#43
MAR 05 2007

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MEMORANDUM **Public Works Department – Memo No. TE07-184**

DATE: FEBRUARY 27, 2007

TO: MAYOR & COUNCIL

THRU: W. MARK PENTZ, CITY MANAGER
DANIEL W. COOK, ACTING PUBLIC WORKS DIRECTOR
MIKE NORMAND, ACTING ASSISTANT PUBLIC WORKS DIRECTOR – TRANSPORTATION & OPERATIONS

FROM: MIKE MAH, CITY TRANSPORTATION ENGINEER

SUBJECT: Traffic Signal Clearance (Yellow and All-Red) Intervals

In response to Councilmember Caccamo's request at the Council meeting of February 22, 2007, the following is a description of the methodology used by the City in determining the length of traffic signal clearance intervals.

The City of Chandler uses standard yellow light durations recommended by the Institute of Transportation Engineers (ITE). ITE is an international educational and scientific association of transportation professionals that promotes research and public awareness of transportation issues.

This ITE formula is the most recognized methodology available and is referenced in nearly all textbooks on this subject. Staff contacted eight local jurisdictions (Tempe, Mesa, Gilbert, Phoenix, Scottsdale, Glendale, Maricopa County Department of Transportation, and Arizona Department of Transportation), and found that all use this method. The ITE method is the most commonly used method in the United States, and also recommended by the Federal Highway Administration (FHWA), the publishers of the *Manual of Uniform Traffic Control Devices* (MUTCD). A detailed description of the ITE formula is included in the Appendix.

Basic Components of the Clearance Interval

The clearance interval of our traffic signals has two parts – a yellow interval and an all-red interval – where all directions get a red light for a very brief period before the side streets turn green.

The yellow duration varies between 3 to 6 seconds depending on the speed of the approaching traffic. For a through phase, the circular yellow duration is typically 3.5 seconds for a 35 mph road and 4.5 seconds for a 45 mph road. For left-turn arrows, the yellow arrow duration is typically 3.0 to 4.0 seconds.

The all-red interval after a circular yellow varies from 1.0 to 2.5 seconds. The all-red interval after a yellow arrow is typically 1.0 second.

Increasing the Length of the Yellow Interval

We have reviewed many papers and references on this topic, and research[1] suggests that a clearance interval lower than the recommended ITE values have higher accident rates. In Chandler, all of our signals meet or exceed the clearance intervals recommended by ITE. By following this standard, we believe that the signals in Chandler are optimized for high capacity, and more importantly, a lower collision rate.

To the best of our knowledge, we have not found any studies to show that using a clearance interval even longer than the recommended value has any impact in reducing collision rates. However, if we lengthen the yellow interval by just one full second, it means one second less 'green' time available for moving traffic. This effectively reduces the capacity of an intersection by 4%. For a typical arterial road carrying 35,000 vehicles per day, we would lose a carrying capacity of 1,400 vehicles at every traffic signal that uses this longer yellow.

Fixed-Length Yellow Intervals

Some of the research papers that we have reviewed make references to cities using a standard length of yellow and all-red period. One survey[2] noted that 11% of the agencies in this country use a single value for a yellow interval. This is typically done in older parts of the country such as New York City or Chicago. In speaking with one engineer[3] who formerly worked for the City of New York, he advised that this was done more for historical reasons and not necessarily as a way to improve traffic safety.

It has been suggested that the City use a consistent value for all intersections. If the City of Chandler were to use a single and consistent value for a clearance interval, we would need to increase the length of the clearance interval at all of our **minor** signalized intersections to match the longer clearance intervals at our **major** arterial roads. If this were to take place, there is a concern that this excessively long clearance interval at the minor streets may cause drivers to become accustomed to the longer clearance and proceed through the intersection later on the yellow light[4]. This could erode the benefit of having a longer yellow interval, and exacerbate the very problem that we are trying to eliminate.

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[1] *Effect of Clearance Interval Timing on Traffic Flow and Crashes at Signalized Intersections*, Zador, Sten, Shapiro, and Tarnoff, ITE Journal, November 1985.
Reducing Red Light Running Through Longer Yellow Signal timing and Red Light Camera Enforcement: Results of a Field investigation, Retting, Ferguson, Farmer, Insurance Institute for Highway Safety, January 2007.

[2] *Traffic Signal Change Intervals*, Prof. Philip Tarnoff, Center for Advanced Transportation Technology, University of Maryland-College Park, ITE Web Seminar, January 2007.

[3] Richard Retting, Insurance Institute for Highway Safety, Arlington VA.

[4] *Influence of Traffic Signal Timing on Red-Light Running and Potential Vehicle Conflicts at Urban Intersections*, Retting and Greene, Transportation Research Record #1595.

Conclusion

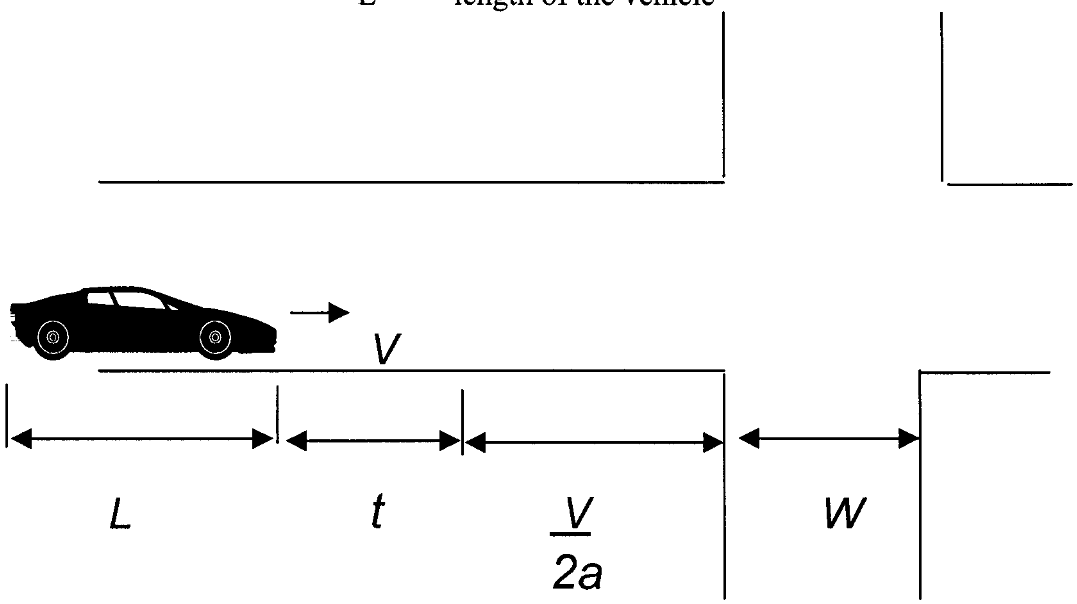
Using a recognized methodology for determining the clearance interval at traffic signals minimizes the City's liability. If the City were to deviate from a recognized standard of care, and drivers file suit against the City for use of a specialized or unique method of calculating clearance intervals, we would need evidence to show that the specialized method is equal to or better than the current accepted practice. To date, we have not found any research to show that making a yellow interval longer than recommended ITE standard provides a greater measure of safety. Additionally, as stated above, a downside to using a longer yellow is reduced intersection capacity. Staff is comfortable with the ITE method, however, should Council wish to evaluate the use of a fixed yellow interval, we would recommend bringing this matter to the Transportation Commission for further review.

Appendix

The ITE methodology is based on Newton's Laws of Motion, and described by the following formula.

$$\text{Clearance Interval} = t + \frac{V}{2a} + \frac{W+L}{V}$$

Where:
- t = perception/reaction time
- V = velocity of the approaching vehicle
- a = deceleration (braking) rate
- W = width of the intersection
- L = length of the vehicle



This formula consists of three components:

- The perception-reaction time for the driver to recognize the onset of the 'yellow',
- The time it takes to come to safe and complete stop, and
- The time it takes to clear the intersection before the side street gets a green light.

The first term is the perception reaction time, and is recommended at 1.0 second. Most healthy adults typically have a perception reaction time of between 0.25 and 0.5 seconds. This 1.0 second duration is established very conservatively to ensure that even drivers who are in poor health, or distracted by outside influences, are able to respond to the onset of the yellow light. Conservative applications of these numbers will tend to create a longer clearance interval.

The second term allows a driver to come to a safe and complete stop behind the stop bar. This value is recommended at 10 feet/second^2. Again, this is a very conservative and comfortable braking rate that can be accomplished under worst-case conditions (nearly bald tires, slick pavement, and wet conditions).

The third term is the time that it takes for the vehicle to clear the entire intersection based on the speed limit, before the side street receives a 'green' light. This will ensure that side street traffic is not permitted to move until the back end of the clearing vehicle is entirely out of the intersection.

The basic tenets of the formula is that the higher the speed limit, the 'yellow' interval is made longer to allow drivers time to respond by coming to a stop. When an intersection is widened and made larger, it takes longer to get through the intersection, and a longer 'all-red' interval is used.

In general, the first two terms typically represents the 'yellow' interval, and the third term represents the 'all-red' interval. This can vary in some specific situations where an excessively long all-red may be undesirable, causing a redistribution of the total clearance interval. However, in all cases, the total duration of the clearance interval remains constant. The length of the clearance interval is often rounded to the nearest ½ second.

cc: Pat McDermott, Assistant City Manager
Rich Dlugas, Assistant City Manager
CAPA

#43

MAR 0 5 2007

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MEMORANDUM **Police Department – Memo 2007-26**

DATE: FEBRUARY 26, 2007

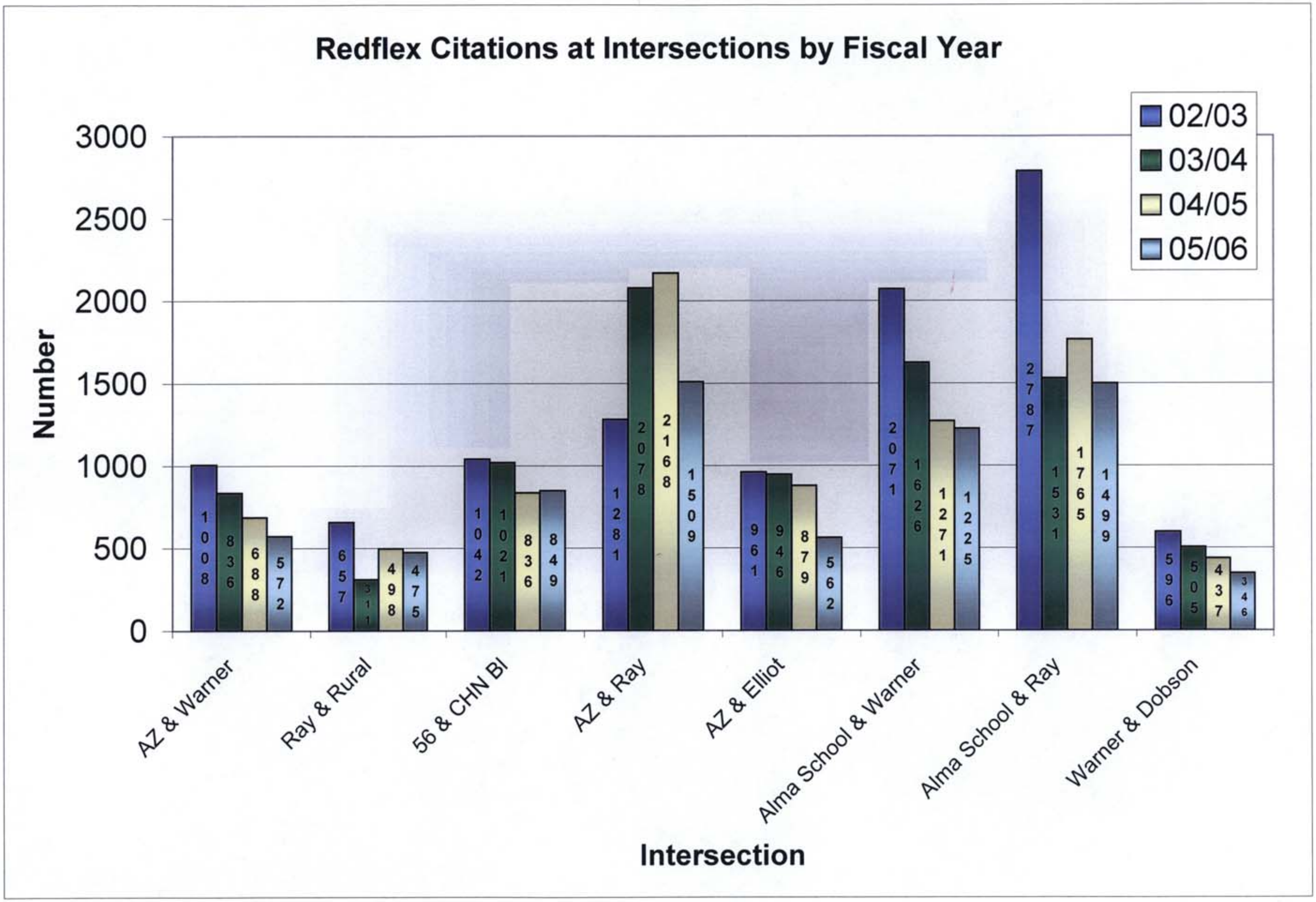
TO: MAYOR AND COUNCIL

THRU: W. MARK PENTZ, CITY MANAGER
RICH DLUGAS, ASSISTANT CITY MANAGER RD

FROM: SHERRY KIYLER, POLICE CHIEF

SUBJECT: ADDITIONAL INFORMATION REQUESTED REFERENCE PHOTO TRAFFIC ENFORCEMENT AGENDA ITEM FOR THE MARCH 5, 2007, COUNCIL MEETING.

Councilmember Weninger asked to be provided with figures relating to the number of red light citations issued per monitored intersection for each of the past four fiscal years. The information is contained in the attached graph.



Redflex Citations at Intersections by Fiscal Year
02/03
03/04
04/05
05/06
Number
3000
2500
2000
1500
1000
500
0
1008
836
688
572
657
311
498
475
1042
1021
836
849
1281
2078
2168
1509
961
946
879
562
2071
1626
1271
1225
2787
1531
1765
1499
596
505
437
346
AZ & Warner
Ray & Rural
56 & CHN Bl
AZ & Ray
AZ & Elliot
Alma School & Warner
Alma School & Ray
Warner & Dobson
Intersection

Add info #21
FEB 22 2007

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MEMORANDUM **Public Works - TE07-179**

DATE: FEBRUARY 21, 2007

TO: MAYOR & COUNCIL

THRU: W. MARK PENTZ, CITY MANAGER
DANIEL W. COOK, ACTING PUBLIC WORKS DIRECTOR
MIKE NORMAND, ACTING ASSISTANT PUBLIC WORKS DIRECTOR – TRANSPORTATION & OPERATIONS

FROM: MIKE MAH, CITY TRANSPORTATION ENGINEER

SUBJECT: Photo Enforcement – A Study of Collision Rates

In response to questions raised by Councilmember Weninger on February 20, 2007, attached is a before and after analysis of the effect of photo enforcement cameras on accidents at the eight existing red light camera locations in Chandler.

The results of this analysis indicate that total accidents decreased by 5 to 10%, and that injury accidents decreased by 22 to 42%, following the installation of the red light cameras. The results also show a substantial 32% reduction in rear-end type accidents on those approaches with red light cameras after the cameras were put into effect.

These data are based on accidents two years before and two years after the installation of the red light cameras. During this evaluation period, the traffic volumes at these intersections had increased by an average of 7%, making the improvements in the accident rate even more pronounced. The accident reduction benefited not only those approaches with the red light cameras, but all of the approaches to these intersections also resulted in reduced accident rates, and injury rates.

Detailed statistics of the above are included in the attached appendix.

Attachments

cc: Rich Dlugas

Appendix

Table 1 shows that the number of accidents on the approaches to red light cameras had dropped by 5% after the installation of the camera. When we measured the number of accidents on all four approaches to the same intersection, it shows that accidents had dropped by 10% after the installation of the camera. In comparison, the "control" intersections (i.e. those intersections nearby that have similar characteristics in terms of road geometry, land use, etc.) showed an accident increase of 15% over the same time period.

Similar but more pronounced results were obtained for 'injury' type accidents as shown in Table 2.

Table 3 shows the statistics broken down by intersection for those approaches with red light cameras. We find that most of the intersections showed a decrease in the number of accidents and injuries, with three out of the six intersections showing a statistically significant reduction. The numbers of 'Rear-End' type accidents also decreased after the cameras were installed.

Similar results were obtained for the intersection as a whole (Table 4) even though only one of the four approaches to the intersection has a red light camera. This would support the notion that the accident rate benefits of these cameras can have broader impact beyond the cameras locations themselves.

TABLE 1.
SUMMARY OF AVERAGE PERCENTAGE CHANGE IN ACCIDENT FREQUENCY
BEFORE AND AFTER RED LIGHT RUNNING CAMERA INSTALLATION

Number of Total Accidents			
	Red-light Camera Approach only	**All 4 approaches to Red Light Camera Intersections**	**Control Intersections**
Before (1998-1999)	198	518	212
After (2001-2002)	188	464	244
Average Change	-5%	-10%	15%

TABLE 2.
SUMMARY OF AVERAGE PERCENTAGE CHANGE IN INJURY SEVERITY
BEFORE AND AFTER RED LIGHT CAMERAS INSTALLATION

Number of Injury Accidents			
	Red-light Camera Approach only	**All 4 approaches to Red Light Camera Intersections**	**Control Intersections**
Before (1998-1999)	79	186	40
After (2001-2002)	62	108	74
Average Change	-22%	-42%	85%

Table 3

Camera Approaches Only

On	At		Total	Rear End Type Accidents Only	Injuries Only
Arizona	Elliott	Before	34	10	21
		After	44	14	16
Alma School	Warner	Before	31	13	9
		After	19	7	8
Alma School	Ray	Before	28	11	2
		After	17	3	3
Arizona	Warner	Before	47	14	20
		After	44	8	12
Arizona	Ray	Before	37	15	16
		After	40	7	17
Warner	Dobson	Before	21	8	11
		After	24	9	6
		Total "Before" =	198	71	79
		Total "After" =	188	48	62
		Percent Change =	-5%	-32%	-22%

Table 4

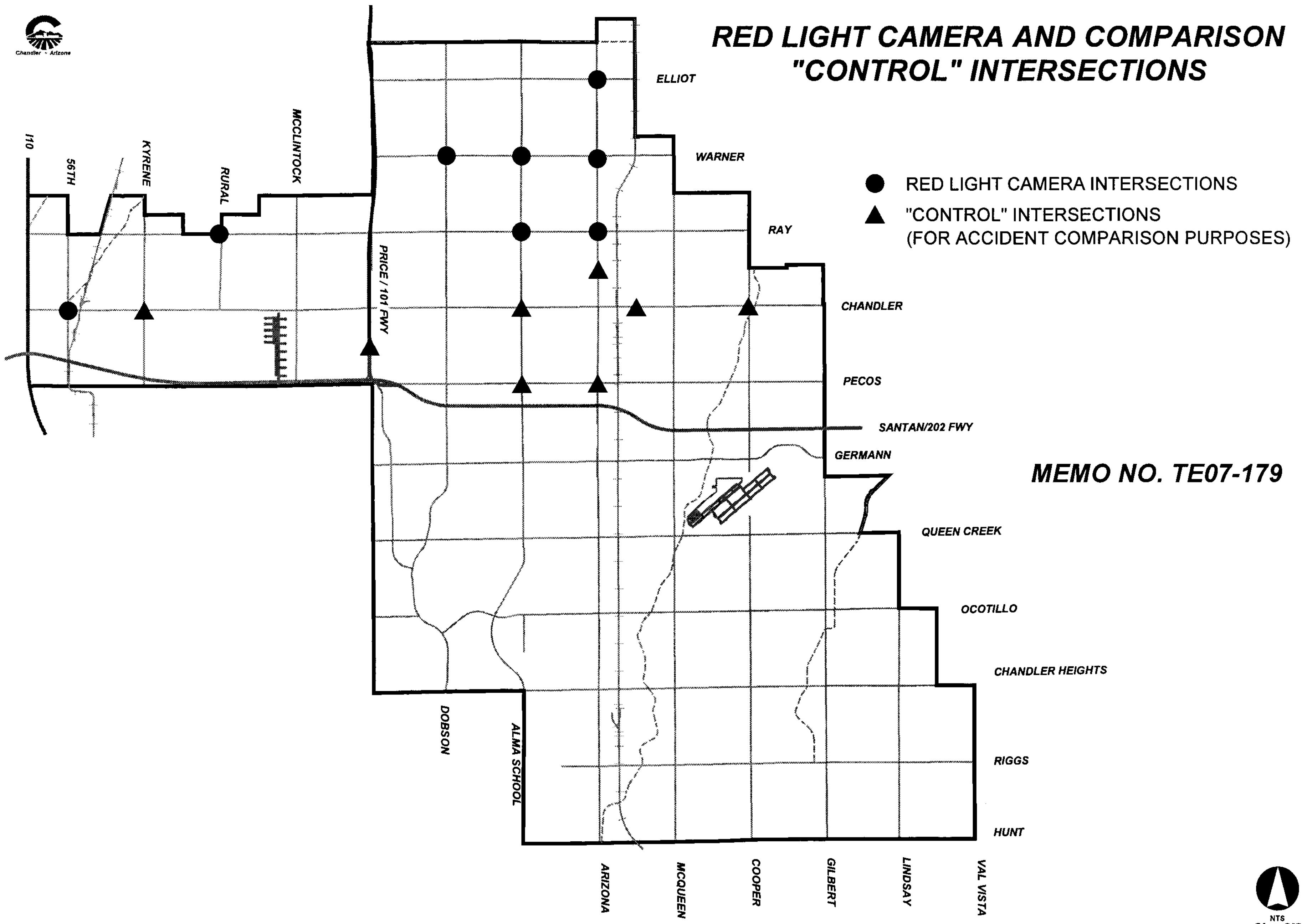
All 4 approaches at Red Light Camera Intersections

On	At		Total	Rear End Type Accidents Only	Injuries Only
Arizona	Elliott	Before	80	26	34
		After	75	28	24
Alma School	Warner	Before	88	44	30
		After	84	33	24
Alma School	Ray	Before	75	41	24
		After	65	29	12
Arizona	Warner	Before	104	57	35
		After	82	26	15
Arizona	Ray	Before	101	59	35
		After	92	31	17
Warner	Dobson	Before	70	33	28
		After	66	23	16
Ray	Rural	Before	40	Insufficient data	
		After	54		
Chandler	56th Street	Before	38	Insufficient data	
		After	29		
		Total "Before" =	596	260	186
		Total "After" =	547	170	108
		Percent Change =	-8%	-35%	-42%

NOTES:

1. Ray & Rural and Chandler & 56th Street were not analyzed because of insufficient data.
2. Before period is a 24 month total between 1998 and 1999.
3. After period is a 24 month total between 2001 and 2002

RED LIGHT CAMERA AND COMPARISON "CONTROL" INTERSECTIONS



MEMO NO. TE07-179

SKB (W:\ENGINEER\GENSERV_ArcMap_Shared\Map Requests\Traffic\TE07-179 RED LIGHT CAMERA AND COMPARISON\TE07-179.mxd) 2/21/2007

Add info #21

FEB 22 2007

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MEMORANDUM **Police Department – Memo 2007-23**

DATE: FEBRUARY 20, 2007

TO: MAYOR AND COUNCIL

THRU: W. MARK PENTZ, CITY MANAGER RD
RICH DLUGAS, ASSISTANT CITY MANAGER RD

FROM: SHERRY KIYLER, POLICE CHIEF

SUBJECT: ADDITIONAL INFORMATION REQUESTED REFERENCE AGENDA ITEM # 21 (PHOTO TRAFFIC ENFORCEMENT) FOR THE FEBRUARY 22, 2007 COUNCIL MEETING.

Councilmember Weninger asked to be provided with a list of the top twenty-five accident intersections in the city. The list is attached to this memorandum and includes the forty-three intersections that have been in the top twenty-five intersections from 2001 to 2006.

