/A^
Left-turn crashes related to speed and signal violations	2.87	2.20	-0.67	Yes

^ *Sample size too small to conduct Wilcoxon Signed Rank Test*

Table 11 displays the statistical analysis results for Phase I intersection control locations when comparing each twelve-month period before and after. Only left-turn crashes and crashes related to speed and signal violations have a statistically significant reduction in mean at a 95% confidence level. Left-turn crashes reduced by 49% and all crashes related to speed and signal violations reduced by 25%.

Control intersections experienced 58% fewer crashes (522 versus 1240) than the enforced intersection locations for the entire before and after analysis period, indicating appropriate site selection because the current enforced intersection locations have the highest potential for safety improvement.

Table 11 – Statistical Analysis Results for Phase I Control Intersections (Crashes Year by Year)

Type of crashes	Sum of Crashes for 13 Phase I intersection *control* locations			Statistical Significance in Different Means
	Before	After	Difference	
All crashes	275.00	247.00	-28.00	No
Rear-end crashes	125.00	109.00	-16.00	No
Right-angle crashes	35.00	37.00	2.00	No
Left-turn crashes	53.00	27.00	-26.00	Yes
All crashes related to speed and signal violations	117.00	88.00	-29.00	Yes
Rear-end crashes related to speed and signal violations	76.00	64.00	-12.00	No
Right-angle crashes related to speed and signal violations	16.00	12.00	-4.00	No
Left-turn crashes related to speed and signal violations	13.00	11.00	-2.00	No

Phase I Enforced Left-Turn Movements at Intersections

Analysis was also conducted for a subset of the Phase I intersection analysis which consists of five locations with photo enforcement of protected left-turn movements. Left-turn enforcement was always simultaneously active with the enforced through movement; however, activation and deactivation of enforcement at these five left-turn movements did not always occur at the same time as their complementary enforced through movement. Crash data analyzed for this subset analysis is broader due to limitations in isolating crashes involving left-turn vehicles; thus, includes crashes involving at least one vehicle (i.e., vehicle unit number one or two) from the enforced approach direction. Therefore, crashes are included where the driver from the enforced approach did and did not have primary fault. Shown in **Table 12**, crashes decreased at each location and there is an overall 25% reduction in crashes.

Table 12 – Before and After Crash Differences for Phase I Enforced Left-turn Movements at Intersections

Enforcement Location	Average number of crashes per year		Difference
	Before	After	
Scottsdale & McDowell (LHT) Eastbound to Northbound	16.00	14.80	-1.20
90th & Shea (LHT) Eastbound to Northbound	26.00	23.40	-2.60
Scottsdale & Thomas (LHT) Northbound to Westbound	23.40	18.40	-5.00
Hayden & Indian School (LHT) Southbound to Eastbound	14.33	8.00	-6.33
Scottsdale & Shea (LHT) Southbound to Eastbound	14.40	5.60	-8.80

Table 13 displays the statistical analysis results for Phase I intersection enforcement locations of left-turn movements when comparing the average number of crashes per year before to the average number of crashes per year after from equivalent time periods. With the exception of right-angle crashes and left-turn crashes related to speed and signal violations, each analysis has a statistically significant reduction in mean at a 95% confidence level. Right-angle crashes had a statistically significant increase in means (47%), which may be due to inclusion of crashes in this analysis involving red light violations on intersection approaches that are not enforced. The largest decrease in crashes, found for left-turn crashes, is 64%. All crashes reduced by 25% and all crashes related to speed and signal violations reduced by 35%, which is commensurate with the analysis results for the superset of all Phase I intersections. Rear-end crashes reduced by 21% and rear-end crashes related to speed and signal violations reduced by 26%.