Rank	Top Accident Intersections		2001	2002	2003	2004	2005	2006	6 YR TOTAL
1	ARIZONA AV	RAY RD	98	72	77	77	84	86	494
2	ALMA SCHOOL RD	WARNER RD	81	77	87	94	88	63	490
3	CHANDLER BL	PRICE RD	70	74	76	85	69	57	431
4	ARIZONA AV	WARNER RD	69	76	66	72	77	59	419
5	ALMA SCHOOL RD	RAY RD	65	73	65	69	69	75	416
6	ALMA SCHOOL RD	CHANDLER BL	56	69	67	68	61	48	369
7	ARIZONA AV	CHANDLER BL	61	66	45	60	68	36	336
8	DOBSON RD	WARNER RD	55	58	51	55	53	51	323
9	ARIZONA AV	ELLIOT RD	59	64	51	50	42	50	316
10	DOBSON RD	RAY RD	47	63	50	47	46	62	315
11	CHANDLER BL	DOBSON RD	46	59	67	42	46	35	295
12	ALMA SCHOOL RD	ELLIOT RD	79	44	43	41	46	40	293
13	PRICE RD	RAY RD	50	48	49	46	43	47	283
14	FRYE RD	PRICE RD	32	36	42	77	42	32	261
15	DOBSON RD	ELLIOT RD	40	54	50	37	33	25	239
16	54TH ST	RAY RD	60	32	43	34	36	31	236
17	MCCLINTOCK DR	RAY RD	39	42	42	36	32	44	235
18	RAY RD	RURAL RD	54	36	38	42	33	30	233
19	ALMA SCHOOL RD	QUEEN CREEK RD	30	48	41	35	37	34	225
20	56TH ST	CHANDLER BL	30	25	33	38	28	38	192
21	CHANDLER BL	MCQUEEN RD	30	35	29	36	24	30	184
22	PRICE RD	WARNER RD	23	25	31	26	38	40	183
23	I10	RAY RD	39	46	28	27	12	22	174
24	CHANDLER BL	CORONADO ST	17	32	46	28	28	21	172
25	CHANDLER BL	KYRENE RD	23	30	39	24	20	33	169

26	CHANDLER BL	RURAL RD	39	28	27	22	22	24	162
27	KYRENE RD	RAY RD	39	19	25	26	20	30	159
28	CHANDLER BL	MCCLINTOCK DR	23	33	32	24	25	21	158
29	MCQUEEN RD	RAY RD	29	25	24	18	30	26	152
30	ALMA SCHOOL RD	SUMMIT PL	26	32	24	28	18	19	147
31	ARIZONA AV	FRYE RD	18	20	29	29	31	17	144
32	ARIZONA AV	PECOS RD	18	16	24	23	32	30	143
33	PRICE RD	QUEEN CREEK RD	18	30	22	31	27	12	140
34	MCQUEEN RD	WARNER RD	19	27	15	32	21	25	139
35	ARIZONA AV	QUEEN CREEK RD	11	16	18	35	37	15	132
36	CHANDLER BL	COOPER RD	39	17	19	16	17	21	129
37	CHANDLER BL	PENNINGSTON DR	21	14	19	31	20	14	119
38	CHANDLER BL	I10	22	38	15	11	20	12	118
39	CHANDLER BL	DELAWARE ST	11	16	29	28	22	10	116
40	ARIZONA AV	GERMANN RD	11	13	13	15	29	15	96
41	202 HWY	ALMA SCHOOL RD	0	0	0	1	21	27	49
42	ARIZONA AV	WILLIS RD	1	0	8	3	29	6	47
43	202 HWY	MCQUEEN RD	0	0	0	0	4	27	31

Red Light Camera Intersections

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PURCHASING ITEM FOR COUNCIL AGENDA

1. Agenda Item Number: 21

2. Council Meeting Date: February 22, 2006

TO: MAYOR & COUNCIL

THROUGH: CITY MANAGER

3. Date Prepared: February 7, 2007

4. Requesting Department: Police

5. SUBJECT: Award of contract PD7-918-2382 for Photo Enforcement to Redflex Traffic Systems, Inc in an estimated amount of $3,537,000.

6. RECOMMENDATION: Recommend award of contract PD7-918-2382 for Photo Enforcement to Redflex Traffic Systems, Inc in an estimated amount of $3,537,000.

7. HISTORICAL BACKGROUND/DISCUSSION In 2001 the City implemented a photo red light program, which included enforcement at four intersections. The program was expanded to eight intersections soon after implementation. During October and November of 2005, the City conducted pilot speed enforcement at three of the intersections.

Based on data collected from the current photo red light program and the pilot speed enforcement program, City staff believes expanding the photo enforcement program to include both speed enforcement and red light enforcement will increase safety on the City streets. The recommended contract will provide photo speed and photo red light enforcement at twelve intersections with provisions to expand to twenty-five intersections.

8. EVALUATION PROCESS: In October of 2006 the City issued Request For Proposal (RFP) PD7-918-2382 for Photo Enforcement. The RFP was advertised, all registered vendors were notified and additional copies were sent to known providers of the requested service. Proposals were due November 30, 2006. The City Received proposals from Redflex Traffic Systems, Inc., American Traffic Solutions, and Nestor Traffic Systems.

An evaluation committee, including representatives from Police, Courts, Traffic, Purchasing and a citizen evaluated the responses received. The evaluation committee recommends award to Redflex Traffic Systems based on the evaluation criteria set forth in the RFP. Some of the Key reasons for the committee's recommendation include; Redflex offered lowest cost per actionable activation, Redflex offered a 1% prompt Payment discount, Redflex provided references that had been customers for several years, Redflex provided a comprehensive public relations program. Redflex is the City's current provider of photo red light enforcement and has provided excellent service.

The requested contract will have a three-year term and have provisions to extend for two additional 3-year terms. The estimated amount is for the first three-year term.

9. FINANCIAL IMPLICATIONS: Funds for the requested service will come from General Fund, Non-Departmental, Photo Red Light (101.1290.0000.5263). A transfer appropriation from General Fund Non-Departmental Contingency (101.1290.0000.5911) in the amount of $182,000 will be used for the remainder of FY 06/07 and will be offset by revenue generated by this contract.

10. PROPOSED MOTION: Move to award contract PD7-918-2382 for Photo Enforcement to Redflex Traffic Systems, Inc in an estimated amount of $3,537,000 and transfer appropriation from General Fund Non-Departmental Contingency (101.1290.0000.5911) in the amount of $182,000.

APPROVALS	
11. Requesting Department Matthew Christensen, Police Commander	**12. Department Head** Sherry Kiyler, Police Chief
13. Buyer/Contract Admin. Mike Mandt	**14. City Manager** W. Mark Pentz

CITY OF CHANDLER SERVICES AGREEMENT
NAME OF CONTRACT Photo Enforcement (red light and speed)

CONTRACT NO.: PD7-918-2382

THIS AGREEMENT is made and entered into this day of , 200 , by and between the CITY of Chandler, a Municipal Corporation of the State of Arizona, hereinafter referred to as "CITY", and Redflex Traffic Systems, Inc a Delaware Corporation, hereinafter referred to as "CONTRACTOR".

WHEREAS, CONTRACTOR represents that CONTRACTOR has the expertise and is qualified to perform the services described in the Agreement.

NOW THEREFORE, in consideration of the mutual promises and obligations set forth herein, the parties hereto agree as follows:

1. CONTRACT ADMINISTRATOR:

1.1. Contract Administrator. CONTRACTOR shall act under the authority and approval of the Police Chief /designee (Contract Administrator), to provide the services required by this Agreement.

1.2. **Key Staff.** This Contract has been awarded to CONTRACTOR based partially on the key personnel proposed to perform the services required herein. CONTRACTOR shall not change nor substitute any of these key staff for work on this Contract without prior written approval by CITY.

1.3. **Subcontractors.** During the performance of the Agreement, CONTRACTOR may engage such additional SUBCONTRACTORS as may be required for the timely completion of this Agreement. In the event of subcontracting, the sole responsibility for fulfillment of all terms and conditions of this Agreement rests with CONTRACTOR.

2. SCOPE OF WORK: CONTRACTOR shall provide Photo enforcement (red light and speed) services all as more specifically set forth in the Scope of Work, labeled Exhibit A, attached hereto and made a part hereof by reference and as set forth in the Specifications and details included therein.

2.1. **Non-Discrimination**. The CONTRACTOR shall comply with State Executive Order No. 99-4 and all other applicable CITY, State and Federal laws, rules and regulations, including the Americans with Disabilities Act.

2.2. **Licenses**. CONTRACTOR shall maintain in current status all Federal, State and local licenses and permits required for the operation of the business conducted by the CONTRACTOR as applicable to this contract.

2.3. **Advertising, Publishing and Promotion of Contract**. The CONTRACTOR shall not use, advertise or promote information for commercial benefit concerning this Contract without the prior written approval of the CITY.

2.4. **Compliance With Applicable Laws**. CONTRACTOR shall comply with all applicable Federal, state and local laws.

3. ACCEPTANCE AND DOCUMENTATION: Each task shall be reviewed and approved by the Contract Administrator to determine acceptable completion.

3.1. **Records**. The CONTRACTOR shall retain and shall contractually require each SUBCONTRACTOR to retain all data and other "records" relating to the acquisition and performance of the Contract for a period of five years after the completion of the Contract.

3.2. **Audit.** At any time during the term of this Contract and five (5) years thereafter, the CONTRACTOR'S or any SUBCONTRACTOR'S books and records shall be subject to audit by the CITY to the extent that the books and records relate to the performance of the Contract or Subcontract. Upon request, the CONTRACTOR shall produce a legible copy of any or all such records.

4. PRICE: CITY shall pay to CONTRACTOR $19.00 per Actionable Activation for the completion of all the work and services described herein, which sum shall include all costs or expenses incurred by CONTRACTOR, payable as set forth herein.

4.1. **Taxes.** CONTRACTOR shall be solely responsible for any and all tax obligations, which may result out of the CONTRACTOR'S performance of this Agreement. The CITY shall have no obligation to pay any amounts for taxes, of any type, incurred by the CONTRACTOR.

4.2. **Tax Credits or Exemptions.** When equipment, materials or supplies generally taxable to CONTRACTOR are eligible for a tax exemption due to the nature of the work, CONTRACTOR shall assist the CITY in applying for and obtaining such tax credits and exemptions which shall be paid or credited to the CITY.

4.3. **Payment.** Payment to the Contractor for service provided shall be made for all Actionable Activations occurring the previous 30 days. An Actionable Activation is an activation where the images of the driver and license plate are identifiable for court purposes and the driver's gender/age matches the registered owner's or the nomination protocol for rental or business owned vehicles has produced a person who's gender/age matches the image. All instances where the gender/age of the registered owner and the driver appear to match will be considered actionable even if this is later shown to be false. The City will not be responsible for payment to the Contractor for any image, which is determined by the Contract Administrator to not be an Actionable Activation. The CITY will pay the contractor monthly within 30 days of the end of the month. Payment will be based on the number of Actionable Activations as determined by the Contract Administrator. Payment per Actionable Activation will be the only compensation the Contractor will receive from the CITY for services provided under this contract. There is no guarantee regarding the actual number of Actionable Activations. The Contractor will be responsible for all expenses relating to providing service under this contract including but not limited to photo enforcement systems, system installation, system maintenance, system operation, supplies, labor, overhead, printing, programming, mailing, and process service. CITY will reimburse CONTRACTOR the amount collected from defendant for process service.

4.4. **Prompt Payment Discount**. A prompt payment discount will be applied to all invoices paid by CITY within 30 days.

5. TERM: This contract will commence on the date of contract signing and continue for three (3) years from completion of the installation of Contractor's system at the sixth (6^{th}) intersection unless sooner terminated in accordance with the provisions herein. CITY reserves the right, by mutual agreement, to extend the Contract for up to two (2) additional terms of three (3) years each.

6. USE OF THIS CONTRACT:

6.1. **Cooperative Use of Contract.** In addition to the CITY of Chandler and with approval of the CONTRACTOR, this Contract may be extended for use by other municipalities, school districts and government agencies of the State. A current listing of eligible entities may be found at www.maricopa.gov/materials and then click on 'Contracts', 'S.A.V.E.' listing and 'ICPA'. Any such usage by other entities must be in accordance with the ordinance, charter and/or procurement rules and regulations of the respective political entity.

7. CITY'S CONTRACTUAL REMEDIES:

7.1. **Right to Assurance.** If the CITY in good faith has reason to believe that the CONTRACTOR does not intend to, or is unable to perform or continue performing under this Contract, the Contract Administrator may demand in writing that the CONTRACTOR give a written assurance of intent to perform. Failure by the CONTRACTOR to provide written assurance within the number of Days specified in the demand may, at the CITY's option, be the basis for terminating the Contract in addition to any other rights and remedies provided by law or this Contract.

7.2. **Stop Work Order.** The CITY may, at any time, by written order to the CONTRACTOR, require the CONTRACTOR to stop all or any part, of the work called for by this Contract for period(s) of days indicated by the CITY after the order is delivered to the CONTRACTOR. The order shall be specifically identified as a stop work order issued under this clause. Upon receipt of the order, the CONTRACTOR shall immediately comply with its terms and take all reasonable steps to minimize the incurrence of costs allocable to the work covered by the order during the period of work stoppage.

7.2.1 If a stop work order issued under this clause is canceled or the period of the order or any extension expires, the CONTRACTOR shall resume work. The Contract Administrator shall make an equitable adjustment in the delivery schedule or Contract price, or both, and the Contract shall be amended in writing accordingly.

7.3. **Non-exclusive Remedies.** The rights and the remedies of the CITY under this Contract are not exclusive.

7.4. **Nonconforming Tender.** Services and materials supplied under this Contract shall fully comply with Contract requirements and specifications. Services or materials that do not fully comply constitute a breach of contract.

7.5. **Right of Offset.** The CITY shall be entitled to offset against any sums due CONTRACTOR, any expenses or costs incurred by the CITY, or damages assessed by the CITY concerning the CONTRACTOR'S non-conforming performance or failure to perform the Contract, including expenses to complete the work and other costs and damages incurred by CITY.

8. TERMINATION:

8.1. **Termination for Convenience.** CITY reserves the right to terminate this Agreement or any part thereof for its sole convenience with thirty (30) days written notice. In the event of such termination, CONTRACTOR shall immediately stop all work hereunder, and shall immediately cause any of its suppliers and SUBCONTRACTORS to cease such work. As compensation in full for services performed to the date of such termination, the CONTRACTOR shall receive a fee for the percentage of services actually performed. This fee shall be in the amount to be mutually agreed upon by the CONTRACTOR and CITY, based on the agreed Scope of Work. If there is no mutual agreement, the **Management Services Director** shall determine the percentage of work performed for each task detailed in the Scope of Work and the CONTRACTOR'S compensation shall be based upon such determination and CONTRACTOR'S fee schedule included herein.

8.2. **Termination for Cause.** CITY may, upon written notice, terminate this Agreement for CONTRACTOR'S failure to comply with the terms of this Agreement.

8.3. **Cancellation for Conflict of Interest.** Pursuant to A.R.S. § 38-511, CITY may cancel this Contract within three (3) years after Contract execution without penalty or further obligation if any person significantly involved in initiating, negotiating, securing, drafting or creating the Contract on behalf of the City is or becomes at any time while this Contract or an extension of this Contract is in effect, an employee of or a consultant to any other party to this Contract. The cancellation shall be effective when the CONTRACTOR receives written notice of the cancellation unless the notice specifies a later time.

8.4. **Gratuities.** CITY may, by written notice, terminate this Contract, in whole or in part, if CITY determines that employment or a Gratuity was offered or made by CONTRACTOR or a representative of

CONTRACTOR to any officer or employee of CITY for the purpose of influencing the outcome of the procurement or securing this Contract, an amendment to this Contract, or favorable treatment concerning this Contract, including the making of any determination or decision about contract performance. The CITY, in addition to any other rights or remedies, shall be entitled to recover exemplary damages in the amount of three times the value of the Gratuity offered by CONTRACTOR.

8.5. **Suspension or Debarment.** CITY may, by written notice to the CONTRACTOR, immediately terminate this Contract if CITY determines that CONTRACTOR has been debarred, suspended or otherwise lawfully prohibited from participating in any public procurement activity, including but not limited to, being disapproved as a SUBCONTRACTOR of any public procurement unit or other governmental body. Submittal of an offer or execution of a contract shall attest that the CONTRACTOR is not currently suspended or debarred. If CONTRACTOR becomes suspended or debarred, CONTRACTOR shall immediately notify CITY.

8.6. **Continuation of Performance Through Termination.** The CONTRACTOR shall continue to perform, in accordance with the requirements of the Contract, up to the date of termination, as directed in the termination notice.

8.7. **No Waiver.** Either party's failure to insist on strict performance of any term or condition of the Contract shall not be deemed a waiver of that term or condition even if the party accepting or acquiescing in the nonconforming performance knows of the nature of the performance and fails to object to it.

9. FORCE MAJEURE: Neither party shall be responsible for delays or failures in performance resulting from acts beyond their control. Such acts shall include, but not be limited to, acts of God, riots, acts of war, epidemics, governmental regulations imposed after the fact, fire, communication line failures, power failures, or earthquakes.

10. ALTERNATE DISPUTE RESOLUTION: Notwithstanding anything to the contrary provided elsewhere in the Contract documents, the alternate dispute resolution (ADR) process provided herein shall be the exclusive means for resolution of claims or disputes and other matters in question between the City and the CONTRACTOR arising out of, or relating to the Contract documents, interpretation of the Contract, or the performance of or the breach by any party thereto, including but not limited to, original claims or disputes asserted as cross claims, counterclaims, third party claims or claims for indemnity or subrogation, in any threatened or ongoing litigation or arbitration with third parties, if such disputes involve parties to contracts containing this ADR provision.

10.1. **Notice.** CONTRACTOR shall submit written notice of any claim or dispute to the Contract Administrator within thirty (30) days of the occurrence, event or disputed response from CITY for immediate resolution pursuant to these provisions. Each claim or dispute shall be submitted and resolved as it occurs and not postponed until the end of the Contract nor lumped together with other pending claims.

10.2. **Forfeiture.** Failure to submit a notice of any claim, dispute, or other issue within such thirty (30) days shall constitute CONTRACTOR'S forfeiture of its right to dispute the issue, raise the claim or make the request and shall also constitute CONTRACTOR'S agreement and acceptance of the CITY'S position.

10.3. **CITY Response.** The Contract Administrator will provide to CONTRACTOR a written response to any claim, request for clarification or dispute on or before thirty (30) days from receipt of CONTRACTOR'S written claim.

10.4. **Appeal.** If CONTRACTOR disagrees with the response of the Contract Administrator, within fifteen days of the date of the response by the Contract Administrator, CONTRACTOR shall file with the Contract Administrator, written notice of appeal. The Contract Administrator shall provide copies of all relevant information concerning the Contract and claim or dispute to the Assistant Management Services Director who will determine the appeal. The Assistant Management Services Director may request additional information from either party, may hold an informal informational hearing or may make the determination based on the information provided. The Assistant Management Services Director shall make a final determination of the appeal and provide written notice to CONTRACTOR within sixty (60) days from the date of CONTRACTOR'S written notice of appeal.

10.5. **Arbitration.** If CONTRACTOR is not satisfied with the determination of the Assistant Management Services Director, the following binding arbitration procedure shall serve as the exclusive method to resolve all unresolved disputes. If CONTRACTOR chooses not to accept the decision of the Assistant Management Services Director, CONTRACTOR shall notify the Contract Administrator in writing within ten (10) business days of receipt of the Assistant Management Services Director's decision of a request for arbitration. The CONTRACTOR shall post a cash bond with the Arbitrator in the amount of $5,000, or a greater amount as determined by the Arbitrator, that will defray the cost of the arbitration as set forth in paragraph M, Fees and Costs, and proceeds from said bond shall be allocated in accordance with said paragraph by the Arbitrator.

A. **Arbitration Panel:** The Arbitration Panel shall consist of the arbitrators selected by the parties involved in the dispute, (i.e., CITY will select one arbitrator, CONTRACTOR will select one arbitrator, and any other CONTRACTOR who has a contract with the CITY which contains this ADR provision and is a party to the same dispute will also select an arbitrator), and the foregoing arbitrators shall select a neutral Arbitrator who will hear the matter and make a final determination, as set forth herein.

B. **Expedited Hearing:** The parties have structured this procedure with the goal of providing for the prompt and efficient resolution of all disputes falling within the purview of this ADR process. To that end, any party can petition the Arbitrator to set an expedited hearing if circumstances justify it. The Arbitrator shall contact the parties and schedule the arbitration at the earliest possible date. In any event, the hearing of any dispute not expedited will commence as soon as practical, but in no event later than sixty (60) days after notification of request for arbitration having been submitted. This deadline can be extended only with the consent of all the parties to the dispute, or by decision of the Arbitrator upon a showing of emergency circumstances.

C. **Procedure:** The Arbitrator shall conduct the hearing that will resolve disputes in a prompt, cost efficient manner giving due regard to the rights of all parties. Each party shall supply to the Arbitrator a written pre-hearing statement, which shall contain a brief statement of the nature of the claim or defense, a list of witnesses and exhibits, a brief description of the subject matter of the testimony of each witness who will be called to testify, and an estimate as to the length of time that will be required for the arbitration hearing. The Arbitrator shall determine the nature and scope of discovery, if any, and the manner of presentation of relevant evidence consistent with the deadlines provided herein, and the parties' objective that disputes be resolved in a prompt and efficient manner. No discovery may be had of privileged materials or information. The Arbitrator, upon proper application, shall issue such orders as may be necessary and permissible under law to protect confidential, proprietary, or sensitive materials or information from public disclosure or other misuse. Any party may make application to the Maricopa County Superior Court to have a protective order entered as may be appropriate to conform to such orders of the Arbitrator.

D. **Hearing Days:** To effectuate the parties' goals, the hearing once commenced, will proceed from business day to business day until concluded, absent a showing of emergency circumstances.

E. **Award:** The Arbitrator shall within ten (10) days from the conclusion of any hearing issue its award. The award shall include an allocation of fees and costs pursuant to the Binding Arbitration Procedure paragraph herein. Any award providing for deferred payment shall include interest at the rate of ten (10%) percent per annum. The award is to be rendered in accordance with the Contract and the laws of the State of Arizona.

F. **Scope of Award:** The Arbitrator shall be without authority to award punitive damages, and any such punitive damage award shall be void. The Arbitrator shall also be without authority to issue an award against any individual party in excess of $500,000, exclusive of interest, arbitration fees, costs, and attorney's fees. If an award is made against any individual party in excess of $50,000, exclusive of interest, arbitration fees, costs and attorneys' fees, it must be supported by written findings of fact, conclusions of law and statement as to how damages were calculated.

G. **Jurisdiction:** The Arbitrator shall not be bound for jurisdictional purposes by the amount asserted in any party's claim, but shall conduct a preliminary hearing into the question of jurisdiction upon application of any party at the earliest convenient time, but not later than the commencement of the arbitration hearing.

H. **Entry of Judgment:** Any party can make application to the Maricopa County Superior Court for confirmation of any award and for entry of judgment on it.

I. **Severance and Joinder:** To reduce the possibility of inconsistent adjudications, the Arbitrator, may at the request of any party, join and/or sever parties, and/or claims arising under other contracts containing this ADR provision, and the Arbitrator may, on his own authority, join or sever parties and/or claims subject to this ADR process as they deem necessary for a just resolution of the dispute, consistent with the parties' goal of the prompt and efficient resolution of disputes. Nothing herein shall create the right by any party to assert claims against another party not recognized under the substantive law applicable to the dispute. The Arbitrator is not authorized to join to the proceeding parties not in privity with the CITY.

J. **Appeal:** Any party may appeal errors of law by the Arbitrator if, but only if, the errors arise in an award in excess of $100,000; the exercise by the Arbitrator of any powers contrary to or inconsistent with the Contract; or any of the grounds provided in A.R.S. 12-1512. Appeals shall be to the Maricopa County Superior Court within fifteen (15) days of entry of the award. The standard of review in such cases shall be that applicable to the consideration of a motion for judgment notwithstanding the verdict, and the Maricopa County Superior Court shall have the authority to confirm, vacate, modify or remand an award appealed under this section.

K. **Uniform Arbitration Act:** Except as otherwise provided herein, binding arbitration pursued under this provision shall be governed by the Uniform Arbitration Act as enacted in Arizona in A.R.S. I2-1501, et. seq.

L. **Fees and Costs:** Each party shall bear its own fees and costs in connection with any informal hearing before the Assistant Management Services Director. All fees and costs associated with any arbitration before the Arbitrator, including without limitation, the Arbitrator's fees, the prevailing party's attorneys' fees, expert witness fees and costs, will be paid by the nonprevailing party, except as provided for herein. The determination of prevailing and nonprevailing parties, and the appropriate allocation of fees and costs, will be included in the award by the Arbitrator.

M. **Equitable Litigation:** Notwithstanding any other provision of ADR to the contrary, any party may petition the Maricopa County Superior Court for interim equitable relief as necessary to preserve the status quo and prevent immediate and irreparable harm to a party or to ongoing work pending resolution of a dispute pursuant to ADR provided for herein. No court may order any permanent injunctive relief except as may be necessary to enforce an order or award entered by the Arbitrator. The fees and costs incurred in connection with any such equitable proceeding shall be determined and assessed in ADR.

11. INDEMNIFICATION: To the fullest extent permitted by law, CONTRACTOR shall defend, indemnify and hold harmless the City of Chandler, its Mayor and Council, appointed boards and commissions, officials, officers, employees individually and collectively; from and against all losses, claims, suits, actions, payments and judgments, demands, expenses, damages, including consequential damages and loss of productivity, attorney's fees, defense costs, or actions of any kind and nature relating to, arising out of, or alleged to have resulted from CONTRACTOR'S work or services. CONTRACTOR'S duty to defend, hold harmless and indemnify the City of Chandler, its Mayor and Council, appointed boards and commissions, officials, officers, employees shall arise in connection with any claim or amounts arising or recovered under Worker Compensation Laws, damage, loss or expenses relating to, arising out of or alleged to have resulted from any acts, errors, mistakes, omissions, work or services in the performance of this Contract including any employee of CONTRACTOR, anyone directly or indirectly employed by them or anyone for whose acts CONTRACTOR may be liable, regardless of whether it is caused in part by a party indemnified hereunder, including the City of Chandler. IT IS THE INTENTION OF THE PARTIES to this contract that the City of Chandler, its Mayor and Council, appointed boards and commissions, officials, officers, employees, individually and collectively, are to be indemnified against their own negligence unless and except their negligence is found to be the sole cause of the injury to persons or damages to property. The amount and type of insurance coverage requirements set forth herein will in no way be construed as limiting the scope of the indemnity in this paragraph.