Table 13 – Statistical Analysis Results for Phase I Enforced Left-turn Movements at Intersections (Average Crashes per Year)

Type of crashes	Sum of Average Number of Crashes per Year for 5 Phase I Locations with Left-Turn Enforcement			Statistical Significance in Different Means
	Before	After	Difference	
All crashes	94.13	70.20	-23.93	Yes
Rear-end crashes	45.27	35.73	-9.53	Yes
Right-angle crashes	11.27	16.60	5.33	Yes
Left-turn crashes	15.20	5.40	-9.80	Yes
All crashes related to speed and signal violations	40.33	26.13	-14.20	Yes
Rear-end crashes related to speed and signal violations	27.07	20.13	-6.93	Yes
Right-angle crashes related to speed and signal violations	4.00	1.93	-2.07	N/A^
Left-turn crashes related to speed and signal violations	4.93	2.47	-2.47	N/A^

^ *Sample size too small to conduct Wilcoxon Signed Rank Test*

Table 14 displays the statistical analysis results for Phase I intersection enforcement locations of left-turn movements when comparing each twelve-month period before and after. With the exception of right-angle crashes, each analysis has a statistically significant reduction in means at a 95% confidence level. Right-angle crashes had a statistically significant increase in means (49%), which may be due to inclusion of crashes in this analysis involving red light violations on intersection approaches that are not enforced. All crashes reduced by 24%; rear-end crashes reduced by 20%; left-turn crashes reduced by 63%; all crashes related to speed and signal violations reduced by 34%; rear-end crashes related to speed and signal violations reduced by 36%; right-angle crashes related to speed and signal violations reduced by 50%; and left-turn crashes related to speed and signal violations reduced by 50%.

Table 14 – Statistical Analysis Results for Phase I Enforced Left-turn Movements at Intersections (Crashes Year by Year)

Type of crashes	Sum of Crashes for 5 Phase I Locations with Left-Turn Enforcement			Statistical Significance in Different Means
	Before	After	Difference	
All crashes	442.00	335.00	-107.00	Yes
Rear-end crashes	217.00	174.00	-43.00	Yes
Right-angle crashes	53.00	79.00	26.00	Yes
Left-turn crashes	68.00	25.00	-43.00	Yes
All crashes related to speed and signal violations	191.00	126.00	-65.00	Yes
Rear-end crashes related to speed and signal violations	153.00	98.00	-55.00	Yes
Right-angle crashes related to speed and signal violations	18.00	9.00	-9.00	Yes
Left-turn crashes related to speed and signal violations	22.00	11.00	-11.00	Yes

Phase I Control Left-turn Movements at Intersections

Table 15 displays the statistical analysis results for Phase I intersection control locations of left-turn movements when comparing the average number of crashes per year before to the average number of crashes per year after from equivalent time periods. All crashes, rear-end crashes related to speed and signal violations, and right-angle crashes related to speed and signal violations have a statistically significant reduction in means at a 95% confidence level. The remaining tests did not have enough samples to perform the analysis. All crashes reduced by 16%; rear-end crashes related to speed and signal violations reduced by 43%; and right-angle crashes related to speed and signal violations reduced by 56%.

Table 15 – Statistical Analysis Results for Phase I Control Left-turn Movements at Intersections (Average Crashes per Year)

Type of crashes	Sum of Average Number of Crashes per Year for 5 Phase I Left-Turn *Control* Locations			Statistical Significance in Different Means
	Before	After	Difference	
All crashes	34.53	29.13	-5.40	Yes
Rear-end crashes	15.60	9.53	-6.07	N/A^
Right-angle crashes	7.33	7.93	0.60	N/A^
Left-turn crashes	6.00	3.33	-2.67	N/A^
All crashes related to speed and signal violations	15.07	8.47	-6.60	N/A^
Rear-end crashes related to speed and signal violations	8.67	4.93	-3.73	Yes
Right-angle crashes related to speed and signal violations	3.93	1.73	-2.20	Yes
Left-turn crashes related to speed and signal violations	1.53	0.80	-0.73	N/A^

^ *Sample size too small to conduct Wilcoxon Signed Rank Test*

Table 16 displays the statistical analysis results for Phase I intersection control locations of left-turn movements when comparing each twelve-month period before and after. With the exception of all crashes and right-angle crashes, the remaining tests had a statistically significant reduction in means at a 95% confidence level. Rear-end crashes reduced by 36%; left-turn crashes reduced by 38%; all crashes related to speed and signal violations reduced by 42%; rear-end crashes related to speed and signal violations reduced by 50%; right-angle crashes related to speed and signal violations reduced by 53%; and left-turn crashes related to speed and signal violations reduced by 43%.

Table 16 – Statistical Analysis Results for Phase I Control Left-turn Movements at Intersections (Crashes Year by Year)

Type of crashes	Sum of Crashes for 5 Phase I Left-Turn *Control* Locations			Statistical Significance in Different Means
	Before	After	Difference	
All crashes	146.00	129.00	-17.00	No
Rear-end crashes	64.00	41.00	-23.00	Yes
Right-angle crashes	32.00	35.00	3.00	No
Left-turn crashes	26.00	16.00	-10.00	Yes
All crashes related to speed and signal violations	64.00	37.00	-27.00	Yes
Rear-end crashes related to speed and signal violations	40.00	20.00	-20.00	Yes
Right-angle crashes related to speed and signal violations	17.00	8.00	-9.00	Yes
Left-turn crashes related to speed and signal violations	7.00	4.00	-3.00	Yes

PHASE I LOCATIONS VS CONTROL LOCATIONS

The Mann-Whitney U test was used to determine if there is a significant mean difference between the camera locations and control locations. The sample for this test includes the thirteen Phase I intersection locations and their matching control locations. This test was performed for all crashes and for crashes related to speed too fast for conditions, exceeding lawful speed violations, and disregard traffic signal. The differences in crash means for before and after crashes were calculated for both the enforcement and control locations. The resulting differences were then ranked based on their magnitude of difference, with the greatest difference receiving the highest ranking. As shown in **Figure 4** and **Figure 5**, Result 1: U-Value indicates there is a significant difference in the means between the two groups. Additionally, Result 2: Z-ratio, indicates that the locations with photo enforcement experienced a greater reduction in crashes than the control locations.

Location	Difference	Rank
Enforced	-7.20	1
Enforced	-7.00	2
Enforced	-5.67	3
Control	-5.33	4
Enforced	-4.33	5
Enforced	-4.00	6
Enforced	-3.40	7
Enforced	-3.00	8.5
Control	-3.00	8.5
Enforced	-2.67	10
Control	-2.00	11
Enforced	-1.80	12
Enforced	-1.50	13
Enforced	-1.00	14
Control	-0.75	15
Control	-0.60	16
Enforced	-0.33	18.5
Control	-0.33	18.5
Control	-0.33	18.5
Control	-0.33	18.5
Control	0.00	21
Control	0.60	22
Control	1.00	23
Control	1.20	24
Enforced	1.75	25
Control	6.00	26

R – Rank Total N - number

Test Statistics	
R-Enforced	125
R-Control	226
N-Enforced	13
N-Control	13
U-Enforced	135
U-Control	34
E(U)	84.5
Sigma U	19.5
Z	2.59

Calculations	
U-Value Enforced:	135
U-Value Control:	34
Expected Value = E(U) =	84.5
Standard Dev = σ_U =	19.5
Z-Score	2.5897

Confidence	90%	95%	99%
Z values	1.645	1.96	2.575
$U_{critical,n=13/13,\alpha=.05}$ =	45		

Result 1: U-Value (if $U \le U_{critical}$, then reject H_o)			
U-Value =	34	Significant	at $p < 0.05$
$U_{critical}$ =	45		

Result 2: Z-ratio (if $\lvert Z \rvert > Z_{critical}$, then reject H_o)			
Z-Score =	2.59	Significant	at $p < 0.05$
$Z_{critical}$ =	1.96		

Conclusion:
Crash reduction at enforced locations is significantly higher than the reduction at control locations @ 95% confidence level

Figure 4 – Mann-Whitney U Test for All Crashes at Phase I Enforcement and Control Locations