12. INSURANCE:

12.1. **Insurance Representations and Requirements:**

A. CONTRACTOR, at its own expense, shall purchase and maintain insurance of the types and amounts required in this section, with companies possessing a current A.M. Best, Inc. rating of B++6, or better and legally authorized to do business in the State of Arizona with policies and forms satisfactory to CITY.

B. Policies written on a "Claims made" basis are not acceptable without written permission from the City's Risk Manager.

C. All insurance required herein shall be maintained in full force and effect until all work or services required to be performed under the terms of this Agreement is satisfactorily completed and formally accepted. Failure to do so may, at the sole discretion of CITY, constitute a material breach of this Agreement and may result in termination of this contract.

D. If any of the insurance policies are not renewed prior to expiration, payments to the CONTRACTOR may be withheld until these requirements have been met, or at the option of the City, the City may pay the Renewal Premium and withhold such payments from any monies due the CONTRACTOR.

E. All insurance policies, except Workers' Compensation required by this Agreement, and self-insured retention or deductible portions, shall name, to the fullest extent permitted by law for claims arising out of the performance of this contract, the City of Chandler, its agents, representatives, officers, directors, officials and employees as Additional Insureds.

F. CONTRACTOR'S insurance shall be primary insurance over any insurance available to the CITY and as to any claims resulting from this contract, it being the intention of the parties that the insurance policies so effected shall protect both parties and be primary coverage for any and all losses covered by the described insurance.

G. The insurance policies, except Workers' Compensation, shall contain a waiver of transfer rights of recovery (subrogation) against CITY, its agents, representatives, officers, directors, officials and employees for any claims arising out of CONTRACTOR'S acts, errors, mistakes, omissions, work or service.

H. The insurance policies may provide coverage, which contain deductibles or self-insured retentions. Such deductible and/or self-insured retentions shall be assumed by and be for the account of, and at the sole risk of CONTRACTOR. CONTRACTOR shall be solely responsible for the deductible and/or self-insured retention. The amounts of any self-insured retentions shall be noted on the Certificate of Insurance. CITY, at its option, may require CONTRACTOR to secure payment of such deductibles or self-insured retentions by a Surety Bond or an irrevocable and unconditional letter of credit. Self-insured retentions (SIR) in excess of $25,000 will only be accepted with the permission of the Management Services Director/Designee.

I. All policies and certificates shall contain an endorsement providing that the coverage afforded under such policies shall not be reduced, canceled or allowed to expire until at least thirty (30) days prior written notice has been given to CITY.

J. Information concerning reduction of coverage on account of revised limits or claims paid under the General Aggregate, or both, shall be furnished by the CONTRACTOR with reasonable promptness in accordance with the CONTRACTOR'S information and belief.

K. In the event that claims in excess of the insured amounts provided herein, are filed by reason of any operations under this contract, the amount of excess of such claims, or any portion thereof, may be withheld from payment due or to become due the CONTRACTOR until such time as the CONTRACTOR shall furnish such additional security covering such claims as may be determined by the CITY.

12.2. **Proof of Insurance – Certificates of Insurance**

A. Prior to commencing work or services under this Agreement, CONTRACTOR shall furnish to CITY Certificates of Insurance, issued by CONTRACTOR'S insurer(s), as evidence that policies providing the required coverages, conditions and limits required by this Agreement are in full force and effect and obtain from the City's Risk Management Division approval of such Certificates.

B. If a policy does expire during the life of this Agreement, a renewal certificate must be sent to the City of Chandler five (5) days prior to the expiration date.

C. All Certificates of Insurance shall identify the policies in effect on behalf of CONTRACTOR, their policy period(s), and limits of liability. Each Certificate shall include the job site and project number and title. Coverage shown on the Certificate of Insurance must coincide with the requirements in the text of the contract documents. Information required to be on the certificate of Insurance may be typed on the reverse of the Certificate and countersigned by an authorized representative of the insurance company.

D. REQUIRED CITY reserves the right to request and to receive, within 10 working days, certified copies of any or all of the herein required insurance policies and/or endorsements. CITY shall not be obligated, however, to review same or to advise CONTRACTOR of any deficiencies in such policies and endorsements, and such receipt shall not relieve CONTRACTOR from, or be deemed a waiver of CITY'S right to insist on, strict fulfillment of CONTRACTOR'S obligations under this Agreement.

12.3. **Coverage**

A. Such insurance shall protect CONTRACTOR from claims set forth below which may arise out of or result from the operations of CONTRACTOR under this Contract and for which CONTRACTOR may be legally liable, whether such operations be by the CONTRACTOR or by a SUBCONTRACTOR by anyone directly or indirectly employed by any of them, or by anyone for whose acts any of them may be liable. Coverage under the policy will be at least as broad as Insurance Services Office, Inc., policy form CG00011093 or equivalent thereof, including but not limited to severability of interest and waiver of subrogation clauses.

B. Claims under workers' compensation, disability benefit and other similar employee benefit acts which are applicable to the Work to be performed;

C. Claims for damages because of bodily injury, occupational sickness or disease, or death of the CONTRACTOR'S employees;

D. Claims for damages because of bodily injury, sickness or disease, or death of any person other than the CONTRACTOR'S employees;

E. Claims for damages insured by usual personal injury liability coverage;

F. Claims for damages, other than to Work itself, because of injury to or destruction of tangible property, including loss of use resulting therefrom;

G. Claims for damages because of bodily injury, death of a person or property damage arising out of ownership, maintenance or use of a motor vehicle; Coverage will be at least as broad as Insurance Service Office, Inc., coverage Code "I" "any auto" policy form CA00011293 or equivalent thereof.

H. Claims for bodily injury or property damage arising out of completed operations;

I. Claims involving contractual liability insurance applicable to the CONTRACTOR'S obligations under the Indemnification Agreement;

J. Claims for injury or damages in connection with one's professional services;

K. Claims involving construction projects while they are in progress. Such insurance shall include coverage for loading and off loading hazards. If any hazardous material, as defined by any local, state or federal authorities are to be transported, MCS 90 endorsement shall be included.

12.4. **Commercial General Liability - Minimum Coverage Limits.**

The Commercial General Liability insurance required herein shall be written for not less than $500,000 limits of liability or ten percent (10%) of the Contract Price, whichever coverage is greater. Any combination between general liability and excess general liability alone amounting to a minimum of $1,000,000 per occurrence (or 10% per occurrence) and an aggregate of $2,000,000 (or 20% whichever is greater) in coverage will be acceptable. The Commercial General Liability additional insured endorsement shall be as broad as the Insurance Services, Inc's (ISO) Additional Insured, Form B, CG 20101001, and shall include coverage for CONTRACTOR'S operations and products, and completed operations.

12.5. **General Liability - Minimum Coverage Limits**

The General Liability insurance required herein, including, Comprehensive Form, Premises-Operations, Explosion and Collapse, Underground Hazard, Products/Completed Operations, Contractual Insurance, Broad Form Property Damage, Independent CONTRACTORS, and Personal Injury shall be written for Bodily Injury and Property Damage Combined shall be written for not less than $1,000,000 or 10% of the contract cost and with a $2,000,000 aggregate.

12.6. **Automobile Liability**

CONTRACTOR shall maintain Commercial/Business Automobile Liability insurance with a combined single limit for bodily injury and property damage of not less than $1,000,000 each occurrence with respect to any owned, hired, and non-owned vehicles assigned to or used in performance of the CONTRACTOR'S work. Coverage shall be at least as broad as coverage code 1, "any auto", (Insurance Service Office, Inc. Policy Form CA 00011293, or any replacements thereof).

Worker's Compensation and Employer's Liability

CONTRACTOR shall maintain Workers' Compensation insurance to cover obligations imposed by federal and state statutes having jurisdiction over CONTRACTOR'S employees engaged in the performance of the work or services; and, Employer's Liability insurance of not less than $1,000,000 for each accident, $ 1,000,000 disease coverage for each employee, and $1,000,000 disease policy limit.

In case any work is subcontracted, CONTRACTOR will require the SUBCONTRACTOR to provide Workers' Compensation and Employer's Liability to at least the same extent as required of CONTRACTOR.

13. NOTICES: All notices or demands required to be given pursuant to the terms of this Agreement shall be given to the other party in writing, delivered by hand or registered or certified mail, at the addresses set forth below, or to such other address as the parties may substitute by written notice given in the manner prescribed in this paragraph.

In the case of the CITY		In the case of the CONTRACTOR	
Contract Administrator:	Police Commander	Firm Name:	Redflex Traffic Systems, Inc.
Contact:	Matt Christensen	Contact:	Karen Finley President/CEO
Mailing Address:	Mail Stop 303W PO Box 4008	Address:	15020 N 74th Street
Physical Address:	251 North Desert Breeze Blvd West	City, State, Zip	Scottsdale, AZ 85260
City, State, Zip	Chandler, AZ 85044	Phone:	480-607-0705
Phone:	480-782-4840	FAX:	480-607-0752
FAX:	480-782-4880		

Notices shall be deemed received on date delivered, if delivered by hand, and on the delivery date indicated on receipt if delivered by certified or registered mail.

14. CONFLICT OF INTEREST:

14.1. **No Kickback.** CONTRACTOR warrants that no person has been employed or retained to solicit or secure this Agreement upon an agreement or understanding for a commission, percentage, brokerage or contingent fee; and that no member of the City Council or any employee of the CITY has any interest, financially or otherwise, in the firm unless this interest has been declared pursuant to the provisions of A.R.S. Section 38-501. Any such interests were disclosed in CONTRACTOR'S proposal to the CITY.

14.2. **Kickback Termination.** CITY may cancel any contract or agreement, without penalty or obligation, if any person significantly involved in initiating, negotiating, securing, drafting or creating the agreement on behalf of the CITY is, at any time while the Agreement or any extension of the Agreement is in effect, an employee of any other party to the Agreement in any capacity or a CONTRACTOR to any other party to the Agreement with respect to the subject matter of the Agreement. The cancellation shall be effective when written notice from CITY is received by all other parties, unless the notice specifies a later time (A.R.S. §38-511).

14.3. **No Conflict:** CONTRACTOR stipulates that its officers and employees do not now have a conflict of interest and it further agrees for itself, its officers and its employees that it will not contract for or accept employment for the performance of any work or services with any individual business, corporation or government unit that would create a conflict of interest in the performance of its obligations pursuant to this project.

15. GENERAL TERMS:

15.1. **Entire Agreement.** This Agreement, including Exhibits A and B attached hereto, constitutes the entire understanding of the parties and supersedes all previous representations, written or oral, with respect to the services specified herein. This Agreement may not be modified or amended except by a written document, signed by authorized representatives or each party.

15.2. **Arizona Law.** This Agreement shall be governed and interpreted according to the laws of the State of Arizona.

15.3. **Assignment:** Services covered by this Agreement shall not be assigned in whole or in part without the prior written consent of the CITY.

15.4. **Amendments.** The Contract may be modified only through a written Contract Amendment executed by authorized persons for both parties. Changes to the Contract, including the addition of work or materials, the revision of payment terms, or the substitution of work or materials, directed by a person who is not specifically authorized by the City in writing or made unilaterally by the CONTRACTOR are violations of the Contract. Any such changes, including unauthorized written Contract Amendments shall be void and without effect, and the CONTRACTOR shall not be entitled to any claim under this Contract based on such changes.

15.5. **Independent CONTRACTOR.** The CONTRACTOR under this Contract is an independent CONTRACTOR. Neither party to this Contract shall be deemed to be the employee or agent of the other party to the Contract.

15.6. **No Parole Evidence.** This Contract is intended by the parties as a final and complete expression of their agreement. No course of prior dealings between the parties and no usage of the trade shall supplement or explain any terms used in this document and no other understanding either oral or in writing shall be binding.

15.7. **Authority:** Each party hereby warrants and represents that it has full power and authority to enter into and perform this Agreement, and that the person signing on behalf of each has been properly authorized and empowered to enter this Agreement. Each party further acknowledges that it has read this Agreement, understands it, and agrees to be bound by it.

IN WITNESS WHEREOF, the parties have hereunto subscribed their names to this day of 20 .

FOR THE CITY OF CHANDLER	FOR THE CONTRACTOR
______________________	By: Karen Finley
MAYOR	Signature
ATTEST:	ATTEST: If Corporation
______________________	______________________
City Clerk	Secretary
Approved as to form:	
______________________	
City Attorney	SEAL

Exhibit A
Scope of Work
For
Photo Enforcement (red light and speed)

1 Background

1.1 The City of Chandler intends to utilize a minimum of 12 photo enforcement intersections, the location of which to be selected by the City. Each intersection may have from 1 to 4 approaches monitored. The City anticipates an average of two approaches per intersection. Each approach may have speed enforcement, red light enforcement or both. The long-term goal of the program is to reduce the number of traffic accidents in Chandler.

1.2 The Contractor shall provide a "turn key" operation with all equipment, training, and all related services.

1.3 The Photo Enforcement Program will begin as a Public Works project and upon completion of installation will become a Police Department project. Appropriate input and support will come from the City Prosecutor and Municipal Court.

2 Enforcement Camera Systems

2.1 The Contractor shall provide all necessary material and equipment, i.e. poles, loops, cameras, and data recording systems needed to identify and photograph vehicles violating Arizona Red Signal Light and speed statutes at twelve (12) intersections designated by the City. Additional locations up to 25 locations may be added by mutual agreement between the City and the Contractor.

2.2 The Contractor shall provide and install poles, and secure enclosures for photo enforcement cameras. Installation shall be subject to the approval of the City of Chandler Traffic Engineering Department in accordance with all current professional standards as set forth by Traffic Engineering. The Contractor shall make efforts to install and locate poles and enclosures to minimize the visual impacts to the adjacent properties.

2.3 The Contractor shall provide cameras in the enclosures capable of photographing violator vehicles from both the front and rear.

2.4 Contractor shall supply a system and equipment that meets the following criteria:

2.4.1 The ability to operate during both daylight and nighttime.

2.4.2 The ability to provide photographs which, clearly identify the driver, vehicle and license plate.

2.4.3 Capable of setting different tolerances for speed and red light violations which will insure that the system does not activate on violations below the tolerances set by the City. The contractor shall adjust tolerances during the term of the contract as directed by City. Capable of providing digital images.

2.4.4 Capable of electronically transferring information between the Police Department, Municipal Court, and Contractor to allow for timely issuance of initial complaints, second copies of the summons and complaint and a copy of the summons and complaint to be delivered to the process server.

2.4.5 Each camera shall have sufficient computer and associated equipment to record, document and track data for record keeping and court purposes.

2.5 The Contractor shall maintain and service the enforcement cameras on a daily basis as necessary to maintain operation of the system.

2.6 The Contractor shall coordinate all system installations with the City of Chandler Traffic Engineering Department. Prior to installation, the Contractor shall submit engineering drawings to the City. Installations must conform to all local, state, and federal guidelines. The City will incur the cost of electricity required to run the system. All of the photo enforcement equipment must be wholly separate from the traffic signal system, with the exception of two wires leading out from the City's traffic controller indicating the onset of the red light. The photo enforcement system cannot use existing conduits utilized by the traffic signal nor use any of the detection equipment used to operate the traffic signal.

2.7 Contractor shall insure that malfunctions in the enforcement camera system do not interfere with the continued operation of any traffic control systems.

2.8 Contractor may make installations, loop placements, and timing sequences only after prior approval of the Traffic Engineering Division, and with input from the Police Department.

2.9 The Contractor shall maintain, repair and service all of the enforcement camera system and related components. Contractor shall notify the City of all malfunctions in any system immediately upon their discovery.

2.10 The Contractor, at their expense, shall relocate equipment as necessary and as directed by City due to roadway construction.

2.11 When the contract term ends, the Contractor shall remove all equipment and return intersections, sidewalks, etc. to their original condition.

3 Complaint and Warning Processing

3.1 Contractor shall issue warnings based on criteria established by the Police Department. When issuing warnings, Contractor shall follow the same procedures for mailing as for a first notification of a complaint.

3.2 Contractor shall be available for contact from the Contract Administrator, a representative of Traffic Engineering, or a representative from Municipal Court to make contact with a representative of the Contractor during the City's normal business hours. The Contractor shall provide toll free telephone service for City staff and violators located within the 602, 623 and 480 area code.

3.3 The Contractor shall maintain all records and images in accordance with established law, and make them available as requested for court purposes.

3.4 City will send Contractor a copy of the notice of hearing. Upon receipt of the notice of hearing, the Contractor shall prepare a court packet and send it either electronically or in hard copy to the Contract Administrator within 10 days of receipt of the notice of hearing but no later than 12 hours prior to the court hearing date. Contractor shall include in the court packet the following:

3.4.1 All images of the violator vehicle.

3.4.2 All violation data.

3.4.3 Certification that the system was operating properly prior to and after the violation.

3.5 Contractor shall issue all complaints and warnings within the time frames established by City.

4 Issuing of Complaints

4.1 The Contractor shall process all images and record all data related to individual violations.

4.2 The Contractor shall obtain registration information on violator vehicles from both in-state and out-of-state sources and driver's license information for the registered owner. The Contractor shall provide this information to the Police Department and the Municipal Court in a format compatible with the City's system. The Contractor shall match driver's license information to registered owner information.

4.3 The Contractor shall provide complaints to Contract Administrator within seven (7) calendar days of violation for in-state registrations. Contractor shall provide out of state registration complaints to the Contract Administrator within 14 calendar days of violation.

4.4 Contractor shall issue complaints only in cases where the photographs of the violator vehicle are clearly visible and identifiable, the vehicle plate is legible, and the driver is clearly depicted and registration information matches the vehicles depicted.

4.5 The Contractor shall forward the electronic file to the Contract Administrator for review. The Contract

Administrator will then forward acceptable complaints to the Municipal Court and notify the Contractor of accepted complaints. The Contractor shall mail accepted complaints on the same day notification is received from the Contract Administrator.

4.6 The Contractor shall match the gender and age of the driver of an imaged vehicle with that of the registered owner of that vehicle. The Contractor shall not issue when the gender or apparent age of the depicted driver and that of the registered owner conflict. In such cases, the Contractor shall mail a notice of violation to the registered owner, which contains violation date, time, location and a request for driver identification. The Contractor shall work with the Contract Administrator to draft the notice of violation.

4.6.1 In cases where the vehicle is not registered to an individual, the Contractor shall mail a notice of violation to the registered owner. The notice of violation shall contain violation date, time, location and a request for driver identification. The Contractor shall work with the Contract Administrator to draft the notice of violation.

4.6.2 In cases where the named defendant is found not to be the driver depicted in the photograph, the City shall develop a nomination process. Once an individual is identified as the driver and that information is transmitted to the Contractor, the Contractor shall issue a new complaint to the identified driver.

4.7 Mailing of accepted complaints.

4.7.1 The Contractor shall send a copy of the summons, complaint and images of the violation by first class mail, postage pre-paid to the person to be served, together with two copies of a notice and acknowledgment of receipt of summons and complaint, and return envelope, postage prepaid, addressed to the Municipal Court. The Contractor shall include the fine amount designated by the Court in the mailed materials.

4.7.2 Contractor shall schedule the initial appearance date and time as required by law, currently 30 days from date complaint is mailed and as directed by the Municipal Court. .

4.7.3 If the named defendant fails to respond to the complaint by the court date, the City will advise the Contractor. The Contractor shall mail a second copy of the summons and complaint to the listed defendant on the same day notification is received from the City.

4.7.4 If the named defendant fails to comply within the time frame listed in the second copy of the summons and complaint, the City will advise the Contractor. The Contractor shall issue a third copy of the summons and complaint and shall contract with a process server to serve complaints as directed by the City. Additional service, including process service, shall be provided by the Contractor in accordance with procedures established by the City.

5 Records Retention/Photo Images

5.1 The Contractor shall maintain a proper chain of evidence in accordance with established law, as well as the policy of the Chandler Police Department.

5.2 The Contractor shall retain all records and images associated with photo enforcement violations issued in a fireproof location.

5.3 Contractor shall retain all images and records for a period of time that meets both legal requirements and those of the City (a minimum of three (3) years). All images and records are the property of the City of Chandler.

5.4 The Contractor shall provide an audit trail.

5.5 The Contractor shall produce an audit trail of all unusable and unactionable images which shall include, but not be limited to:

5.5.1 The total number of unusable/unactionable images.

5.5.2 Location code.

5.5.3 Date of the image.

5.6 Images of violators shall include at a minimum, the following information:

5.6.1 Time of violation in hours, minutes, seconds.

5.6.2 Day, month, year of the violation.

5.6.3 Speed of the vehicle depicted.

5.6.4 Location coding.

5.6.5 Direction of travel (if non-stationary cameras).

5.6.6 Signal Phase (picture of signal). The color of the traffic signals should be visible in the image.

5.7 The Contractor shall make all files available for Contract Administrator for inspection on-line.

Information Management Systems

6.1 The Contractor shall input data and provide data in a format compatible with the Police Department and the Municipal Court computer systems to allow for the transfer of electronic information between the Contractor and Police Department, the Contractor and the Municipal Court, and the Police Department and Municipal Court. Contractor shall pay fees associated with the electronic data transfer.

6.2 Contractor must obtain the prior approval of the information management representatives of the Police Department, the Municipal Court, Traffic Engineering Division and Information Technology Division for all software applications.

7 Reporting Requirements

7.1 The Contractor shall provide a system, which allows the Contract Administrator to run reports on the data listed below for the time period (eg. Month, quarter, year) specified by the Contract Administrator.

7.1.1 Total number of photographs taken.

7.1.2 Total number of usable images.

7.1.3 Total number of unusable images.

7.1.4 Total number of warnings issued.

7.1.5 The number of complaints filed with the Municipal Court.

7.1.6 The number of second notices issued.

7.1.7 The number complaints pending service by personal service.

8 Support

8.1 The Contractor shall provide continuous technical and operational support and training to the City for Contractor's system and equipment. The Contractor shall provide all training to enforcement operators, Traffic Engineering personnel and other City personnel as specified by the Contract Administrator.

8.2 The Contractor shall provide an action plan for requested services within 24 hours of request.

9 Training

9.1 The Contractor shall provide training including, but not be limited to, providing appropriate City staff with an understanding of how the equipment works and the system operates. Training shall be sufficient to enable City staff to testify in court as to the technical aspects of the system. The Contractor shall provide expert witnesses for court purposes as requested by the Contract Administrator.

9.2 The City will provide adequate training facilities and scheduling for City employees.

9.3 The Contractor shall provide appropriate training records and forward them to the Contract

Administrator in a timely manner.

9.4 The Contractor shall provide training on systems operations, as well as the procedures that occur once a photograph is taken and a summons is issued.

9.5 Training outlines shall be prepared by the Contractor and submitted to the Contract Administrator for review and approval.

10 Community Awareness

10.1 The Contractor shall assist the City in community awareness efforts in cooperation with the Contract Administrator. The Contractor shall provide professional quality public relations assistance and materials.

10.2 The Contractor shall assist with a media relations campaign at the time of initial deployment of photo enforcement systems. All public awareness activities shall be coordinated through the City's public information office and the Contract Administrator.

Chandler • Arizona
Where Values Make The Difference

MEMORANDUM **Police Department – Memo 2007-011**

DATE: FEBRUARY 14, 2007

TO: MAYOR AND COUNCIL

THRU: W. MARK PENTZ, CITY MANAGER
RICH DLUGAS, ASSISTANT CITY MANAGER

FROM: SHERRY KIYLER, POLICE CHIEF

SUBJECT: TRAFFIC PHOTO ENFORCEMENT PROPOSAL

The Police Department, in conjunction with Traffic Engineering and the City Court, has been studying the potential applications of photo enforcement as a part of the City of Chandler Traffic Safety Strategy. The current program of red light enforcement has shown, with statistical significance, to reduce the number of accidents associated with red light violations. The speed enforcement pilot program showed a reduction in the average speeds and the number of violations during the course of the program. This information, as well as a study of other photo speed enforcement deployment including Scottsdale, Mesa, and Tempe, leads the Police Department, Traffic Engineering, and the City Court to believe that this type of enforcement would benefit the citizens of Chandler by reducing injury accidents.

The Evolution of Photo Enforcement In Chandler

In 2000, the City of Chandler entered into a contract with Redflex Traffic Systems to install a photo red light enforcement system. The first three locations (Alma School and Warner, Ray Road and Rural Road, and Warner Road and Dobson Road) were equipped and operational during August of 2000. Since that time the program has expanded to its current size of eight intersections.

These intersections are:

1. 56th Street and Chandler Blvd.
2. Rural Road and Ray Road
3. Dobson Road and Warner Road
4. Warner Road and Alma School Road

5. Alma School Road and Ray Road
6. Arizona Avenue and Ray Road
7. Arizona Avenue and Warner Road
8. Arizona Avenue and Elliot Road

These intersections were chosen due to the high number of red light (90 degree impact) accidents that occurred at these locations. The original contract was for five years with an additional five years allowed with City Council approval. In March of 2006, the City Council approved a one-year extension of the contract to allow staff to conduct a cost benefit examination of photo speed enforcement, as it would apply to the City of Chandler.

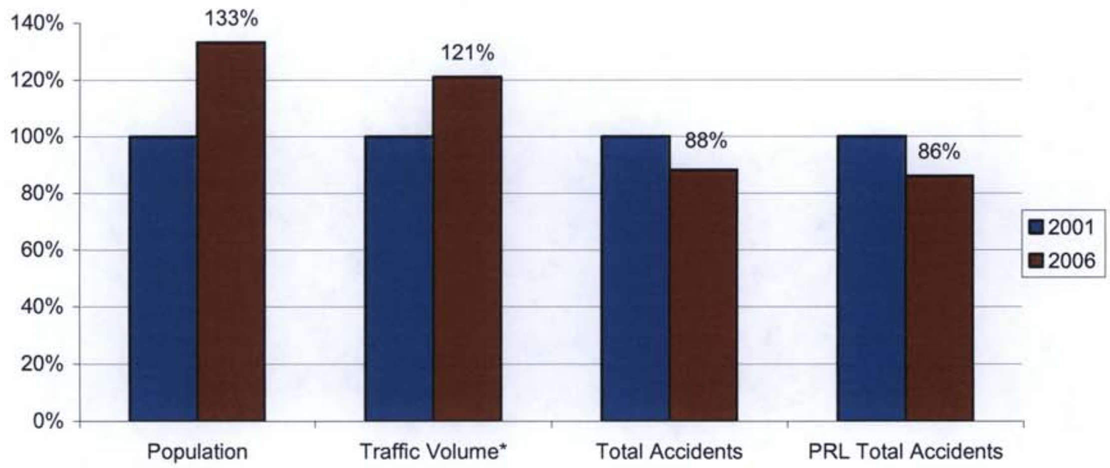
Influence of Photo Red Light Enforcement on Driver Behavior in Chandler 2001-2006

The City of Chandler had a population of 183,828 in January 2001 and has increased 33% to 244,949 as of December 2006. During this time frame there has been a 21% increase in the volume of traffic traveling on the streets of Chandler. Traffic patterns have changed, and the freeway system in Chandler has been opened. There would be a reasonable expectation that the total number of accidents in the city would have increased due to traffic volume alone; however, this assumption is not true. Overall accidents in Chandler have decreased by 12 % since 2001.

When looking at the Red Light Photo Enforcement program, the fact that the intersections were and are some of the highest accident intersections in the city should be taken into consideration. In 2001, the eight photo red light intersections accounted for 8.1% of all accidents, and in 2006 they accounted for 7.9% of all accidents in the city.[*] At the photo red light enforcement intersections, the percent change in overall accidents is greater than the citywide reduction with a 14% decrease. This information leads staff to believe that photo red light enforcement does have the effect of reducing accidents and creating a safer community, as seen in the following chart.

[*] All accident data excludes private property accidents from the totals.

Percentage Change From 2001-2006
Citywide and Photo Red Light Intersections (PRL)



* Does not include freeway

Photo Speed Enforcement Pilot Program

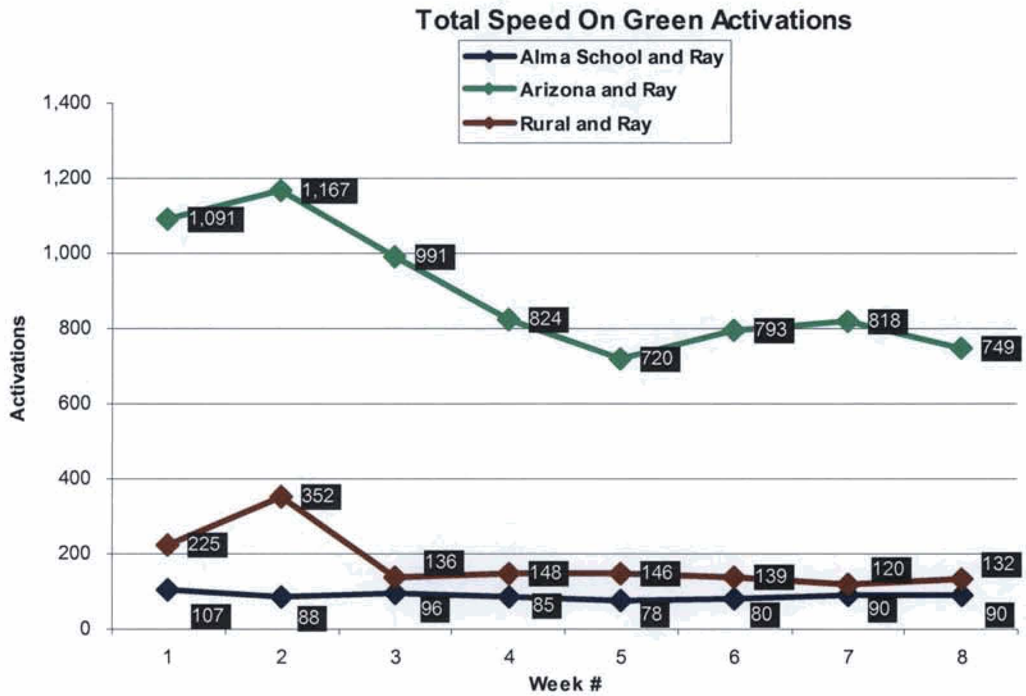
The Police Department, in conjunction with Traffic Engineering and the City Court, completed a pilot program to test photo speed on green enforcement at three intersections in the City of Chandler on November 30, 2005. The three intersections selected for the pilot program were along Ray Road at Arizona Avenue, Alma School Road, and Rural Road.

The intent of the pilot program was to gather statistical information on the potential influence of increased photo enforcement on the number and severity of accidents in the City of Chandler, provide citizens an opportunity to comment on the program, and estimate city staffing needs should an expanded program be implemented. Based on direction from the City Council, no citations were issued during this pilot program.

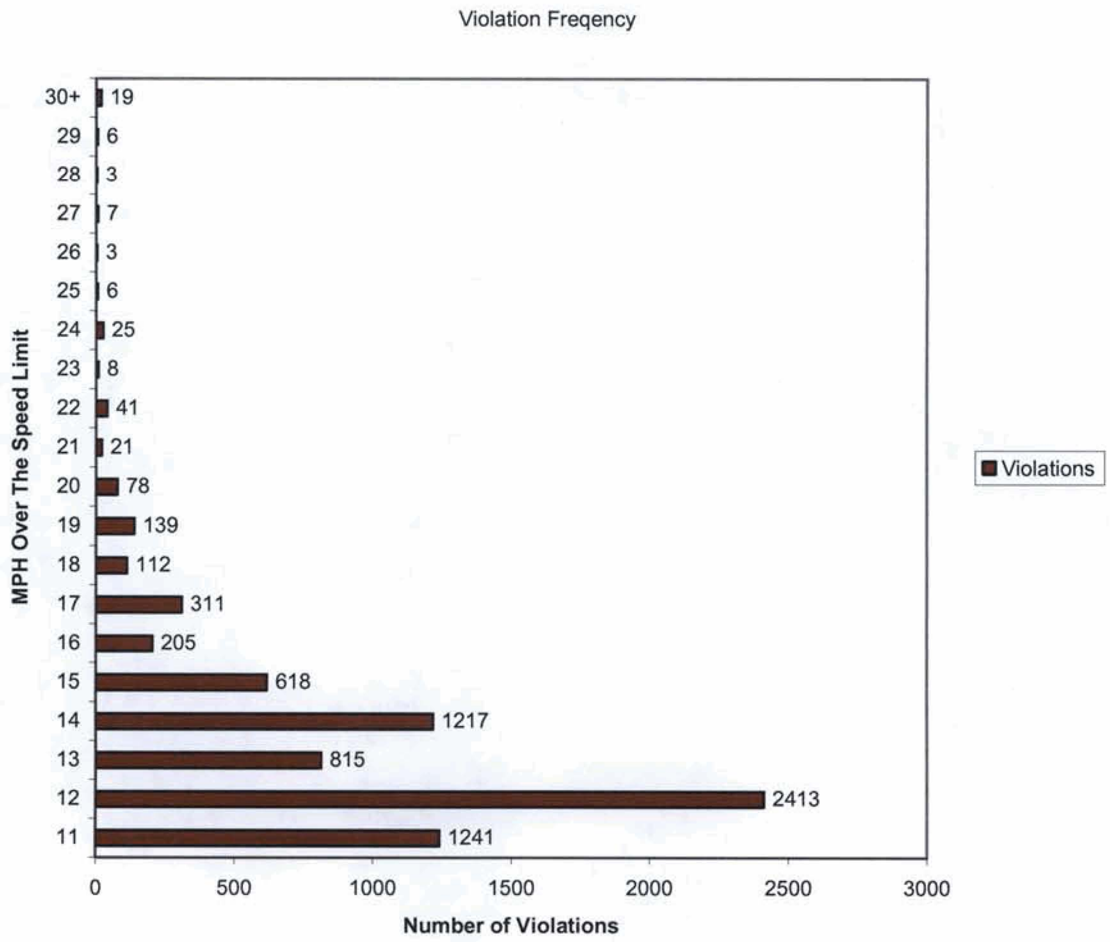
The pilot program consisted of three phases. The first phase ran from September 1, 2005, through September 15, 2005. This phase was solely educational and included identifying the affected intersections with signage and providing the locations to the media for dissemination. During this phase of the pilot program, the Citizens' Police Advisory Board met on September 12, 2005, at the Chandler Center for the Arts and provided an opportunity for citizens to comment on the program.

The second phase of the pilot program was to issue written warnings to drivers violating the speed limit. This phase ran from September 24, 2005, through November 30, 2005. Staff received additional citizen comment during this phase of the program.

The third phase, information consolidation and analysis, has been completed. The specific data from the pilot program can be found in Attachment #1. Although the short duration of the pilot program does not allow for a statistically significant analysis of this enforcement strategy in Chandler, it did show a general downward trend in the speeds at the monitored intersections as well as a downward trend in injury accidents.



This study also provided a distribution of activations beginning at 11mph over the posted speed limit.



Issuing warnings rather than citations was also a valuable opportunity to gather data relating to operations with the vendor and the ability to vary the notices/citations issued to the drivers.

Use and Deployment of Photo Enforcement in Other East Valley Cities

Mesa - The City of Mesa started using photo enforcement in 1996 as a pilot program. In 1999, a full deployment initiated using five speed vans and having 17 intersections with photo red light enforcement. In 2005 the program was re-bid and changed to four speed vans and thirty intersections with photo red light and one alternating intersection having speed enforcement. They did not have fixed intersection speed enforcement until 2005 and do not have enough data to determine its effect at this time.

Tempe - The City of Tempe currently has two intersections with photo red light and two mobile vans. They are in the process of adding an additional five intersections for a total of seven intersections. All seven are proposed to include speed on green capability. They will continue to use speed vans as well.

Scottsdale - The City of Scottsdale currently has photo enforcement, including red light and speed, at eight intersections. They also have a fixed speed enforcement zone mid-block on Frank Lloyd Wright Blvd, and four additional speed vans. The history of photo enforcement in Scottsdale goes back to 1997. Attachment #2 is a document from Scottsdale Police Department that details the evolution of photo enforcement in Scottsdale from 1997 to 2004 as well as detailing the effectiveness of the program in other jurisdictions. Attachment #3 is a copy of the draft report on the effectiveness of the photo speed enforcement pilot program on the Loop 101. The findings of this draft report state that all crash types were reduced, except rear end crashes, and the severity of crashes were reduced for all crash types.

Scottsdale has also conducted "Photo-Based Traffic Enforcement Attitude Studies" in 2004, 2005, and 2006. The 2006 study, in its entirety, is included as Attachment #4.

Citizen Input and Opinion

Our citizens have been solicited for their input/opinion on adding speed enforcement to the photo enforcement program in Chandler. The following is a synopsis of the methods and responses from the public relating to the photo speed on green pilot program.

- Advertised Public Meeting: No Input, Positive or Negative, from Citizens.
- Phone Messages: 1- Positive, 1- Concerned about distraction from flashing lights.
- E-Mail: 6-Support, 2-Oppose (3 from same person)

For the past four years, the City of Scottsdale has retained the Behavior Research Center to survey its citizens, Maricopa County, Pima County and "Rural Areas" about the photo enforcement program in general and, in specific, their city. The report submitted in January of 2007 stated that in Maricopa County, 61% of those polled agree that photo enforcement improves traffic safety either "some" (31%) or "a great deal" (30%). When questioned about support or opposition to photo enforcement, the response in Maricopa County was 73% of the people polled "Supported" (43%) or "Strongly Supported" (30%) the use of photo enforcement. The full report is included as Attachment #4.

Financial Impact of the Program

Based on other city's photo enforcement programs the number of activations drops significantly over time and any revenue realized from this program for the first few years should be used for one-time traffic safety expenses like; speed reader signs, traffic calming devices in neighborhoods, education and other initiatives that do not require on-going funding. The following two spreadsheets show a cost/revenue analysis of the current program and an estimated change in the cost/revenue projection for the first year based on the proposed contract.

Current Contract

	Fine	State and County Fees	Base to City	Court Enhancement Fee	Net To City
Red Light	$ 200.00	$ 94.45	$ 105.55	$ 15.00	$ 30.49
Defensive Driving School	$ 130.00	$ 45.00	$ 85.00	$ 15.00	$ 9.94

Cost and Revenue Analysis

Fixed Costs

		Wages
Court Clerks (Processing)	2	$ 96,523.00
Police Officer (Review)	1	$ 90,497.00
Police Support (Tracking)	1/2	$ 31,004.50
Total		$ 218,024.50

Variable Costs Based On FY 05/06 Data From Photo Red Light Program

		Payment to Vendor	Payment to City
Total Activations	8057		
Traffic School 27%	2204	$ 132,372.24	$ 67,199.96
Citations Paid 22%	1818	$ 109,189.08	$ 55,430.82
Total		$ 241,561.32	$ 122,630.78

Operating Loss For FY 05/06 (Wages-Revenue) **$ (95,393.72)**

Proposed Contract

	Fine	State and County Fees	Base to City	Redflex Fee	Court Enhancement Fee	Net To City
Red Light	$ 200.00	$ 94.45	$ 105.55	$ 19.00	$ 15.00	$ 71.55
Speed 0-19	$ 190.00	$ 90.00	$ 100.00	$ 19.00	$ 15.00	$ 66.00
Speed 20-29	$ 255.00	$ 119.00	$ 136.00	$ 19.00	$ 15.00	$ 102.00
Speed 30-39	$ 325.00	$ 150.00	$ 175.00	$ 19.00	$ 15.00	$ 141.00
Speed 40-49	$ 495.00	$ 226.00	$ 269.00	$ 19.00	$ 15.00	$ 235.00
Defensive Driving School	$ 130.00	$ 45.00	$ 85.00	$ 19.00	$ 15.00	$ 51.00

Wage Expense

Fixed Costs		Wages
Court Clerks (Processing)	2	$ (96,523.00)
Police Officer (Review)	1	$ (90,497.00)
Police Support (Tracking)	1/2	$ (31,004.50)
Total		$ (218,024.50)

Photo Red Light Revenue Estimate

		Payment to Vendor	Payment to City
Total Activations	12086	$ 229,624.50	
Traffic School 27%	3263		$ 166,417.34
Citations Paid 22%	2659		$ 190,237.86
	Total	**$ 229,624.50**	**$ 356,655.19**

Speed Cost/Revenue Estimate

		Payment to Vendor	Payment to City
Estimated Speed Activations/ Year 12 intersections*	54000	$ 1,026,000.00	
Warnings	27540		$ -
Traffic School 27%	14580		$ 743,580.00
Paid Citations 22% (0-19 over limit)	11880		$ 784,080.00
Total		**$ 1,026,000.00**	**$ 1,527,660.00**

*This is approximately 1 activation every two hours at each intersection

Proposed Photo Enforcement Strategy

The Police Department, Traffic Engineering, and City Court have collaborated to create a photo enforcement program directed at changing driver behavior and creating a safer driving environment in Chandler. A Request For Proposal (RFP) that included the ability to issue written warnings to drivers and did not make payment to the vender dependant on the number of citations issued was created and issued. This RFP included an expansion of the photo enforcement program into the southern and eastern sides of the city by expanding the number of intersections with this technology by four to a total of twelve. There were three vendors who submitted proposals; the Redflex proposal was selected by the review committee based on overall maximum points in the evaluation process.

An analysis of the high accident intersections, road construction as well as information received from the Police Traffic Unit resulted in the current eight intersections retaining photo enforcement (the direction of the cameras changed in five of the eight intersections) and an additional four being selected for enforcement. A map of the intersections selected is included as Attachment #5.

The implementation plan includes a public awareness campaign and issuing warnings for the first thirty days of an intersection beginning speed enforcement for all non-criminal speed violations (19 mph or less over the limit). Once the warning period is complete, citations and warnings will be issued based on the tolerances determined by the police department. An example of the inclusion of warnings would be to issue a warning for the first violation for a driver that is between 11mph and 14 mph (78% of the violations in the pilot program) and issue a citation for all other violations.

Attachment #1

Photo Speed Pilot Program Results

Photo Speed Pilot Program Results

Total Activations (This is the total number of vehicles speeding through the intersection in one direction with a built-in tolerance of 11 mph)

Speed on Green - 9363
Photo Red Light (at the same three intersections) - 1338

Total Notices/Citations Issued (This is the number of usable photos after review)

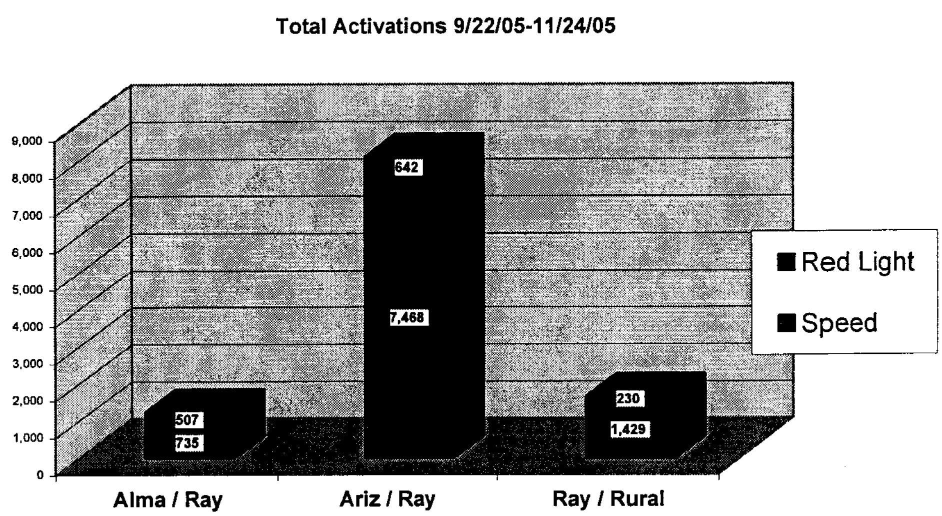
Speed On Green - 5446
Photo Red Light (at the same three intersections)- 666

Percentage of Violators Actually Issued a Notice/Citation

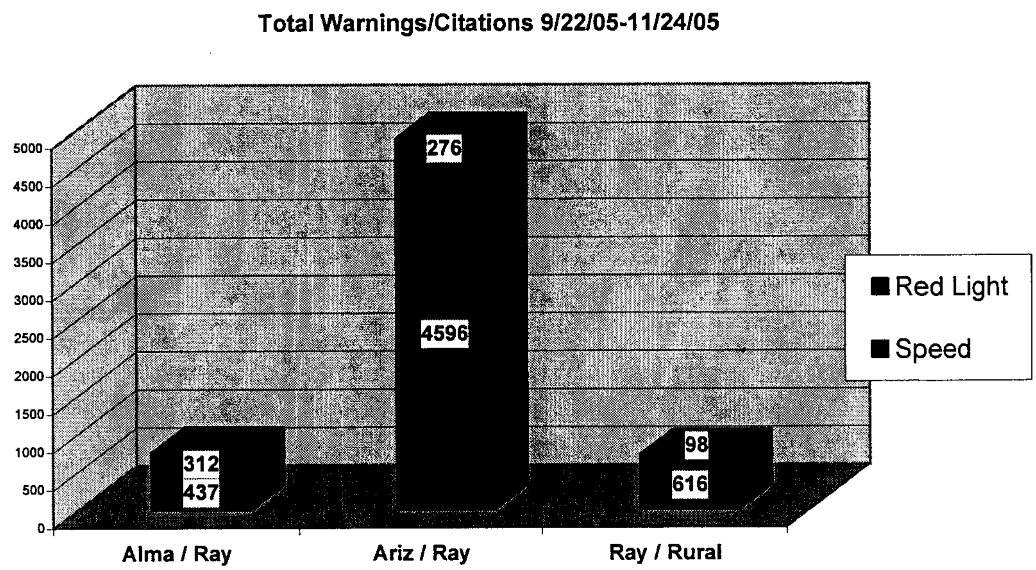
Speed On Green - 58%
Photo Red Light (at the same three intersections) - 50%

Individual Intersection Totals

This chart represents the total number of violations that occurred at each of the intersections.

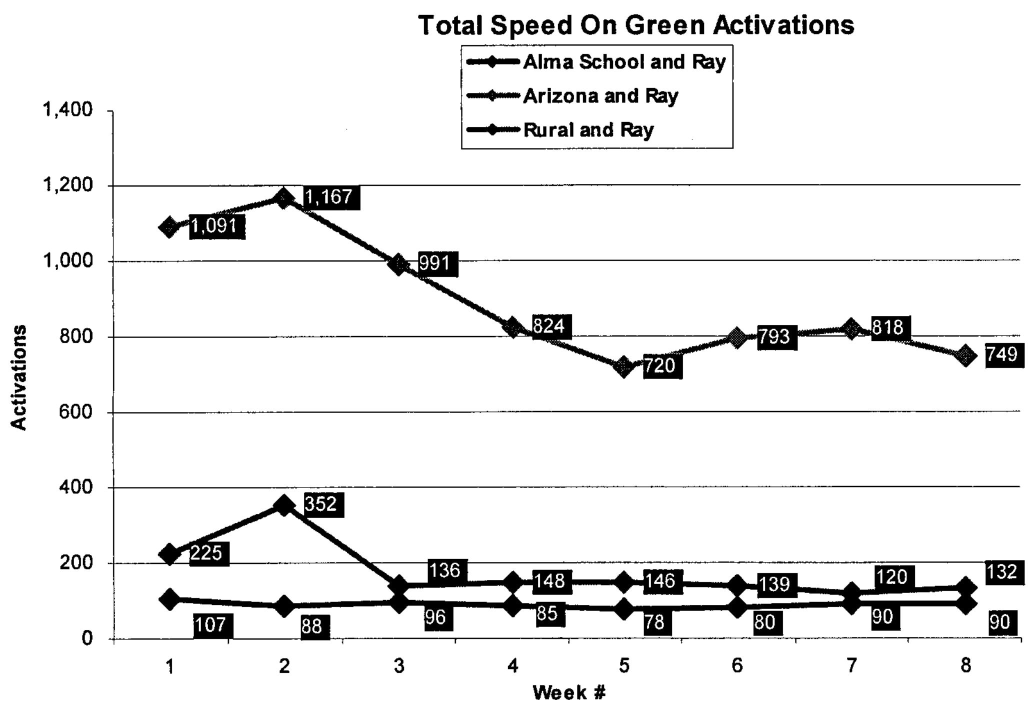


This chart shows the total number of notices/warning sent out at each of the three intersections.

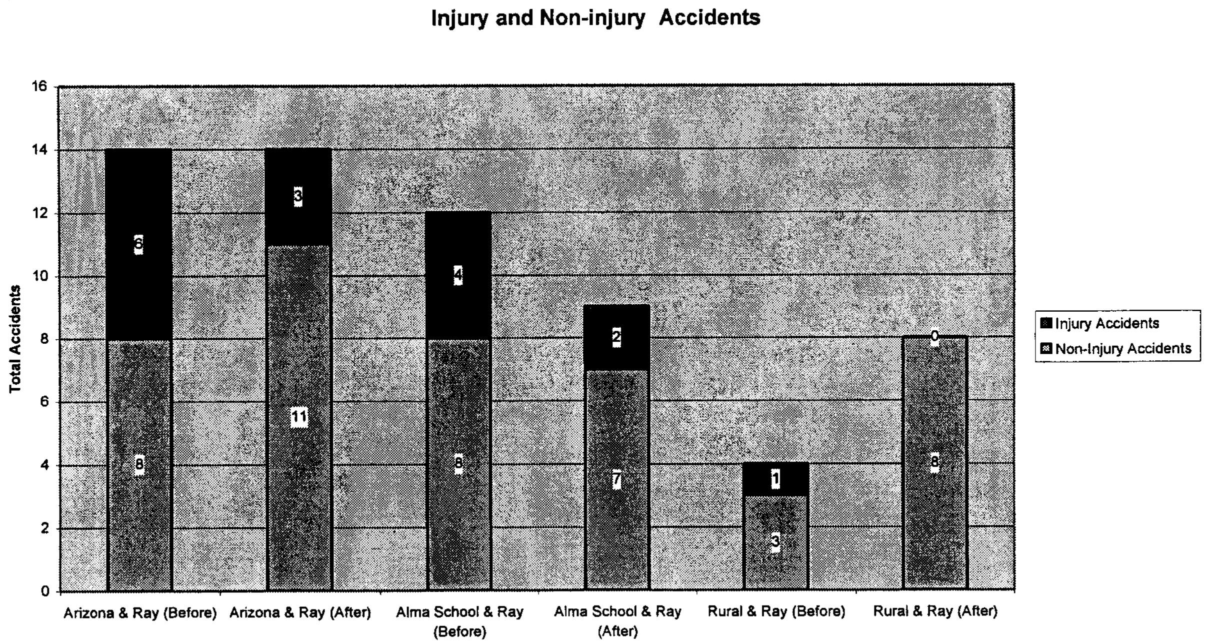


Trend Analysis

The following chart shows the number of activations per week at each of the intersections. Although the limited time of the pilot program does not provide a data set that can be used for an in-depth statistically significant analysis, there seems to be a downward trend in the number of vehicles speeding in two of the three intersections.