Location	Difference	Rank
Enforced	0.00	1
Enforced	0.20	2
Enforced	0.33	3
Control	0.33	4
Enforced	0.33	5
Enforced	0.50	6
Enforced	0.60	7.5
Enforced	0.60	7.5
Control	0.75	9
Enforced	0.80	10
Control	0.80	11
Enforced	0.80	12
Enforced	1.00	13
Enforced	1.25	14
Control	1.33	15
Control	1.33	16
Enforced	1.80	17
Control	1.80	18
Control	2.00	19
Control	2.20	20
Control	2.33	21
Control	2.50	22
Control	3.00	23
Control	3.60	24
Enforced	4.00	25
Control	5.67	26

Test Statistics	
R-Enforced	123
R-Control	228
N-Enforced	13
N-Control	13
U-Enforced	137
U-Control	32
E(U)	84.5
Sigma U	19.5
Z	2.69

Calculations	
U-Value Enforced:	137
U-Value Control:	32
Expected Value = E(U) =	84.5
Standard Dev = σ_U =	19.5
Z-Score	2.6923

Confidence	90%	95%	99%
Z values	1.645	1.96	2.575
$U_{critical,n=13/13,\alpha=.05}$ =	45		

Result 1: U-Value
(if $U \le U_{critical}$, then reject H_o)

U-Value =	32	Significant	at $p < 0.05$
$U_{critical}$ =	45		

Result 2: Z-ratio
(if $|Z| > Z_{critical}$, then reject H_o)

Z-Score =	2.69	Significant	at $p < 0.05$
$Z_{critical}$ =	1.96		

Conclusion:

Crash reduction at enforced locations is significantly higher than the reduction at control locations @ 95% confidence level

R – Rank Total N - number

Figure 5 – Mann-Whitney U Test for Crashes Related to Speed Too Fast for Conditions, Exceeding Lawful Speed Violations, and Disregard Traffic Signal at Phase I Enforcement and Control Locations

DISCUSSION OF RESULTS

This Phase I analysis of enforcement cameras activated by ATS Digital Cameras in the City of Scottsdale during the years 2007 through 2014 indicate that there is a statistically significant reduction in the total numbers of crashes after activation of speed photo enforcement on segments and red-light photo enforcement at intersections.

A summary of the statistical findings at segment locations is provided in **Table 17**.

Table 17 – Summary of Statistical Findings Before and After Photo Enforcement Activation at Segments

Pairing Technique	Crash Type	Findings of the Wilcoxon Signed Rank Test			
		Enforced Segment Locations		Control Segment Locations	
Average number of crashes per year: before-after	Based on all types of crashes	37%	Reduction of total number of crashes is significant	-	Total number of crashes // sample size too small //
		51%	Reduction of rear-end crashes is significant	-	Rear-end crashes // sample size too small //
	Crashes related to violations: exceeding lawful speed and speed too fast for conditions.	-	Total number of crashes // sample size too small //	-	Total number of crashes // sample size too small //
		-	Rear-end crashes // sample size too small //	-	Rear-end crashes // sample size too small //
Each year's crash frequency: before-after	Based on all types of crashes	33%	Reduction of total number of crashes is significant	-	Reduction of total number of crashes is not significant
		50%	Reduction of rear-end crashes is significant	25%	Increase of rear-end crashes is significant
	Crashes related to violations: exceeding lawful speed and speed too fast for conditions.	65%	Reduction of total number of crashes is significant	25%	Increase of rear-end crashes is significant
		53%	Reduction of rear-end crashes is significant	-	Reduction of rear-end crashes is not significant

For the segment locations, total crashes and rear end crashes have a significant statistical reduction after enforcement activation; however, the sample size was too small to evaluate sub-sets of crashes using the Wilcoxon Signed-Rank test. The control locations for the segment analysis also had too few samples to apply the Wilcoxon Signed-Rank test. This is due to multiple locations having identical before and after crash averages, therefore eliminating them from the analysis and decreasing the sample size.

When comparing crashes for each twelve-month period before and after enforcement activation, total crashes reduced by 33% (13 crashes) across the five enforced segment locations. Rear-end crashes reduced by 50% (13 crashes) and crashes related to speed violations reduced by 65% (17 crashes). During the same period at control locations, these types of crashes increased, which indicates that speed photo enforcement on segments is altering driver behavior to travel at prudent speeds, thus reducing collisions.