One of the objectives of the pilot program was to see what the influence of photo speed enforcement was on accidents, primarily injury accidents. The following graph shows that in all intersections during the pilot program, injury accidents were down when related to the number of accidents during the previous two months.



Attachment #2

History of Photo Enforcement In Scottsdale

INTRODUCTION

In the early 1990's, population, miles driven and traffic collisions in Scottsdale were on an alarming upward trend. In 1995 the Scottsdale Police Department added a second, five-member squad of traffic enforcement officers in an attempt to reduce traffic collisions and make the city a safer place to live in, and visit. As a result of the increased enforcement efforts, almost **10,000** speeding citations were written in 1995. In spite of that **42%** increase in enforcement over the 1994 level, collisions continued to rise.

In 1994 and 1995, traffic safety became a citywide priority. On-going efforts to reduce hazardous driving behavior and collisions included:

- Addition of a night traffic enforcement unit
- Participation in DUI task forces and sobriety checkpoints
- Training and participation in commercial vehicle inspections
- Increased internal training of officers in traffic enforcement
- Training and certification of drug recognition experts (DREs)
- Public education strategies (MADD/SADD)
- Timing signals to reduce stop and go traffic
- Addressing community traffic concerns through community policing
- Partnership with traffic engineering and the adjusted speed limit study

As 1995 drew to a close it was apparent to city decision-makers that traditional enforcement methods needed to be enhanced. Traffic collisions continued to rise and the idea of adding more police officers had proven to be ineffective and cost-prohibitive.

Photo enforcement technology had the potential to significantly reduce traffic violations and collisions in the community, while placing associated costs for the initiative on the violator rather than the taxpayer. Success of such a program was dependent upon support of the citizens, reasonable application of speed limits, public awareness and education, and commitment to all aspects of the program.

Research and data from cities utilizing the technology at that time demonstrated a clear relationship between the use of photo enforcement technology and the reduction of traffic collisions and hazardous driving violations. It was believed that a technology-based traffic safety program could be implemented without any additional costs to the taxpayers.

PROBLEM STATEMENT

In 1995, the Scottsdale Police Department investigated **4,435** traffic collisions, compared to **2,593** in 1991; a **71%** increase. This equated to **7,377** work hours or **$175,573** spent by the police department investigating reported collisions in 1995. This did not reflect those officers required to control the collision scenes during the investigations. At that pace, based on the first quarter of 1996, the police department anticipated a total of **5,400** collisions by the end of the year.

The Rural Metro Fire Department (RMFD) responded to approximately **1,890** collision scenes in 1995. Each injury collision required at least one fire engine and one ambulance for over 30 minutes. Fifteen percent of the time, two ambulances were required.

National statistics reported that:

- Every year approximately **18,000** people were victims of homicides, while **44,000** people died in motor vehicle collisions

- Annually, personal and household crimes cost Americans **$13 billion** compared to **$74 billion** for motor vehicle collisions

1991-1995 TRAFFIC COLLISIONS STATISTICAL ANALYSIS

- **69 fatal collisions**
- **60%** of all collisions occurred at intersections
- **37%** involved rear end collisions at the approach to an intersection
- **25%** involved a driver failing to yield
- **18%** involved angle impacts
- **6%** from disregarding traffic control devices

1997: THE FOCUS ON SAFETY PROGRAM

The Focus On Safety (FOS) program was implemented in an effort by the Scottsdale Police Department to reduce what had been a growing trend of traffic collisions in Scottsdale. During the five years prior to 1997, there were over **24,000** collisions, **14,000** people injured, and **87** collisions with fatalities. Collisions had risen **31%** over that period despite the success of an additional traffic squad, a **42%** increase in citations in 1996; and numerous other efforts. Contributing factors included increased lane miles, traffic volume and congestion, and significant population growth.

The program had three components: Awareness, Education and Enforcement. The goal was to obtain voluntary driver compliance with traffic laws; and to significantly reduce collisions, deaths, injuries and property damage. The comprehensive awareness and education campaign was intended to be on-going. The plan was to focus on the hazards of speeding, ignoring red lights, tailgating, aggressive driving and DUI.

The program was multi-faceted and employed photo enforcement, proactive DUI enforcement, seatbelt and child restraint awareness workshops, motorcycle officer deployment to high accident areas, speed awareness trailers, active citizen participation through the use of "citizens with radar" and participation by the City Traffic Engineering and Citizen and Neighborhood Resources (CNR) departments.

Beginning in 1997, the City contracted with an outside vendor to provide equipment, technology, services and personnel required for the photo enforcement component of the program. Required services included:

- Awareness and education campaign
- Creative development
- Four mobile speed vans
- Three sets of Red Light cameras installed and rotated among nine intersections
- Staffing of the speed vans

The cameras were deployed in high collision areas, school zones, and to address citizen complaints, where other efforts had been ineffective. The police department maintained control of all aspects with regard to deployment of the cameras. We determined the locations, enforcement margins, and times of deployment. Enforcement margins were based on reasonable and prudent speed for a given location.

Focus On Safety also included the deployment of several speed monitoring trailers. Scottsdale's CNR department partnered with the police to deploy four speed-monitoring trailers. These trailers were deployed in areas of high collision and citizen complaints. The trailers are advisory tools intended to inform the motoring public of vehicle speed. In addition, CNR loans to concerned citizens a handheld radar device. Citizens use the radar to monitor speeds in their immediate neighborhood and report the findings along with license plates. The police department issues an advisory letter to the registered owner of a speeding vehicle. This letter is advisory in nature, and does not require further follow-up. This is designed to be an awareness tool and to increase voluntary compliance with traffic laws.

1997-1998 PROGRAM RESULTS

When photo enforcement was implemented in early 1997, the number of speed violations per hour of camera operation was over **17**. In 1998 that number dropped to an hourly average of **9.1**. Another positive result of the Focus On Safety program was the citywide decline in reported collisions. In 1996 the City recorded **4,680** collisions. In 1998 the City saw the collision numbers drop an average of **3.3%** for 1997 and 1998. During the same time period, the Scottsdale population increased **12.6%**. Calculations from 1996 and 1998 showed the number of miles traveled increased **12%** to a total of **4.29 million miles**. In addition, injuries related to collisions dropped an average of **2.4%** during the 1997 - 1998 time period, compared to 1996. This evidence compared to the steady increase in the collision rate for the five years prior to 1997 indicated that the Focus On Safety program was successful.

1999-2000 PROGRAM RESULTS

In 1999, there were **4,975** collisions citywide in Scottsdale. In 2000, there were **4,514** collisions citywide. This was a **10%** decrease. Photo Enforcement could not take all of the credit for that improvement, but the reduction was significant.

A poll of Scottsdale residents conducted by Behavior Research Center, Inc. between December 26, 2000 and January 7, 2001, showed that support for photo safety technologies was steadily increasing. Seventy-seven percent of drivers approved of photo radar; up from **74%** in 1997. There was also a substantial increase in the percentage of men who supported the program (up from **59%** in 1997 to **75%** in

2001). The survey indicated that public perceptions of the program's benefits since implementation included:

- **77%** favored expansion of the program to use photo radar and red light cameras in more locations around the city
- **63%** believed that it had improved traffic safety
- **60%** believed the program had reduced the number of people who ran red lights
- **52%** believed that the continued use of photo radar in Scottsdale had reduced speeding in the city
- **50%** believed that photo radar had slowed down traffic in general
- **48%** believed the program had reduced the number of collisions

2001-2003 PROGRAM RESULTS

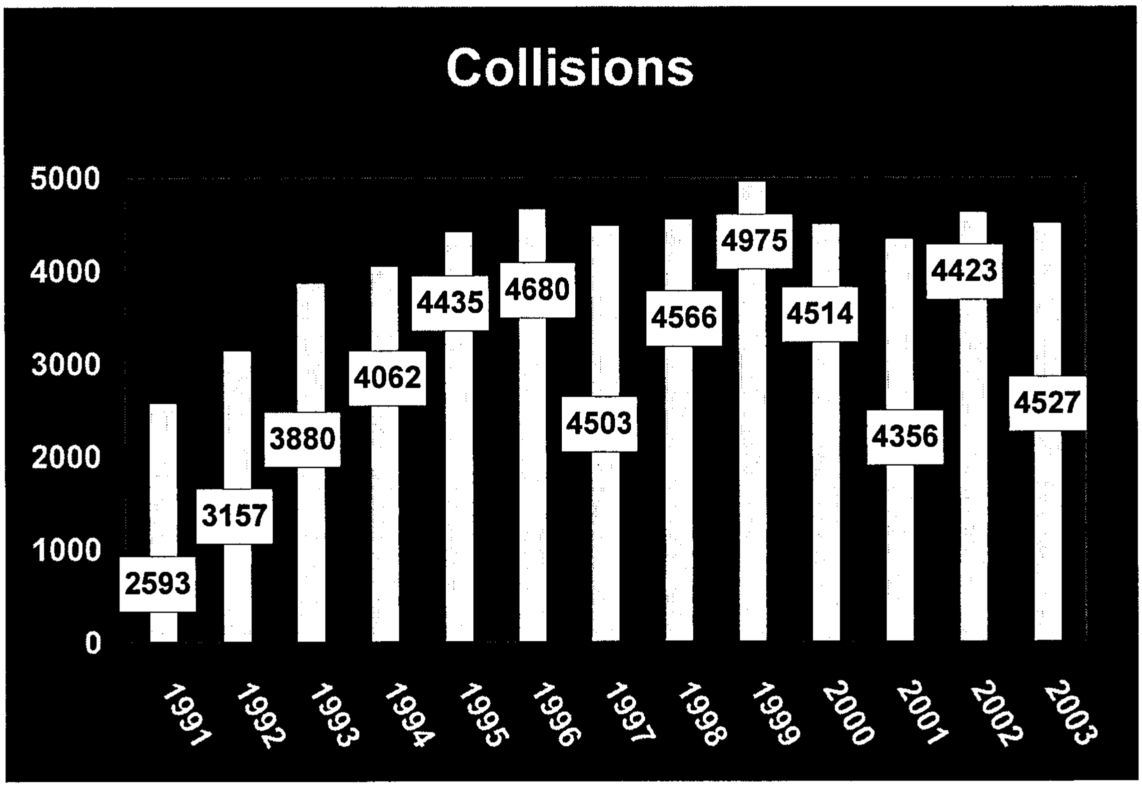
Scottsdale's first photo enforcement contract expired at the end of 2001. All of the early detection equipment was based on 35 mm wet film camera technology. As the city entered into negotiations with the successful bidder on the current contract, the next generation of digital detection equipment was emerging. Contract negotiations were difficult and protracted. As a result, all four speed vans were taken out of service for five months in 2002. One intersection installation was destroyed by a vehicle in a collision during the same period of time, and was not repaired.

The current contract was signed on July 2, 2002 and included provisions to upgrade all of the intersections and vans to digital technology. Several new intersection locations were selected by the City. The installation process was delayed considerably due to many unrelated street construction and improvement projects. As a result, the program was not fully functional with all four vans and six intersections operational until May of 2003.

National collision statistics report that **42,116** people were killed in traffic collisions in 2001. Of that number, **1,048** people were killed in the State of Arizona; **492** people were killed in Maricopa County; and **22** people were killed in Scottsdale. It is also shocking to note that traffic deaths rank second only to heart disease in the United States as the most frequent cause of death.

As the following chart graphically illustrates, traffic collisions had been on a downward trend until 2002. We attribute the small increase in the number of collisions in Scottsdale in 2002, at least in part, to the fact that a significant portion of our photo enforcement equipment was not operational for nearly six months of that year. There was a significant amount of publicity regarding the lack of photo enforcement in Scottsdale during 2002. Accidents dropped again in 2003.

The other trend that must be taken into consideration is the increase in population. Between 1996 and 2003 the population of Scottsdale increased **25%**, from **177,000** to **221,000** residents. During the same period of time, collisions decreased **3%**, from **4,680** to **4,527**. Collision fatalities dropped from **24** persons killed in Scottsdale in 2002, to **11** persons killed in 2003. We believe it is safe to conclude that photo enforcement has a demonstrable positive (deterrent) impact on driving behavior.



FY2003-2004 PROGRAM RESULTS

On August 7, 2003, the United Nations General Assembly published a report in response to General Assembly resolution 57/309 entitled, "Global Road Safety Crisis." The report, "...emphasizes that road traffic injuries now pose a global public health crisis that requires urgent action at the national and international levels."

In the fall of 2003 the Scottsdale Police Department submitted a budget request to expand the Focus On Safety program by adding three additional fixed digital detection systems in the FY2004-2005 City Budget.

On April 7, 2004, the World Health Organization (WHO) chose World Health Day 2004 to declare traffic collision injuries and deaths to be a, "...very critical and rapidly growing public health problem." WHO chose the slogan, "Road Safety Is No Accident" to focus the world's attention on this issue. In his introductory message, WHO Director-General, Dr. Lee Jong-wook summarized this global health threat by stating:

*"Every day as many as **140,000** people are injured on the world's roads. More than **3,000** die and some **15,000** are disabled for life. Each of those people has a network of family, friends, neighbours, colleagues or classmates who are also affected, emotionally and otherwise. Families struggle with poverty when they lose a breadwinner or have the added expense of caring for disabled family members.*

*Current figures are alarming enough. Even more alarming are trends. If they continue, by 2020, the numbers of people killed and disabled every day on the world's roads will have grown by more than **60%**, making road traffic injuries a leading contributor to the global burden of disease and injury."*

On May 18, 2004, Scottsdale voters overwhelmingly approved a 0.10 percentage point increase in the city sales tax that will generate nearly $8 million annually to fund expansions of police and fire public safety needs. Passage of the tax initiative resulted in approval of the budget proposal to add the three new detection systems. Two of the new sites will detect speed and red light violations at high volume/high collision intersections. The third system will detect speed violations only, mid-block in both directions of travel, on a high volume/high collision segment of Frank Lloyd Wright Boulevard.

In June 2004, the PA Consulting Group of London published its three-year evaluation report of the United Kingdom's (UK) national photo enforcement program. The analysis covers three years of nation-wide photo enforcement activity from April 2000 to March 2003. The 114-page report reached the following four conclusions:

- **Vehicle speeds were down** – surveys showed that vehicle speeds at speed camera sites had dropped by around **7%** following the introduction of cameras. At new sites, there was a **32%** reduction in vehicles breaking the speed limit. At fixed sites, there was a **71%** reduction and at mobile sites there was a **21%** reduction. Overall, the proportion of vehicles speeding excessively (ie 15mph more than the speed limit) fell by **80%** at fixed camera sites, and **28%** at mobile camera sites

- **Both casualties and deaths were down** - after allowing for the long-term trend there was a **33%** reduction in personal injury collisions (PICs) at sites where cameras were introduced. Overall, this meant that **40%** fewer people were killed or seriously injured. At camera sites, there was also a reduction of over **100** fatalities per annum (**40%** fewer). There were **870** fewer people killed or seriously injured and **4,030** fewer personal injury collisions per annum

- **There was a positive cost-benefit of around 4:1.** In the third year, the benefits to society from the avoided injuries were in excess of **£221 million** compared to enforcement costs of around **£54 million**

- **The public supported the use of safety cameras for targeted enforcement.** This was evidenced by public attitude surveys, both locally and at a national level

FY2004-2005 PROGRAM RESULTS

In July 2004, Scottsdale officials announced the City's intention to partner with the Arizona Department of Transportation (ADOT) and the Arizona Department of Public Safety (ADPS) to launch a pilot photo detection and enforcement effort on the eight-mile segment of the Loop 101 freeway that passes through Scottsdale between 90TH Street and Scottsdale Road.

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Attachment #3

Loop 101 Draft Report

Evaluation of the City of Scottsdale Loop 101 Photo Enforcement Demonstration Program

Draft Summary Report

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January 11th, 2007

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in cooperation with
U.S. Department of Transportation
Federal Highway Administration

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Executive Summary

This executive summary presents the *preliminary analysis results* of the fixed speed-enforcement camera demonstration program (SEP) that was implemented on Arizona State Route 101 from January 2006 through October 2006. The analysis is focused on quantifying:

- The impact of the SEP on speeding detections (76 mph or faster)
- The impact of the SEP on average speeds
- The effect of the SEP on traffic safety (motor vehicle crashes)
- The expected economic costs and benefits of the SEP
- The financial and public perception impacts of the program (appendix)

This evaluation, administered by the Arizona Department of Transportation (ADOT), utilizes data from the Arizona Department of Public Safety (crash reports), ADOT (motor vehicle crashes, traffic volumes, traffic speeds), the City of Scottsdale (traffic volumes and speeds), RedFlex (detections, traffic speeds), the Arizona Crash Outcome Data Evaluation System (crashes and crash costs), and the National Highway Safety Administration (crash costs). A *Final Report*, based on a more complete and expanded data set and containing additional analyses, will be available during the spring of 2007. Note that these preliminary results reflect an initial assessment with incomplete data and analyses—and so results are likely to change with updated data. It is anticipated, however, that the data and analyses presented here are sufficient to indicate the direction of effects and to draw general conclusions as to the effectiveness of the program.

Four time periods are referenced in this analysis.

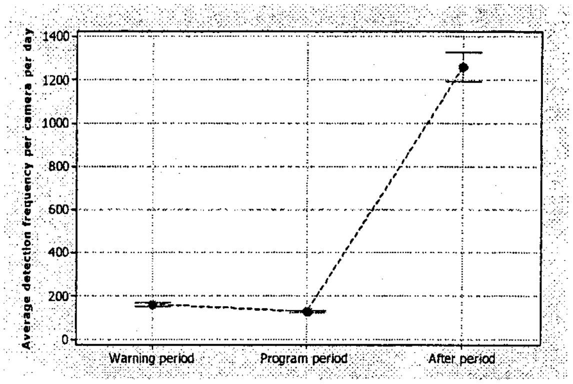
- Before (2001 – 2005 – various periods)
- Warning (01/22/06 – 02/21/06)
- Program (02/22/06 – 10/23/06)
- After (10/24/06 – 12/03/06)

SEP Demonstration Sites

Site ID	Site	Direction
1	Scottsdale Rd. and Hayden Rd.	EB
2	Hayden Rd. and Princess Dr.	WB
3	Frank Lloyd Wright Blvd. and Raintree Dr.	SB
4	Raintree Dr. and Cactus Rd.	NB
5	Shea Blvd. and Mountain View Rd.	NB
6	Shea Blvd. and Mountain View Rd.	SB

The Scottsdale 101 automated enforcement program consists of 6 speed detection stations within a 6.5 mile segment of route 101 within the city limits of Scottsdale, Arizona. Three cameras are positioned to enforce speeds for each direction of travel (clockwise and counter-clockwise) on the Scottsdale portion of the loop 101 freeway.

Effect on Speeding Detections



The average number of speeds detected (per day per camera) in excess of 76-mph was 162.2 during the *warning* period, 129.7 during the *program* period, and 1259.7 in the *after* period. Frequencies were higher on weekends than on weekdays. The average detection frequency for weekdays significantly increased by about 825% (847% for weekends and holidays) from the *program* to *after* period.

Effect on Mean Speeds

The preliminary results reveal that mean traffic speeds were reduced by about 9.4 mph, indicating that the SEP was an effective deterrent to speeding. Reduced speeds lead to decreases in speed variation, reduced crash impact speeds, and reduced demands on vehicular control systems (braking, steering, and suspension).

Because peak hour traffic speeds are constrained by congestion, it is highly unlikely that speeds in excess of 76-mph are possible during peak periods. As a result, it is assumed that the SEP will only affect unconstrained period travel speeds (and associated crashes).

Period	Estimated Mean Speeds (mph)
Before period (1)	73.57
Program period (2)	64.17
Difference (1 – 2)	**-9.407**

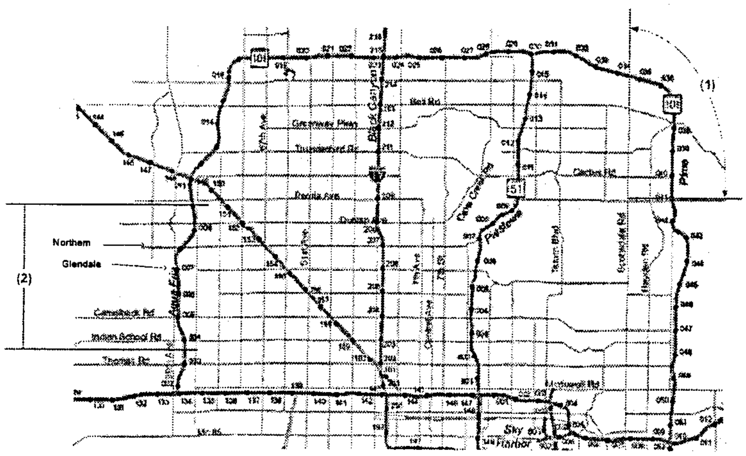
Impact on Traffic Safety

The safety analyses results are based on crash data through August 31st, 2006; however, the SEP ended on October 23rd, 2006. These additional (nearly) two months of crash data will be included in the analysis for the Final Report. Crash types affected by the SEP are categorized into four categories: single-vehicle, sideswipe-same direction, rear-end crashes, and other. These crashes constitute about 54%, 19%, 16%, and 11% of all crashes respectively. Only the off-peak periods are analyzed because of the limited expected influence of the cameras on slow moving peak period traffic.

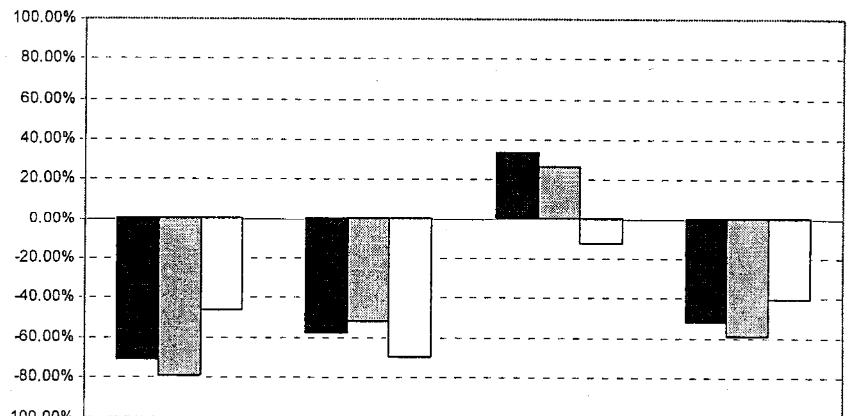
The safety analysis consists of three different methodologies: a simple or naïve before and after (BA) analysis, a BA analysis using a comparison group, and an empirical Bayes' analysis. The three analysis methods have varying assumptions, as discussed in the report. The results of the simple BA and the BA with comparison group are presented here. The comparison site is a 6.5 mile segment on the west-side 101, chosen because of the availability of traffic speed and volume data.

Comparison and Enforcement Sites

(1) Enforcement zone: MP 34.51– MP 41.06 (Approximately 6.5 miles)
(2) Comparison zone: MP 3.5 – MP 10 (6.5 miles)

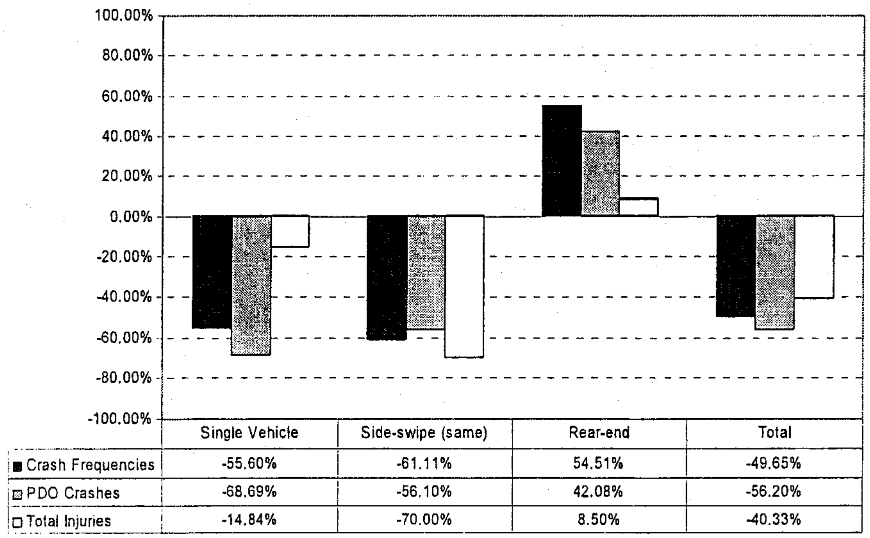


Using a BA analysis with correction for traffic flow, the estimated change in crashes from the SEP ranges from an increase of 33% (rear-end crash frequencies) to a reduction of 79% (single vehicle property damage only crashes). It should be noted that the BA approach estimates an increase in rear-end injury crashes—suggesting that rear-end crashes have increased compared to the *before* period, but a decrease (12.57%) in injuries associated with rear-end crashes. The BA approach assumes there have been no trends in crashes from the *before* to *program* periods, which is sometimes questionable due to changes in road users, weather, vehicle improvements, enforcement programs and policies, etc.



	Single Vehicle	Side-swipe (same)	Rear-end	Total
■ Crash Frequencies	-71.12%	-57.85%	33.24%	-51.88%
▨ PDO Crashes	-79.44%	-52.05%	26.16%	-59.03%
□ Total Injuries	-46.09%	-70.26%	-12.57%	-40.34%

Using the BA analysis with the comparison site to account for crash trends on the 101, the estimated change in crashes from the SEP ranges from an increase of 55% (rear-end crash frequencies) to a reduction of 69% (single vehicle property damage only crashes). It should be noted that the comparison BA approach estimates a relatively negligible increase in rear-end injury crashes—suggesting that although rear-end crashes increase, they result in approximately the same number of injury crashes as in the before period. Nevertheless, it is not clear whether the increase in rear-end crash negates the reduction in the remaining crashes—because different crash types are associated with different crash costs. Therefore, the program effects were converted into crash costs in order to estimate the overall benefits of the SEP.



To illustrate the economic benefits of the program, the results from both the simple BA and the BA with comparison group are presented. Annual estimated benefits of the SEP program range from 11.5 M (BA analysis with traffic correction) to $10.6 M (BA analysis with comparison group). These benefits include medical costs, other costs (lost productivity, wages, long-term care, etc.), and quality of life costs. The overall benefits appear to be very similar in magnitude across categories.

Severity	Fatal Crashes	Disabling Injury	Evident Injury	Possible Injury	Property Damage	Total
Simple BA w/r(tf)	$3,977	-$1,388	$2,382	$34	$6,546	$11,551
BA with Comparison	$5,879	-$1,905	$1,914	$206	$4,484	$10,578

Crash Benefits in $1000/year from Different Analysis Methods

Conclusions, Limitations, and Further Work

Conclusions

This preliminary study—based on the analysis of a variety of limited datasets—suggests the following:

1. Detection frequencies (speeds > 76 mph) increased by about 836% after the SEP ended. The Scottsdale 101 SEP appears to be an effective deterrent to speeding in excess of 75 mph.
2. The SEP reduced average speeds in the enforcement zone by about 9.5 mph.

3. All crashes appear to have been reduced except for rear-end crashes. Increases in rear-end crashes are traded for reductions in other crash types. Also, severity of crashes decreased within all crash types.
4. Swapping of crash types are common for safety countermeasures—many countermeasures exhibit the 'crash swapping' phenomenon observed in this study (left-turn channelization, red-light cameras, conversion of stop signs to signals, etc.).
5. Total estimated SEP benefits range from $1.4 M to $10.6 M per year, depending on the analysis type and associated assumptions, which suggests that the increase in rear-end crashes does not nullify the effects of the SEP on safety.
6. Estimated benefits are conservative because the Scottsdale 101 site was safer than average prior to the SEP. It is likely that benefits would increase if the SEP was applied to sites with higher than average freeways crashes.
7. Results are conservative because additional costs and benefits have not been considered: incident related congestion, reduced manual enforcement costs, risk to officers, and travel time costs.
8. It is not clear which results are more reliable, the BA with correction for traffic, the comparison group BA, or the Empirical Bayesian analysis results. At this point all three results should be weighed and considered. All three methods predict benefits, and only one predicts injury increases by a very small amount. Additional analysis should shed light on which analysis outcome is likely to be more reliable.

Limitations

The results of this analysis should be treated with caution for a variety of important reasons:

1. The results are based on small and incomplete samples. The demonstration program, which was implemented on a 6.5 section over a period of 6 months, none-the-less results in a relatively small sample of crashes. Small numbers of crashes results in large variability and uncertainty surrounding the analysis results, especially fatal and severe crashes which have high associated crash costs. In addition, approximately 7 of the 9 months of the program are evaluated in this analysis. More complete analysis will yield more reliable results.
2. Random fluctuations in crashes are commonly observed, and can influence the results significantly. In particular, severe crashes including fatal crashes will significantly influence the benefit estimates associated with the analysis.
3. Trends in crashes on the 101 are based on a small sample obtained at the comparison site. Analysis of the entire 101 set of crashes will yield more reliable estimates of crash trends on the 101 from the *before* to *program* periods. Also, comparison crashes will be used to expand the analysis (i.e. crashes during peak periods).
4. Detailed analysis of specific crashes has not been conducted as part of this analysis, and may reveal trends in crashes that have not been revealed in this analysis, such as crashes caused by drivers under the influence of drugs or alcohol, crashes as a result of preceding incidents, or crashes as a result of construction projects.

5. The entire set of costs and benefits have not been included in this analysis. The costs of reduced travel times (lost productivity of drivers) have not been included. The additional benefits of reduced risk to law enforcement personnel, of reduced incident-related congestion, and reduced 'secondary' crashes have not been included.

Planned Further Work

Since the current analyses were conducted by using incomplete data, the analysis result will be updated during the spring of 2007, and presented in the Final Report. The planned further work includes:

- Analyze priority 3 crashes (i.e., all SR 101 crashes in 2006)
- Examine additional comparison sites and comparison crashes
- Examine car-following effects
- Update databases (detections and speed)
- Increase sample size of comparison sites to improve analysis consistency
- Focus on implementation recommendations and guidelines
- Compute additional costs and benefits of program, including travel time losses, incident related congestion costs, reduced enforcement costs, and reduced officer risk.

Introduction

1.1 Background and Objectives

Speeding is recognized as one of the most important factors causing traffic crashes. In 2004, 36 percent of all motorcyclists involved in fatal crashes were speeding, approximately twice the rate for drivers of passenger cars or light trucks (National Highway Traffic Safety, 2005). Intelligent Transportation Systems (ITS) now exist to reduce speeding related crashes by enforcing speed limits with camera-based technologies. These enforcement technologies are generically called "speed cameras" and have been effective on municipal streets and arterials in Arizona (Roberts and brown-Esplain, 2005).

The City of Scottsdale began automated enforcement efforts in December of 1996. Between 1996 and 1998, four wet film mobile speed units and 6 wet film red light cameras were deployed for a total of 9 intersections on enforcement rotation, depending on the needs of the City. The cameras on city streets have helped Scottsdale improve safety (Washington and Shin, 2005). Scottsdale expanded these efforts in August of 2004 with a dual direction fixed speed enforcement system on 7700 Frank Lloyd Wright Blvd. This system covers three lanes of traffic Eastbound and three lanes of traffic Westbound on Frank Lloyd Wright Blvd. The city's recent experience on Frank Lloyd Wright Boulevard is that speed violations significantly decreased in one year period after installation of cameras.

With these experiences, the City Council on October 25, 2005, approved the nine-month *speed enforcement camera demonstration program* (hereafter SEP) on a 7.8-mile stretch of the SR 101 segment within Scottsdale. The SEP began on January 22, 2006 and ended on October 23, 2006. The demonstration program on the SR 101 freeway segment in Scottsdale is the first use of the fixed-site photo enforcement equipment on a freeway in Arizona and is believed to be the first in the nation.

Accurately estimating the impacts of the traffic safety countermeasures such as the speed enforcement cameras is challenging for several reasons. First, many safety related factors such as traffic volume, the crash reporting threshold (legal requirement to report a crash), the probability of reporting, and the driving population are uncontrolled during the periods of observation. Second, 'spillover' effects can make the selection of comparison sites difficult. Third, the sites selected for the treatment may not be selected randomly, and as a result may suffer from the regression to the mean effect. Fourth, a speed enforcement program may influence specific types of crashes—called target crashes—which often may be difficult to define and identify. Finally, crash severity needs to be considered to fully understand the safety impact of the treatment.

With these challenges in mind, this study was conducted to estimate the impact of the SEP on traffic safety, speed, and speeding behavior. More specifically, the objective of the research was to:

- Estimate the impact of the SEP on speeding behavior, which is represented as the detection frequency;
- Estimate the changes in mean speed due to the SEP;
- Estimate the impact of the SEP on traffic safety at the enforcement zone;
- Translate the impacts on crashes into estimated economic costs and/or benefits.

1.2 Description of the Demonstration Program

The cameras are at 6 fixed locations (in contrast to mobile photo enforcement vans) along the SR 101 freeway from just north of the 90th Street exit to the Scottsdale Road exit as shown in Figure 1. The directions of each site are summarized in Table 1.

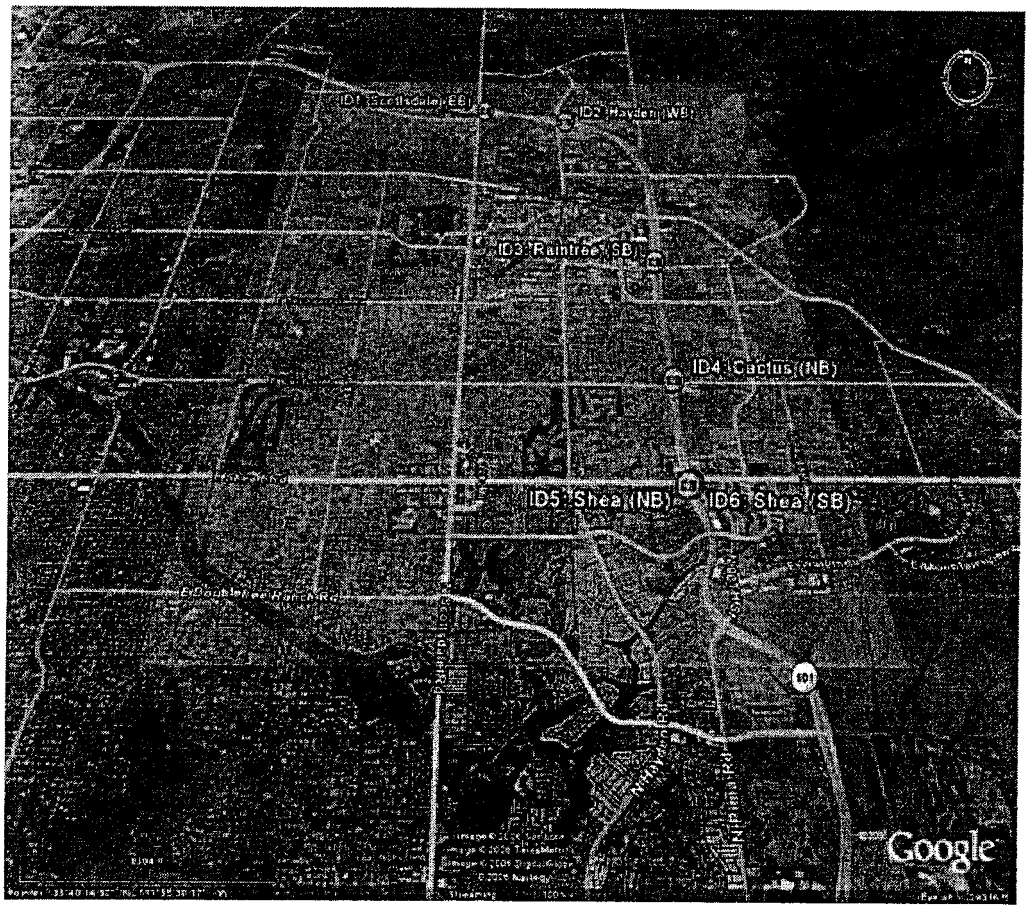


Figure 1: Location of 6 enforcement sites

Table 1: Summary of 6 demonstration sites

Site ID	Site	Direction
1	Scottsdale Rd. and Hayden Rd.	EB
2	Hayden Rd. and Princess Dr.	WB
3	Frank Lloyd Wright Blvd. and Raintree Dr.	SB
4	Raintree Dr. and Cactus Rd.	NB
5	Shea Blvd. and Mountain View Rd.	NB
6	Shea Blvd. and Mountain View Rd.	SB

The speed limit on this stretch of the SR 101 freeway is 65 mph, and the enforcement equipment is set to photograph drivers when they are traveling at 76 mph or faster. As discussed, the SEP began on January 22, 2006 and ended on October 23, 2006. For the first 30 days of the program, the city sent warning notices to drivers who exceeded the 76 mph threshold. The cameras were operated for a total of 275 days:

- Warning period: 1/22/2006 – 2/21/2006 (31 days)
- Program period: 2/22/2006 –10/23/2006 (244 days)

Vehicle speed is determined by measuring the time it takes a vehicle to travel from the first sensor to the last sensor on the detection zone installed at each enforcement site. The Redflex system uses the known distance between the sensors and the measured time to calculate speed. Of course time is measured precisely in order to estimate speeds precisely.

Chapter 2 Literature Review

In this chapter, previous studies on the effect of speed enforcement cameras are summarized, and the lessons and issues raised by literature that could affect study consideration are discussed. As of 2005, at least 75 countries rely on such cameras to enforce speed limits, especially on high-risk roads, including Australia, Austria, Canada, Germany, Greece, Italy, the Netherlands, Norway, Singapore, South Africa, South Korea, Spain, Switzerland, and Taiwan. Although speed enforcement cameras have frequently been used in the United States, their use has been limited (i.e., not at fixed-site) compared to other countries. Cameras currently are being used in several states, including Arizona, California, Colorado, North Carolina, Ohio, Oregon, and the District of Columbia (Roberts and brown-Esplain, 2005). Out of numerous studies conducted in these countries and nation, all possible studies of relevance were initially identified on the basis of internet journal database searches. Then, a number of "critical studies,"—appropriate in terms of methodological rigor and frequently cited by other researchers or in discussions of speed enforcement effectiveness, are examined. Extracted from the critical studies is general information on the effects of speed enforcement cameras and issues that need to be considered in this study.

2.1 Studies for Speed Enforcement Cameras on Freeways

Several studies have evaluated the impacts of speed enforcement cameras on speed and safety in freeways. Lamm and Kloeckner (1984) assessed the effects of fixed automated cameras at autobahn in Germany. In addition to a reduction of about 12.4 mph in speed, the accident frequency decreases from "200 accidents/year" to "84 accidents/year," and the number of fatal and injury accidents are reduced from "80 accidents/year" to "30 accidents/year."

Chen *et al.* (2002) evaluated the effects of mobile cameras on highway 17 in British Columbia in Canada. By using the simple before and after study, they reveal that the mean speed at the deployment locations is reduced to below the posted speed limit. Overall, the mean speed decreased by approximately 1.74 mph, representing a 3% reduction, and the standard deviation of speed declined by 0.3 mph (6% reduction).

Some studies on freeways focused on the spillover effects—time or distance halo effects— rather than the direct effects. The time halo effect is defined as the length of time during which the effect of enforcement is still present after enforcement activity has been withdrawn. The distance halo effect is the number of kilometers from the enforcement site, in which the effect is maintained (Hauer et al., 1982;Vaa, 1997). Sisiopiku and Patel (1999) analyzed both time and distance halo effects of mobile speed cameras on I-96 in Ionia County, Michigan. The average speed just upstream of the police car's location were reduced, but as soon as vehicles passed the patrol car, drivers accelerate to their normal speeds or more, but no "time halo" effects on the vehicles at the increased speed zone were observed.

Ha *et al.* (2003) investigated the distance halo effects using speed data collected from 7 measurement sites on urban highway in South Korea. Drivers tended to reduce their speeds when approaching the speed enforcement camera, but drivers accelerated back to their original speeds on passing the enforcement camera—thus no evidence of distance spill-over effects were observed.

Champness and Folkman (2005) also examined the time and distance halo effects of mobile overt speed cameras in Australia. Time and distance halo effects were analyzed using numerous measurements: mean speeds, 85th, 90th and 95th percentile speeds, etc. Distance halo effects were clearly identifiable, with an observed reduction in speeds one kilometer downstream, but the magnitude of the reduction diminishing at 500 meters downstream of the camera site. The effect of the speed camera was completely dissipated at 1.5 kilometers downstream.

Another study attempted to compare the reduction in speed in terms of enforcement type and time delay in the case of mailed fines on 75 mph motorway in Netherlands (Waard and Rooijers, 1994). Two field experiments were conducted to establish the most effective method of enforcement in reducing driving speeds. The enforcement intensity study showed a clear relationship between intensity level of enforcement and the proportion of speeding drivers. The highest intensity levels led to the largest and longest lasting reduction in driving speeds, but effects on average driving speeds of the methods on-view stopping versus photographing of offenders were similar.

Table 2: Summary of studies on freeway

Reference	Country	Camera type	Enforcement sites	Posted speed limits
(Lamm and Kloeckner, 1984)	Germany	Fixed	2 sites on Autobahn	62 mph (100kph)
(Waard and Rooijers, 1994)	Netherlands	Mobile	6 sites on motorways	75 mph (120kph)
(Sisiopiku and Patel, 1999)	US	Mobile	29-mile segment on I 96, Michigan.	70mph (113kph)
(Chen *et al.*, 2002)	Canada	Mobile	12 sites on Highway 17	56mph (90kph)
(Ha *et al.*, 2003)	South Korea	Fixed	1 site on urban highway	50mph (80kph)
(Champness and Folkman, 2005)	Australia	Mobile	1 site Highway section, Queensland	62 mph (100kph)

Table 2 summarized the experimental details of these studies. Only two studies (Lamm and Kloeckner, 1984; Ha *et al.*, 2003) are similar to the Scottsdale's enforcement environment (i.e., fixed camera). However, highways in Germany and South Korea are likely to have different traffic conditions, road users (skills and 'safety culture'), geometric design standards, and weather compared from the Scottsdale Loop 101. In fact, the cameras on Autobahn were deployed at steep downgrade sections (5% grade).

2.2 Studies for Speed Enforcement Cameras on non-Freeways

While there were relatively few studies for the speed enforcement cameras on freeway, a number of studies analyzed the effects of speed cameras on non-freeway roads. Table 3 shows the summary of outline of these studies.

Table 3: Summary of outline of studies on non-freeway

Reference	Country	Camera type	Enforcement sites	Posted speed limits
(Hauer *et al.*, 1982)	Canada	Fixed	4 sites on suburban two-lane road	37 mph (60kph) or 50mph (80kph)
(Vaa, 1997)	Norway	Fixed and Mobile	Roadway 22 and 170 in Norway (suburban two-lane road)	37 mph (60kph) or 50mph (80kph)
(Elvik, 1997)	Norway	Fixed	64 sites	31 mph (50kph) to 56mph (90kph)
(Retting and Farmer, 2003)	US	Mobile	7 sites on surface streets in Washington D.C.	25 mph or 30 mph
(Hess and Polak, 2003;Hess, 2004)	UK	Fixed	43 (49) sites on rural road	Speed limits vary from sites
(Goldenbeld and van Schagen, 2005)	Netherlands	Mobile	28 sites on rural road	50 mph (80kph) or 62 mph (100kph)
(Cunningham *et al.*, 2005)	US	Mobile	14 sites in City of Charlotte, North Carolina	25 mph to 55mph

Elvik (1997) assessed the effects of 64 fixed speed enforcement cameras in Norway on safety. The study controlled for general trends in the number of accidents and regression to the mean bias by using comparison groups and empirical Bayesian estimation respectively. The injury accidents were significantly reduced by 20%, and the property damage-only accidents were reduced by 12%. However, the reduction in the PDO accidents was not statistically significant.

Retting and Farmer (2003) evaluated the effects of mobile speed enforcements on speed at 7 sites in Washington D.C. With 8 comparison sites in Baltimore, Maryland, speed data collected 1 year before enforcement and approximately 6 months after enforcement began were analyzed. Mean speeds at 7 sites decline by 14%, and the proportion of vehicles exceeding the speed limit by more than 10 mph declined by 82%.

Goldenbeld and Schagen (2005) assessed the impacts of mobile inconspicuous speed cameras on the speed and safety at 28 enforcement sites in the Netherlands. With 15 sites on 80kph rural roads and all other non-enforced roads outside urban areas as comparison sites, the evaluation was performed. The results show that the mean speed decreased by 4kph on the enforced roads and by .5kph on the non-enforced comparison roads during the enforcement period. With regard to reduction in safety, the number of road accidents and casualties decreased by 21%.

Again, there are several studies focusing on the spillover effects. Hauer *et al.* (1982) attempted to investigate both spillover effects (i.e., time halo and distance halo effects) comprehensively. The distance halo effects were measured at 4 enforcement sites with upstream and downstream measurement sites, which are located on semi-rural two land roads in Halton and Peel counties west of Metropolitan Toronto. To investigate "time halo" effects, speeds were monitored prior to, during, and after exposure to enforcement. The investigation on aggregate speed distributions suggested that the average speed of the free flowing vehicles was remarkably reduced at the enforcement site. When enforcement was in place, the average speed at the site was close to the posted speed limit. The downstream distance halo effect follows the general form of exponential decay, representing that the effect of enforcement is reduced by half for approximately every 900 meters. The "time halo" appeared to be the only phenomenon to be affected by the intensity of enforcement: the effect of enforcement at single day is disappeared after 3 days, while enforcement on several consecutive days had a longer term effect.

Vaa (1994) also investigated the impacts of the intensity level of speed enforcement on speeds. Speed was measured at 12 sites in Norway consecutively for 16 weeks: 2 before weeks, 6 enforcement weeks, and 8 after weeks. They concluded that the average speeds during the enforcement period were reduced, but durations for time-halo effects were influenced by the intensity of the enforcement, which were consistent with other results (Hauer *et al.*, 1982;Waard and Rooijers, 1994).

Hess (2004) assessed the effects of 49 fixed speed enforcement cameras in Cambridgeshire, U.K. Two consecutive studies (Hess and Polak, 2003;Hess, 2004) were conducted in order to quantify the performance of the cameras in terms of their catchment area (the effects of cameras for various ranges around the cameras). In the 250-meter range, injury accident numbers were reduced by 45.74%. However, the reductions in the 500-, 1,000-, and 2,000-meter ranges decreased by 41.30%, 31.62%, and 20.86% respectively.

2.3 Summary of Findings

A number of studies have evaluated the effects of speed enforcement cameras on safety and speed. Some studies evaluated the effects on speed or traffic safety solely, while others evaluated both. In addition, several studies focused on the spillover effects in terms of time and space. Not surprisingly, the estimates of the safety effect of speed cameras vary considerably, even though all studies suggest that photo enforcement cameras are effective in reducing speed and crash frequency at photo enforcement camera deployment sites. A recent meta analysis (Pilkington and Kinra, 2005) also suggests that speed cameras are an effective means of reducing road traffic collisions and related causalities.

However, many studies suffer from one or more non-ideal conditions. For example, the results of some studies may under/overestimate the effects of the speed enforcement cameras on traffic safety since total instead of target crashes (crashes that are materially affected by the photo enforcement speed cameras) were analyzed. In addition, failure to account for regression-to-the-mean can overestimate the positive effects, while benefits can be underestimated if spillover effects are ignored. From the literature review several noteworthy observations are relevant:

- *Defining Target crashes*: The lack of precise definition in past studies could have led to the under estimation of the safety effects.
- *Minimizing "spillover effects" in selecting comparison/control sites*: If crashes at control/comparison sites are affected by the demonstration program, estimating the program effect at the treated enforcement zone becomes more difficult.
- *Exposure changes between the before and program periods*: It is important to account for changes in traffic exposure between the before and program periods.

- *Regression to the mean effects*: In many studies, speed enforcement cameras were installed at high-crash sites—which could lead to significant regression to the mean bias that needs to be accounted for—often leading to over-estimation of safety impacts.
- *Effects of speed enforcement cameras on violation frequency*: Since the direct effect of speed cameras is a reduction in speeding, it is expected that violations should decrease, thereby reducing relevant crashes. However, if this assumption does not hold, the speed enforcement countermeasure could be invalid.
- *Spillover effects:* Two spillover effects (i.e., distance and time spillover effects) need to be investigated when analyzing the program effect.

Chapter 3 Effects of the SEP on Speeding Behavior and Speed

In this chapter, the effects of the SEP on speeding behavior and speed are examined. The speeding behavior is analyzed by comparing the detection frequencies during the *warning*, *program*, and *after* periods, collected at the 6 enforcement camera locations, and the impact on speed was compared by analyzing the mean speeds during the *before* and *program* periods. The detection frequency data were obtained from Redflex, while the average speed data were obtained from ADOT. In the following sections, all relevant analysis results are discussed in detail.

3.1 Changes in the Detection Frequency

3.1.1 Data Description

The detection frequency data used in this analysis are the number of vehicles detected by the 6 enforcement cameras, which were collected for 46 weeks (1/22/2006 – 12/3/2006: 316 days). In order to compare the detection frequency by time periods, three time periods were used:

- *warning* period: 1/22/2006 – 2/21/2006 (31 days)
- *program* period: 2/22/2006 –10/23/2006 (244 days)
- *after* period: 10/24/2006 – 12/3/2006 (41 days)

Note that no detection data were collected prior to the *warning* period.