Additionally, control segments experienced 66% fewer crashes (22 versus 65) than the enforced segment locations for the entire before and after analysis period, indicating appropriate site selection because the current enforced segment locations have the highest potential for safety improvement.

A summary of the statistical findings at intersection locations is provided in **Table 18**.

Table 18 – Summary of Statistical Findings Before and After Photo Enforcement Activation at Intersections

Pairing Technique	Crash Type	Findings of the Wilcoxon Signed Rank Test			
		Enforced Intersection Locations		Control Intersection Locations	
Average number of crashes per year: before-after	Based on all types of crashes	24%	Reduction of total number of crashes is significant	-	Reduction of total number of crashes is not significant
		23%	Reduction of rear-end crashes is significant	9%	Reduction of rear-end crashes is significant
		-	Reduction of right-angle crashes is not significant	-	Increase of right-angle crashes is not significant
		61%	Reduction of left-turn crashes is significant	45%	Reduction of left-turn crashes is significant
	Crashes related to violations: disregarded traffic signal, exceeding lawful speed, and speed too fast for conditions.	35%	Reduction of total number of crashes is significant	25%	Reduction of total number of crashes is significant
		30%	Reduction of rear-end crashes is significant	19%	Reduction of rear-end crashes is significant
		50%	Reduction of right-angle crashes is significant	-	Right-angle crashes // sample size too small //
		56%	Reduction of left-turn crashes is significant	23%	Reduction of left-turn crashes is significant
Each year's crash frequency: before-after	Based on all types of crashes	23%	Reduction of total number of crashes is significant	-	Reduction of total number of crashes is not significant
		22%	Reduction of rear-end crashes is significant	-	Reduction of rear-end crashes is not significant
		-	Reduction of right-angle crashes is not significant	-	Increase of right-angle crashes is not significant
		61%	Reduction of left-turn crashes is significant	49%	Reduction of left-turn crashes is significant
	Crashes related to violations: disregarded traffic signal, exceeding lawful speed, and speed too fast for conditions.	33%	Reduction of total number of crashes is significant	25%	Reduction of total number of crashes is significant
		28%	Reduction of rear-end crashes is significant	-	Reduction of rear-end crashes is not significant
		46%	Reduction of right-angle crashes is significant	-	Reduction of right-angle crashes is not significant
		59%	Reduction of left-turn crashes is significant	-	Reduction of left-turn crashes is not significant

For the enforced intersection locations, all but one test showed a statistically significant reduction in crashes after photo enforcement activation. The results indicate there is a significant reduction in all crashes (-23 to -24%, 158 crashes), rear-end crashes (-22 to -23%, 93 crashes), and left-turn crashes (-61%, 42 crashes) after activation. There was also a statistically significant reduction after enforcement activation of all crashes (-33 to -35%, 116 crashes), right-angle crashes (-46 to -50%, 12 crashes), and left-turn crashes (-56 to -59%, 10 crashes) with violations related to red-light running.

The analysis of control intersection locations did not indicate a significant difference in all crashes or right-angle crashes for the matching before and after time periods, but did reveal a statistically significant reduction in left-turn crashes (-45 to -49%, 26 crashes) and all crashes with disregard traffic signal or speed violations (-25%, 29 crashes) after enforcement was implemented at other locations in the City. This supports previous research that photo enforcement has a positive spillover effect on driver behavior in the surrounding area, also referred to as the "distance halo" or "halo effect". Reduced traffic volumes and congestion during the Great Recession may have also improved safety, but the affect appears small since other crash/violation types did not experience significant change at control intersections. Results from the Mann-Whitney U test indicates that the locations with photo enforcement experienced a significantly greater reduction in crashes than the control locations.

Control intersections experienced 58% fewer crashes (522 versus 1240) than the enforced intersection locations for the entire before and after analysis period, indicating appropriate site selection because the current enforced intersection locations have the highest potential for safety improvement.