Table 4 shows the summary statistics of the average detection frequency for the 3 periods, and the interval plot for the mean detection frequencies with 95% CIs is shown in Figure 2.

Table 4: Summary statistics for the average daily detection frequency by site and period

	Warning period (N=31 days)		Program period (N=244 days)		After period (N=41 days)	
Site	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.
1	203.52	84.08	158.41	62.08	1366.68	541.18
2	117.16	47.1	87.2	34.96	999.29	442.07
3	245.42	80.47	254.76	78.93	2341.9	968.51
4	38.84	19.53	31.09	18.3	382.17	214.73
5	186.32	71.68	132.39	58.03	1620.46	857.15
6	181.94	78.27	114.35	57.66	847.76	496.22
Mean	162.2	94.57	129.7	88.06	1259.71	888.17

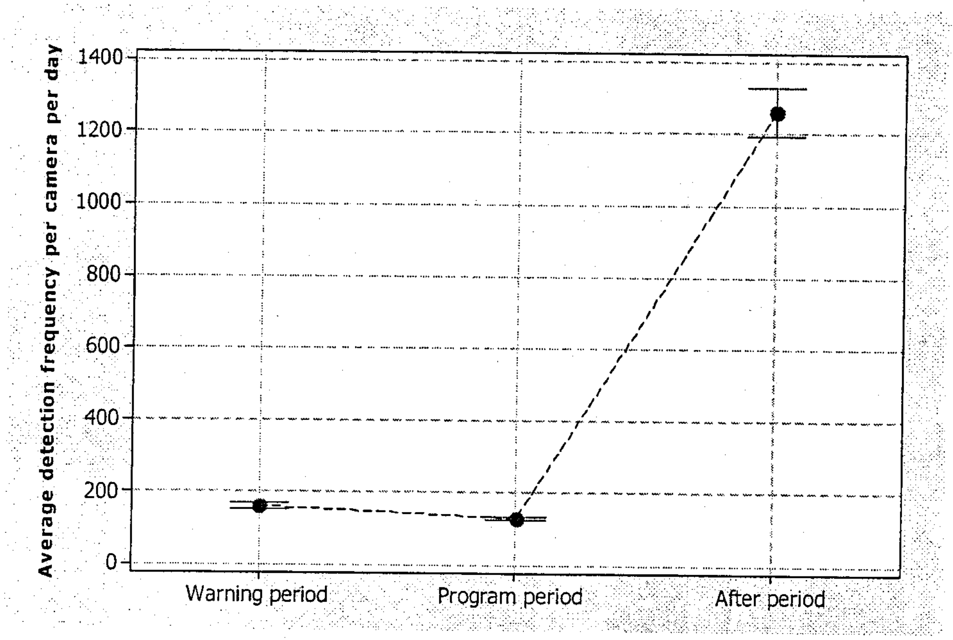


Figure 2: Average daily detection frequency by period

The detection frequencies vary over the enforcement sites—the detection frequencies at site 3 (see Table 1: Frank Lloyd Wright Blvd. and Raintree Dr.) are greater than those at other sites (see Figure 3). Consequently, the summary statistics in Table 4 show that both the period and site effects for the detection frequency exist.

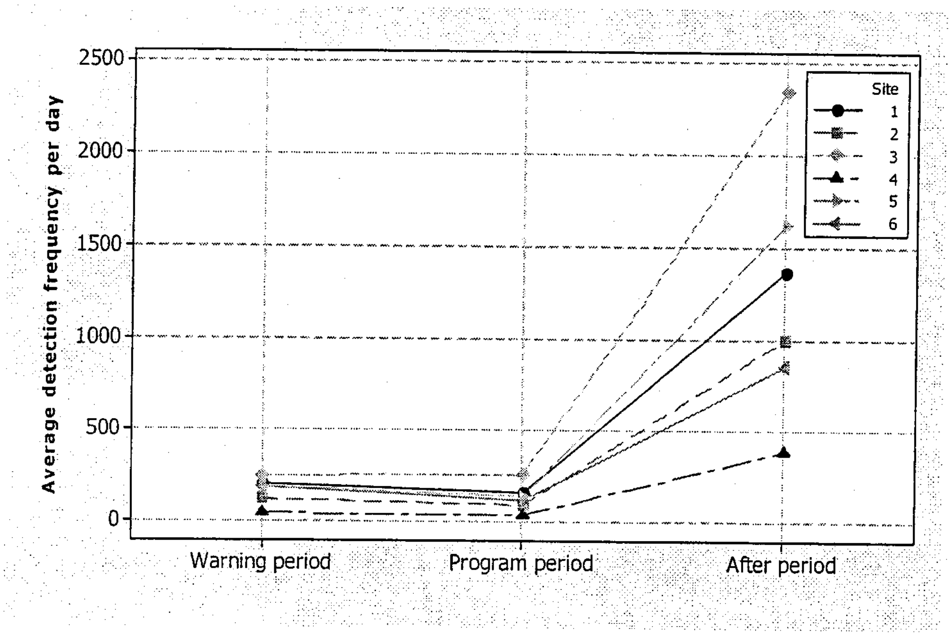


Figure 3: Average daily detection frequency by period and site

Table 5: Summary statistics for the daily detection frequency by day of week and period

	Warning period			Program period			After period		
	Mean	Std.Dev.	N[1]	Mean	Std.Dev.	N	Mean	Std.Dev.	N
Monday	127.67	61.59	24	107.08	66.81	186	1012.47	612.96	30
Tuesday	130.87	61.35	30	98.22	62.98	198	914.75	692.35	36
Wednesday	125.79	57.69	24	99.88	66.13	210	987.53	811.47	36
Thursday	123.75	71.05	24	101.63	66.09	210	905.20	611.42	30
Friday	140.08	77.88	24	114.09	76.49	210	1010.83	729.05	24
Saturday	211.61	92.52	18	188.11	104.02	186	1704.96	1069.35	24
Sunday	223.00	111.41	24	188.88	100.09	186	1694.38	877.84	24
Holiday	259.28	122.64	18	181.03	91.66	78	1857.93	951.16	42
Total	162.20	94.57	186	129.70	88.06	1464	1259.71	888.17	246

In addition, the time series plots illustrated in Figure 5 and Figure 8 show that the detection frequency has periodic patterns–spikes for weekends and holidays. Table 5 shows the summary statistics for the detection frequency per camera per day during the 3 periods by day of week, in which the list of holidays used in this analysis is summarized in Table 6. The detection frequencies during weekends and holidays are relatively greater than those during weekdays, while the detection frequencies during weekdays seem to be similar to each other (see Table 5).

Table 6: A list of holidays in 2006

Description	Official observed date	Holiday	
		Start	End
New Year's Day	Monday, January 2*	December 31, 2005	January 2, 2006
Birthday of Martin Luther King, Jr.	Monday, January 16	January 14, 2006	January 16, 2006
Washington's Birthday	Monday, February 20**	February 18, 2006	February 20, 2006
Memorial Day	Monday, May 29	May 27, 2006	May 29, 2006
Independence Day	Tuesday, July 4	July 1, 2006	July 4, 2006
Labor Day	Monday, September 4	September 2, 2006	September 4, 2006
Columbus Day	Monday, October 9	October 7, 2006	October 9, 2006
Veterans Day	Friday, November 10***	November 10, 2006	November 12, 2006
Thanksgiving Day	Thursday, November 23	November 23, 2006	November 26, 2006
Christmas Day	Monday, December 25	December 23, 2006	December 25, 2006

Table 7 shows the summary statistics for the average daily detection frequency per camera during the 3 periods, in which each day is aggregated by 2 categories: "weekdays" and "weekends and holidays." Regardless of the periods, detection frequencies during weekends and holidays are greater than those during weekdays as shown in Figure 4. This finding suggests that the detection frequency needs to be analyzed by controlling for the day of week effect.

[1] The sample size N indicates total number of Mondays during the warning period times the demonstration sties (6 Mondays×6 sites= 24).

Table 7: Summary statistics for the daily detection frequency during the 3 periods by the 2 categories

	Warning period			Program period			After period		
	Mean	Std.Dev.	N	Mean	Std.Dev.	N	Mean	Std.Dev.	N
Weekdays	129.69	65.27	126	104.18	68.05	1014	963.28	691.52	156
Weekends and holidays	230.47	109.65	60	187.20	100.17	450	1773.52	957.99	90
Total	162.20	94.57	186	129.70	88.06	1464	1259.71	888.17	246

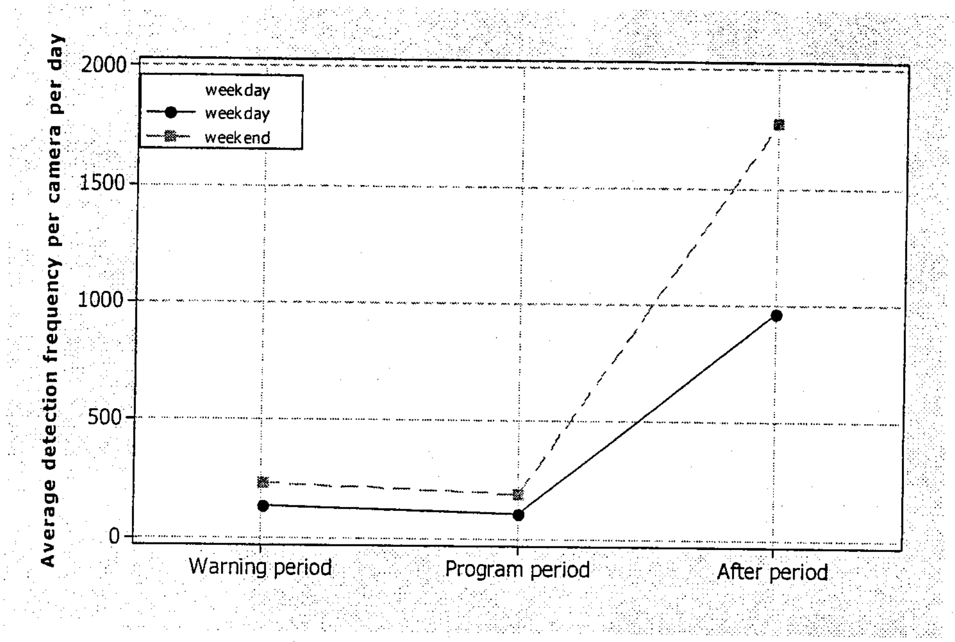


Figure 4: Average daily detection frequency by periods and day of week

The time series plots also suggest that the day of week is one of several important factors that affect the detection frequency. As previously discussed, the time series plots have periodical spikes when weekends and holidays are not excluded (see Figure 5 and Figure 8). However, more stable time series plots can be obtained when the day of week effects are eliminated from the time series plots (see Figure 6, Figure 7, Figure 8, Figure 9, and Figure 10).

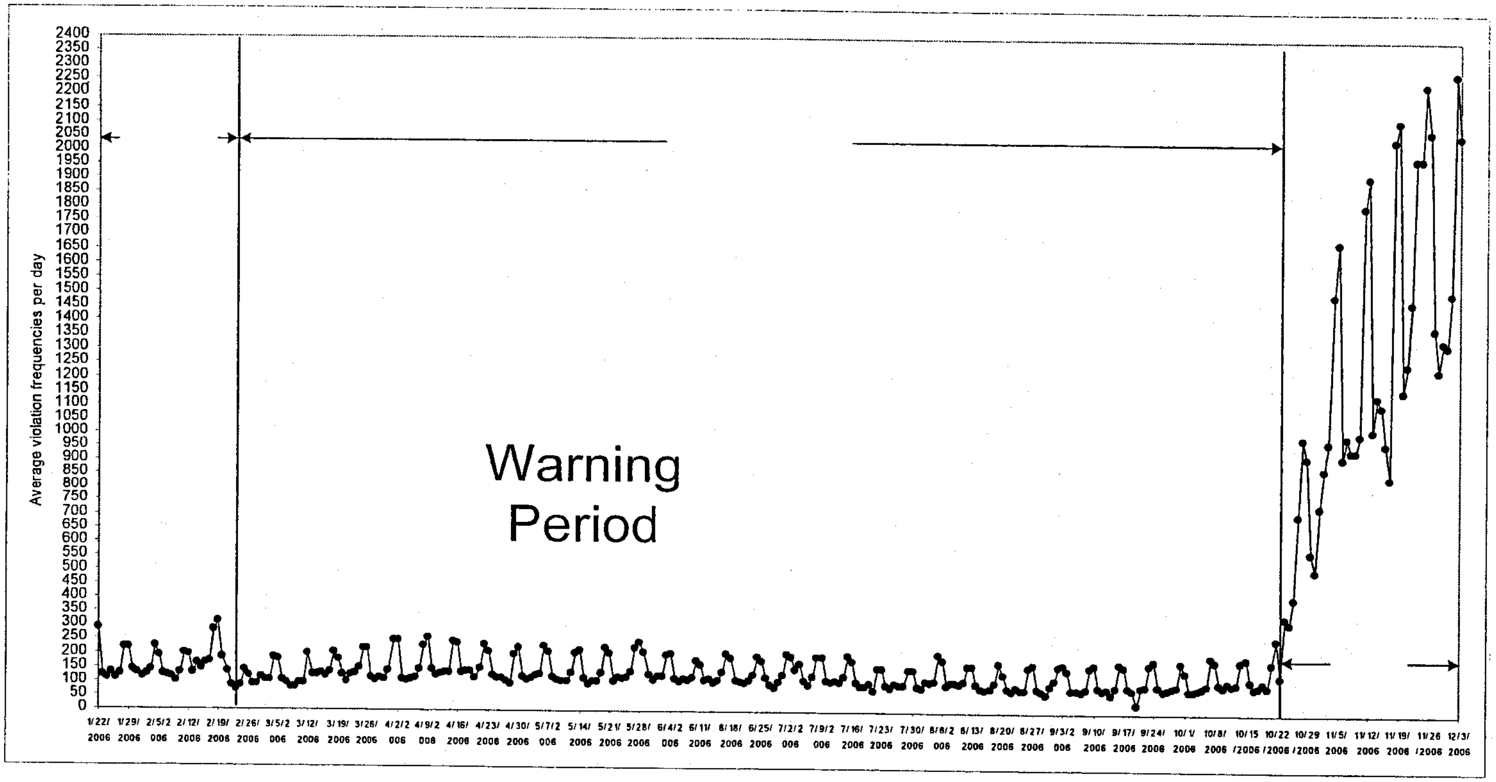


Figure 5: Average detection frequency per camera per day during the 3 periods

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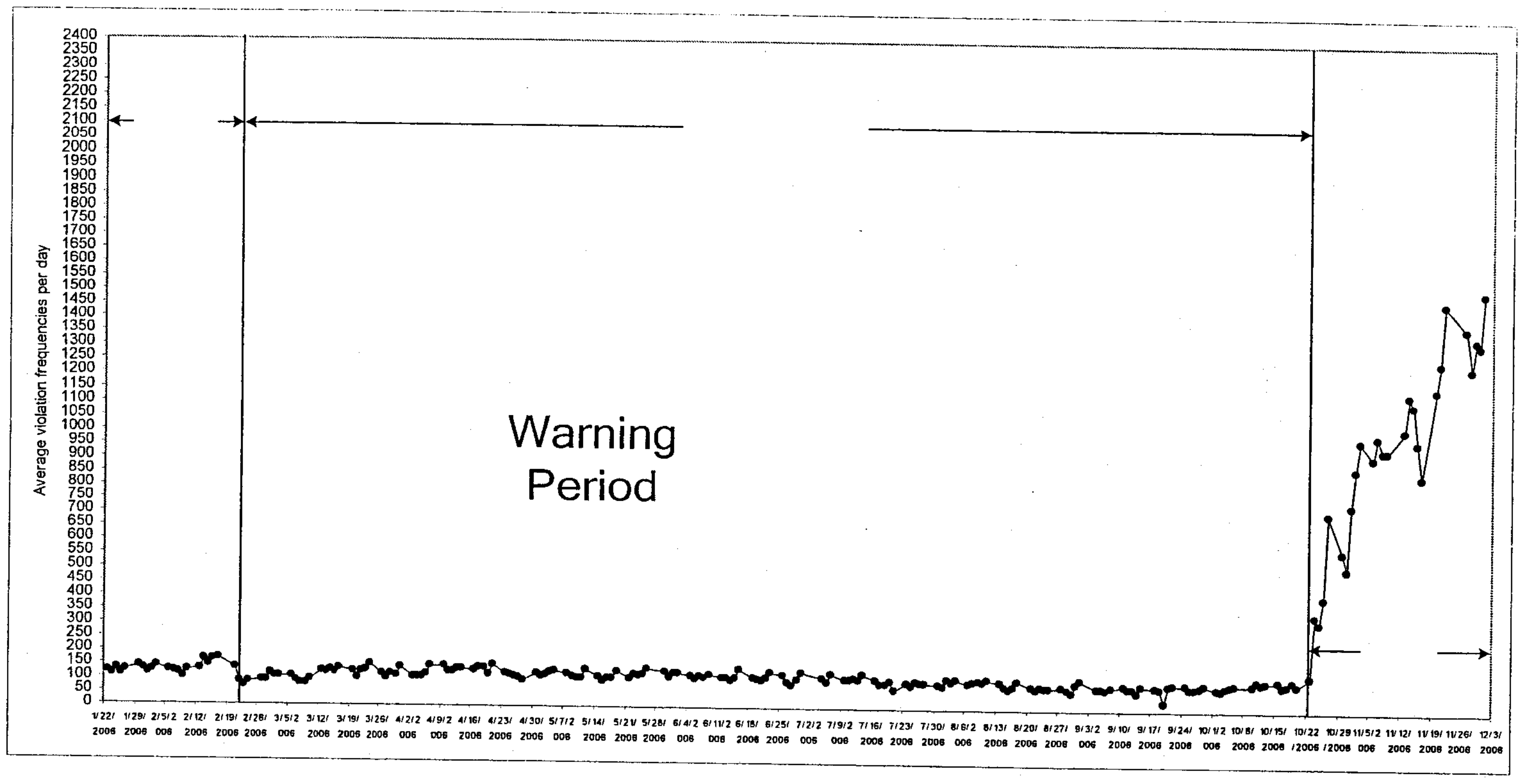

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Figure 6: Average detection frequency per camera per day during the 3 periods (weekday)

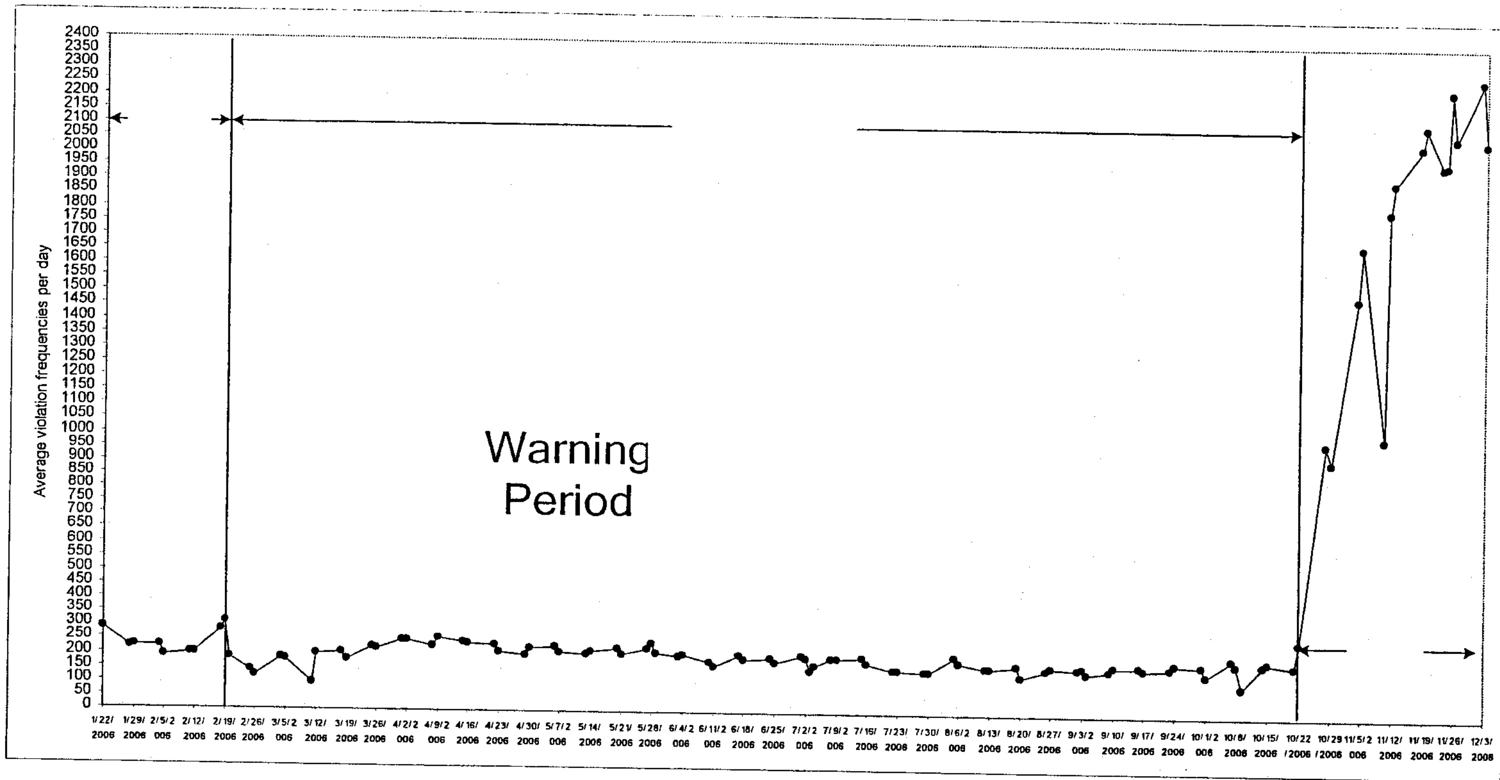

Figure 7: Average detection frequency per camera per day during the 3 periods (weekend and holiday)

Progra

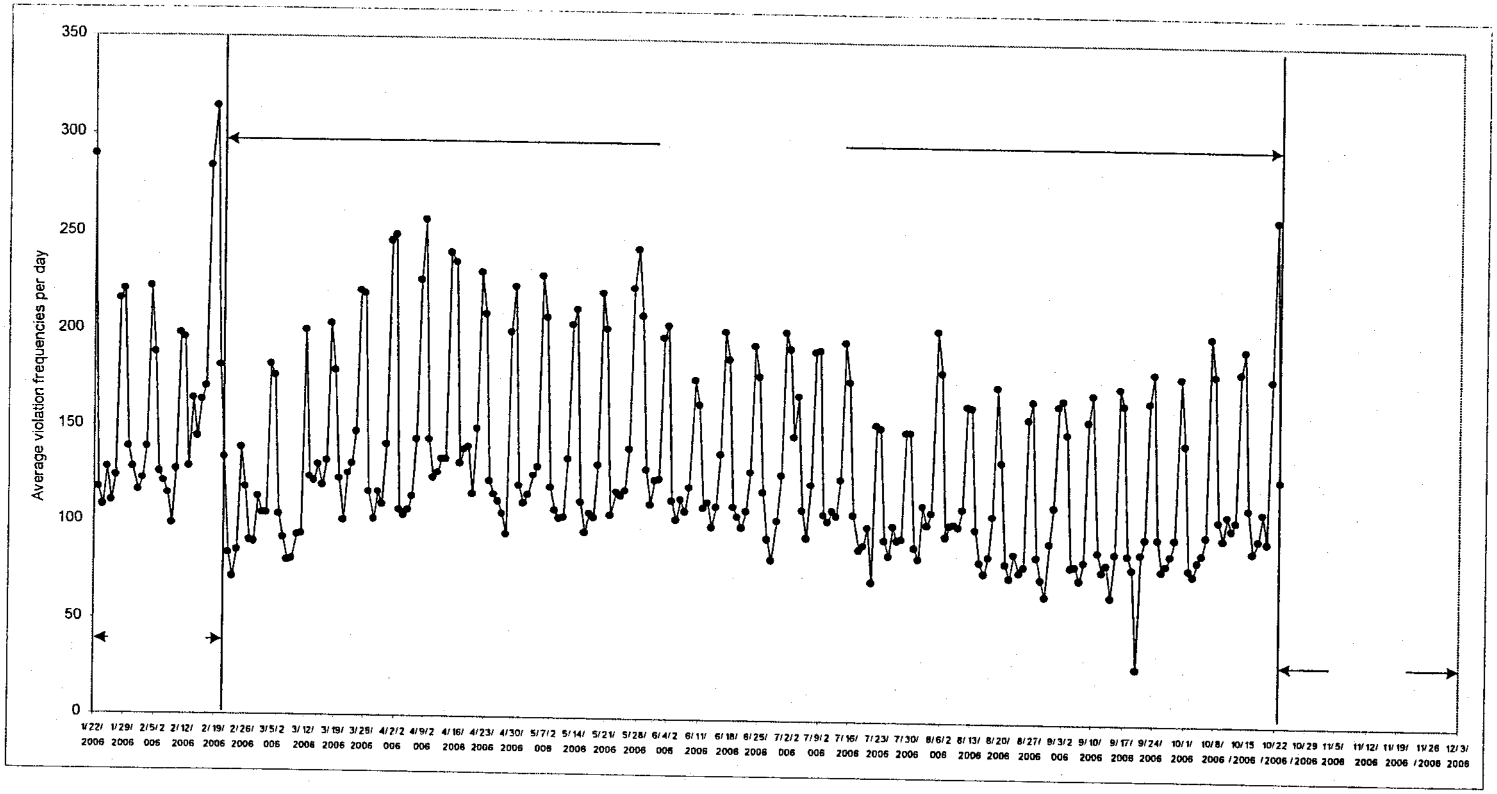

Figure 8: Average detection frequency per camera per day during the warning and program periods