Analysis was also conducted for a subset of the Phase I intersection analysis which consists of five location with photo enforcement of protected left-turn movements. Left-turn enforcement was always simultaneously active with the enforced through movement; however, activation and deactivation of enforcement at these five left-turn movements did not always occur at the same time as their complementary enforced through movement. Crash data analyzed for this subset analysis is broader than for the other tests in this study. A summary of the statistical findings at left-turn locations is provided in **Table 19**.

At the intersections with enforced left-turn movements, all crashes reduced by 24%, rear-end crashes reduced by 20%, left-turn crashes reduced by 63%, and all crashes related to speed and signal violations reduced by 34%, which is commensurate with the analysis results for the superset of all Phase I enforced intersections. Right-angle crashes had a statistically significant increase in crashes (47 - 49%, 26 crashes), which may be due to inclusion of crashes in this analysis involving red light violations on intersection approaches that are not enforced. The respective control locations did not experience a similar increase.

Control locations for these left-turn movements experienced significant reductions in several types of crashes in the matching before and after time periods. Reduced traffic volumes and congestion during the Great Recession or other implemented safety improvements may be contributing factors to these results.

The overall results of this study reveal that Scottsdale's implementation of photo enforcement is having a positive safety impact by reducing crashes at enforced segment and intersection locations and may also be having a positive safety impact on nearby intersections. For identical time periods, control intersection locations experienced a reduction of 28 collisions (not statistically significant) and enforced intersection locations experienced a reduction of 158 collisions (statistically significant). The benefit of enforcing left-turn movements does not appear as great as enforcing through movements at intersections. Additionally, the total number of collisions, which is much higher at enforced locations compared to control locations indicate appropriate enforcement site selection at locations with the highest potential for safety improvement.

Table 19 – Summary of Statistical Findings Before and After Photo Enforcement Activation at Left-Turn Movements

Pairing Technique	Crash Type	Findings of the Wilcoxon Signed Rank Test			
		Enforced Left-Turn Locations		Control Left-Turn Locations	
Average number of crashes per year: before-after	Based on all types of crashes	25%	Reduction of total number of crashes is significant	16%	Reduction of total number of crashes is significant
		21%	Reduction of rear-end crashes is significant	-	Rear-end crashes // sample size too small //
		47%	Increase of right-angle crashes is significant	-	Right-angle crashes // sample size too small //
		64%	Reduction of left-turn crashes is significant	-	Left-turn crashes // sample size too small //
	Crashes related to violations: disregarded traffic signal, exceeding lawful speed, and speed too fast for conditions.	35%	Reduction of total number of crashes is significant	-	Total number of crashes // sample size too small //
		26%	Reduction of rear-end crashes is significant	43%	Reduction of rear-end crashes is significant
		-	Right-angle crashes // sample size too small //	56%	Reduction of right-angle crashes is significant
		-	Left-turn crashes // sample size too small //	-	Left-turn crashes // sample size too small //
Each year's crash frequency: before-after	Based on all types of crashes	24%	Reduction of total number of crashes is significant	-	Reduction of total number of crashes is not significant
		20%	Reduction of rear-end crashes is significant	36%	Reduction of rear-end crashes is significant
		49%	Increase of right-angle crashes is significant	-	Increase of right-angle crashes is not significant
		63%	Reduction of left-turn crashes is significant	38%	Reduction of left-turn crashes is significant
	Crashes related to violations: disregarded traffic signal, exceeding lawful speed, and speed too fast for conditions.	34%	Reduction of total number of crashes is significant	43%	Reduction of total number of crashes is significant
		36%	Reduction of rear-end crashes is significant	50%	Reduction of rear-end crashes is significant
		50%	Reduction of right-angle crashes is significant	53%	Reduction of right-angle crashes is significant
		50%	Reduction of left-turn crashes is significant	43%	Reduction of left-turn crashes is significant

NEXT STEPS

The Phase II analysis will evaluate photo enforcement activated in the City of Scottsdale prior to 2007. Dates of camera activation, deactivation, and the removal of physical infrastructure will be considered in the analysis. Results from the Phase I and Phase II analyses will be compared to other national or local studies. Additionally, a citywide comparison of collisions based upon population and travel miles within the city for the years before and after the photo enforcement program was initiated will be conducted.