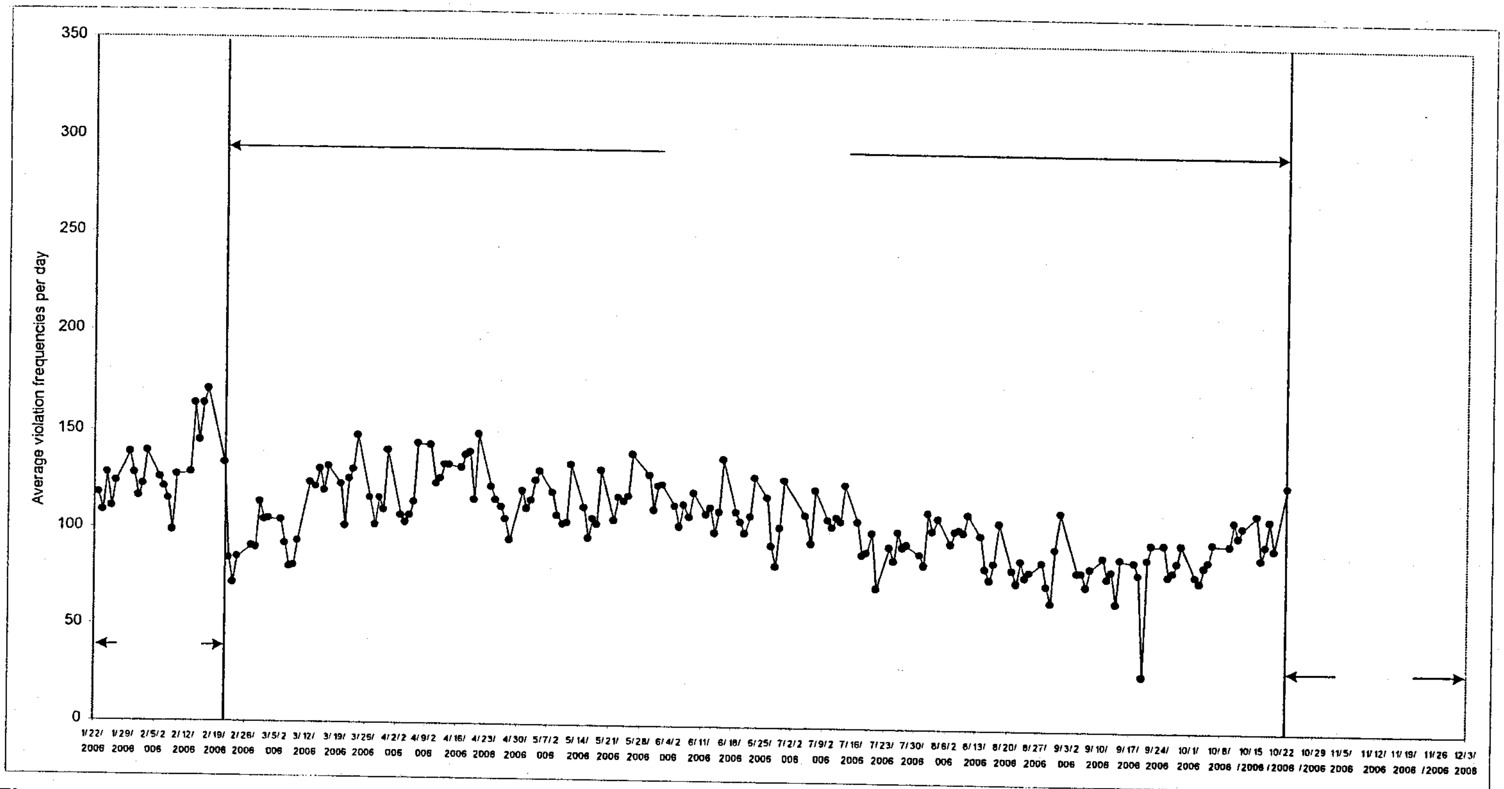

Figure 9: Average detection frequency per camera per day during the warning and program periods (weekday)

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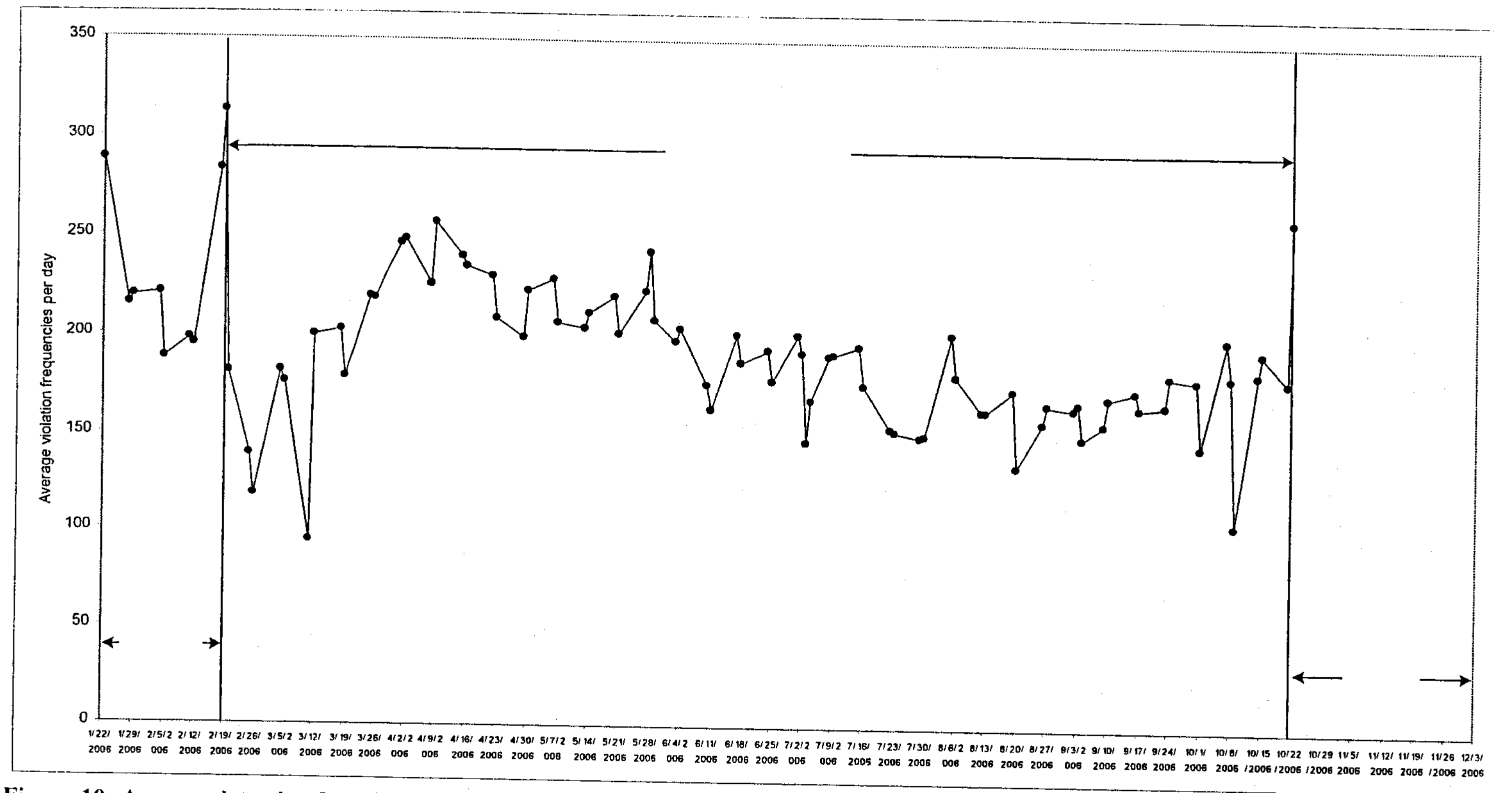

Figure 10: Average detection frequency per camera per day during the warning and program periods (weekend)

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3.1.2 Effects of SEP on the Detection Frequencies

3.1.2.1 Relationship between the Day of Week and Detection Frequencies

The preliminary findings suggest that detection frequencies are affected by the presence of the SEP, day of week, and weekend/holiday effects. Consequently, we first analyze whether detection frequencies are statistically different by day of the week.

The 3 analysis of variance (ANOVA) models summarized in Table 8 are used to investigate the day of week effects for the detection frequencies. The three models consist of the following:

- Model I: Two-factor ANOVA model using all periods
    - Factor A: The 3 periods (3 levels)
    - Factor B: Day of week (7 levels)
- Model II: Two-factor ANOVA model using all periods
    - Factor A: The 3 time periods (3 levels)
    - Factor B: Day of week and holiday (8 levels)
- Model III: Two-factor ANOVA model excluding the after period
    - Factor A: The 2 periods (2 levels)
    - Factor B: Day of week and holiday (8 levels)

Table 8: Preliminary ANOVA model results

Model	Source	DF	Seq SS	Adj SS	Adj MS	F	P	R^2
Model I	Period	2	271771764	271268992	135634496	1319.59	<.0001	0.59
	Day of week	6	12312285	12312285	2052047	19.96	<.0001	
	Error	1887	193955507	193955507	102785			
	Total	1895	478039556					
Model II	Period	2	271771764	254762692	127381346	1263.71	<.0001	0.60
	Day of week	7	16160536	16160536	2308648	22.9	<.0001	
	Error	1886	190107256	190107256	100799			
	Total	1895	478039556					
Model III	Period	1	174303	160750	160750	25.33	<.0001	0.20
	Day of week	7	2586658	2586658	369523	58.23	<.0001	
	Error	1641	10413067	10413067	6346			
	Total	1649	13174028					

The ANOVA model results in Table 8 show that the two factors are significant in all models at α=0.05. Note that the adjusted sum of squares (denoted as Adj SS) is used to conduct F-tests because the data are not balanced. Thus, detection frequencies are significantly associated with the two factors: the time period (*warning*, *program*, and *after*) and day of the week.

In addition, Tukey's pairwise comparisons are used to test whether or not the mean detection frequencies of each treatment level (e.g., day of week) are statistically different from each other. Table 9 shows the Tukey's pairwise comparison matrix, in which the null hypothesis is that the mean detection frequencies of the 2 days (a pair) are the same. Thus, if the p-value in a cell of the comparison matrix is less than a significance level (α=0.05), we could conclude that the difference in the mean detection frequencies of the 2 associated days is statistically significant (i.e., they are statistically not the same). For example, the p-value for Monday and Tuesday in the Model I (0.9505) indicates that the mean detection frequencies between Mondays and Tuesdays are not statistically different, while the p-value for Monday and Saturday in the Model I (<0.0001) indicates that the mean detection frequencies between Mondays and Saturdays are statistically different.

Table 9: Tukey pairwise comparison matrix with associated p-values

Model I	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	
Monday		0.9505	0.9932	1.000	0.9953	<.0001	<.0001	
Tuesday	0.9505		0.9999	0.9815	0.6429	<.0001	<.0001	
Wednesday	0.9932	0.9999		0.9988	0.8357	<.0001	<.0001	
Thursday	1	0.9815	0.9988		0.9822	<.0001	<.0001	
Friday	0.9953	0.6429	0.8357	0.9822		<.0001	<.0001	
Saturday	<.0001	<.0001	<.0001	<.0001	<.0001		1.000	
Sunday	<.0001	<.0001	<.0001	<.0001	<.0001	1.000		
Model II	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Holiday
Monday		0.9944	0.9999	0.9996	0.9998	<.0001	<.0001	<.0001
Tuesday	0.9944		0.9999	1.000	0.9124	<.0001	<.0001	<.0001
Wednesday	0.9999	0.9999		1.000	0.9891	<.0001	<.0001	<.0001
Thursday	0.9996	1.000	1.000		0.9749	<.0001	<.0001	<.0001
Friday	0.9998	0.9124	0.9891	0.9749		<.0001	<.0001	<.0001
Saturday	<.0001	<.0001	<.0001	<.0001	<.0001		1.000	0.0041
Sunday	<.0001	<.0001	<.0001	<.0001	<.0001	1.000		0.0037
Holiday	<.0001	<.0001	<.0001	<.0001	<.0001	0.0041	0.0037	
Model III	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Holiday
Monday		0.9774	0.9892	0.9974	0.9722	<.0001	<.0001	<.0001
Tuesday	0.9774		1.000	1.000	0.4532	<.0001	<.0001	<.0001
Wednesday	0.9892	1.000		1.000	0.5298	<.0001	<.0001	<.0001
Thursday	0.9974	1.000	1.000		0.6568	<.0001	<.0001	<.0001
Friday	0.9722	0.4532	0.5298	0.6568		<.0001	<.0001	<.0001
Saturday	<.0001	<.0001	<.0001	<.0001	<.0001		1.000	1.000
Sunday	<.0001	<.0001	<.0001	<.0001	<.0001	1.000		1.000
Holiday	<.0001	<.0001	<.0001	<.0001	<.0001	1.000	1.000	

Note: "H_0: The difference in the mean detection frequencies between two days is zero."

In Model I, the difference in the mean detection frequencies between Saturdays and Sundays is not significant (the 95% confidence interval for the difference is [−79.03, 82.99]; see Table 10). In addition, the mean detection frequency differences during weekdays are not statistically significant. However, the mean detection frequencies between weekdays and weekends are significantly different, in which the associated p-values are less than 0.001 as shown in Table 9.

In Model II, the Tukey's pairwise comparison matrix yields similar results: the mean detection frequencies for all weekdays are significantly different from those for weekends or holidays, while there is no significant difference in the mean detection frequencies between weekdays. However, the mean detection frequencies for holidays are not the same as those for Saturdays and Sundays. Since the significant difference might stem from the interaction between the periods and holiday effects, we reanalyzed the effect of holidays on the mean detection frequency by excluding the after period (see the results of Model III).

Model III also yields similar results: no difference in the mean detection frequencies between weekdays and significant difference in the mean detection frequencies between weekdays and weekends/holidays. Unlike the results in Model II, the mean detection frequency for holidays is not significantly different from the detection frequencies of weekends. Note that the difference in the mean detection frequencies between weekends and holidays is very small (–2.41 and –0.63; see Table 10).

The ANOVA model results show that the mean detection frequencies are significantly associated with the day of week as well as the time period of observation. Although the factor (i.e., the day of week) can be included in the analysis as a separate factor, the 2 sub-samples were used in the analyses discussed in the next subsection in order to develop parsimonious models.

Table 10: Differences in means and simultaneous 95% CI

Model I

Group A	Group B	Difference in means	95% CIs Lower	95% CIs Upper
Monday	Tuesday	28.03	-53.42	109.49
Monday	Wednesday	19.04	-62.42	100.51
Monday	Thursday	5.02	-76.44	86.49
Monday	Friday	-17.78	-99.25	63.68
Monday	Saturday	-169.63	-251.10	-88.16
Monday	Sunday	-167.65	-248.66	-86.64
Tuesday	Wednesday	-8.99	-90.45	72.47
Tuesday	Thursday	-23.01	-104.46	58.45
Tuesday	Friday	-45.81	-127.27	35.64
Tuesday	Saturday	-197.66	-279.12	-116.20
Tuesday	Sunday	-195.68	-276.68	-114.68
Wednesday	Thursday	-14.02	-95.46	67.42
Wednesday	Friday	-36.83	-118.27	44.62
Wednesday	Saturday	-188.67	-270.12	-107.23
Wednesday	Sunday	-186.69	-267.70	-105.68
Thursday	Friday	-22.81	-104.25	58.63
Thursday	Saturday	-174.66	-256.10	-93.21
Thursday	Sunday	-172.68	-253.69	-91.67
Friday	Saturday	-151.85	-233.29	-70.41
Friday	Sunday	-149.87	-230.88	-68.86
Saturday	Sunday	1.98	-79.03	82.99

Model II

Group A	Group B	Difference in means	95% CIs Lower	95% CIs Upper
Monday	Tuesday	21.95	-63.98	107.88
Monday	Wednesday	10.72	-74.75	96.19
Monday	Thursday	14.56	-71.37	100.48
Monday	Friday	-13.17	-99.59	73.25
Monday	Saturday	-149.69	-238.81	-60.57
Monday	Sunday	-149.24	-237.75	-60.72
Monday	Holiday	-280.07	-383.76	-176.39
Tuesday	Wednesday	-11.23	-94.64	72.17
Tuesday	Thursday	-7.39	-91.28	76.49
Tuesday	Friday	-35.12	-119.53	49.29
Tuesday	Saturday	-171.64	-258.81	-84.47
Tuesday	Sunday	-171.19	-257.72	-84.65
Tuesday	Holiday	-302.02	-403.87	-200.17
Wednesday	Thursday	3.84	-79.55	87.23
Wednesday	Friday	-23.89	-107.80	60.03
Wednesday	Saturday	-160.41	-247.08	-73.73
Wednesday	Sunday	-159.95	-246.02	-73.88
Wednesday	Holiday	-290.79	-392.35	-189.24
Thursday	Friday	-27.73	-112.07	56.62
Thursday	Saturday	-164.24	-251.35	-77.14
Thursday	Sunday	-163.79	-250.29	-77.29
Thursday	Holiday	-294.63	-396.73	-192.53
Friday	Saturday	-136.52	-224.09	-48.94
Friday	Sunday	-136.07	-223.04	-49.09
Friday	Holiday	-266.90	-369.58	-164.23
Saturday	Sunday	0.45	-89.21	90.12
Saturday	Holiday	-130.39	-235.28	-25.49
Sunday	Holiday	-130.84	-235.18	-26.50

Model III

Group A	Group B	Difference in means	95% CIs Lower	95% CIs Upper
Monday	Tuesday	7.46	-15.67	30.58
Monday	Wednesday	6.53	-16.45	29.51
Monday	Thursday	5.17	-17.81	28.15
Monday	Friday	-7.69	-30.67	15.29
Monday	Saturday	-81.57	-105.34	-57.80
Monday	Sunday	-83.34	-106.94	-59.75
Monday	Holiday	-83.97	-113.79	-54.16
Tuesday	Wednesday	-0.93	-23.43	21.57
Tuesday	Thursday	-2.29	-24.79	20.22
Tuesday	Friday	-15.15	-37.65	7.36
Tuesday	Saturday	-89.02	-112.34	-65.71
Tuesday	Sunday	-90.80	-113.92	-67.68
Tuesday	Holiday	-91.43	-120.86	-62.00
Wednesday	Thursday	-1.36	-23.71	20.99
Wednesday	Friday	-14.22	-36.57	8.13
Wednesday	Saturday	-88.10	-111.25	-64.94
Wednesday	Sunday	-89.87	-112.85	-66.89
Wednesday	Holiday	-90.50	-119.85	-61.16
Thursday	Friday	-12.86	-35.21	9.49
Thursday	Saturday	-86.74	-109.90	-63.58
Thursday	Sunday	-88.51	-111.49	-65.53
Thursday	Holiday	-89.14	-118.49	-59.80
Friday	Saturday	-73.88	-97.04	-50.72
Friday	Sunday	-75.65	-98.63	-52.67
Friday	Holiday	-76.28	-105.63	-46.94
Saturday	Sunday	-1.77	-25.55	22.00
Saturday	Holiday	-2.41	-32.39	27.57
Sunday	Holiday	-0.63	-30.45	29.18

3.1.2.2 Analysis Results

The effects of the SEP on detection frequencies were analyzed in terms of the 2 time periods ("Weekdays" and "Weekends and Holidays") as discussed in the previous subsection, and the fixed-effect ANOVA models were used for the 2 time periods. Since the site effects also exist, two factors (i.e., period and site) were used in the two-factor ANOVA models, in which the sites serve as blocks. In addition, the interaction between the block and the fixed factor *period* is included in the full model. Table 11 shows the ANOVA model results, in which all factors are significant at α=0.05.

Table 11: ANOVA model results

Model	Source	DF	Seq SS	Adj SS	Adj MS	F	P	R^2
Weekday	Period	2	100686443	100686443	50343222	2058.99	<.0001	0.83
	Block (Site)	5	17274370	26633511	5326702	217.86	<.0001	
	Period*Site	10	30822283	30822283	3082228	126.06	<.0001	
	Error	1278	31247607	31247607	24450			
	Total	1295	180030703					
Weekend and Holiday	Period	2	191371652	191371652	95685826	2006.4	<.0001	0.90
	Block (Site)	5	21165487	29718887	5943777	124.63	<.0001	
	Period*Site	10	37973515	37973515	3797351	79.63	<.0001	
	Error	582	27755754	27755754	47690			
	Total	599	278266408					

Since our interest is in comparing the mean detection frequencies for each time period, the mean detection frequencies for each period shown in Table 12 are simultaneously compared. The Tukey's pairwise comparison method was again used, and the comparison results in Table 13 show that the difference in the mean detection frequencies between the warning and program periods is not significant (p-values are 0.1955 and 0.3203), while the mean detection frequencies of the *warning* and *program* periods are significantly different from those of the *after* period.

Table 12: Factor level means and 95% CI

Day of week	Period	Mean detection frequency	95% CIs	
			Lower	Upper
Weekday	Warning period	129.69	102.36	157.02
	Program period	104.18	94.55	113.82
	After period	963.28	938.72	987.84
Weekend and Holiday	Warning period	230.47	175.09	285.84
	Program period	187.20	166.98	207.42
	After period	1773.52	1728.31	1818.73

Table 13: Tukey pairwise comparison results

Day of week	Pair	Difference	P-value	95% CIs	
				Lower	Upper
Weekday	"Warning"–"Program"	25.51	0.1955	-9.15	60.17
	"Warning"–"After"	-833.59	<0.0001	-877.54	-789.64
	"Program"–"After"	-859.10	<0.0001	-890.65	-827.54
Weekend and Holiday	"Warning"–"Program"	43.27	0.3203	-27.26	113.79
	"Warning"–"After"	-1543.06	<0.0001	-1628.58	-1457.53
	"Program"–"After"	-1586.32	<0.0001	-1645.57	-1527.07

Using the Tukey pairwise comparison results, the relative changes are estimated and summarized in Table 14.

Table 14: Relative changes in the detection frequencies

Day of week	Pair	Difference	95% CIs	
			Lower	Upper
Weekday	"Warning"–"Program"	-0.20	-0.46	0.07
	"Warning"–"After"	6.43	6.09	6.77
	"Program"–"After"	8.25	7.94	8.55
Weekend and Holiday	"Warning"–"Program"	-0.19	-0.49	0.12
	"Warning"–"After"	6.70	6.32	7.07
	"Program"–"After"	8.47	8.16	8.79

The estimated results show that:

- After the SEP was implemented, the detection frequencies decreased by 20% (or 19%) from the *warning* to *program* period. However, the decrease in the detection frequencies is not statistically significant.
- After the SEP ended, the detection frequencies increased 825 % (or 847%) from the *program* to those in the *after* period.

3.2 Changes in the Mean Speed

In this section, the effects of the SEP on the mean speed are analyzed by comparing the mean speeds that were collected from the enforcement zone during the *before* and *program* periods. Unlike the analysis for the changes in the detection frequency, the mean speeds during the *after* period are not compared in this analysis due to incomplete data. The analysis was conducted using mean speeds during unconstrained traffic conditions, since traffic congestion will impact traffic speeds.

3.2.1 Data Description

In this subsection, the speed data obtained from the enforcement zone during the *before* period (see Table 15) are summarized, and the speed data during the *program* period are described in the analysis subsection.

Table 15: Description of the 6 measurement sites for the *before* period

ID	Direction	Location	Measurement date		
1	NB	CACTUS RD & SHEA BLVD	4/13/2005	4/14/2005	4/15/2005
2	SB	CACTUS RD & SHEA BLVD	4/13/2005	4/14/2005	4/15/2005
3	NB	RAINTREE DR & CACTUS RD	4/19/2005	4/20/2005	4/21/2005
4	SB	RAINTREE DR & CACTUS RD	4/19/2005	4/20/2005	4/21/2005
5	NB	SCOTTSDALE RD & PIMA/PRINCESS DR	6/27/2005	6/28/2005	6/29/2005
6	SB	SCOTTSDALE RD & PIMA/PRINCESS DR	6/27/2005	6/28/2005	6/29/2005

In order to reduce the variance from the different measurement dates, the middle of the day (24 hours) was consistently used in this analysis (i.e., 4/14/2005; 4/20/2005; 6/28/2005). The descriptive statistics for the speed data are summarized in Table 16, in which an individual speed data observation is the aggregated mean speed in each lane during 15 minute intervals. For instance, the mean speed at site i ($\overline{S_{i\bullet}}$) is estimated by the aggregated mean speed at site i during the jth interval (S_{ij}).

$$\overline{S_{i\bullet}} = \frac{\sum_{j=1}^{n_i} S_{ij}}{n_i}$$

where $i = 1, 2, \cdots, 6$ and $j = 1, 2, \cdots, n_i$.

Table 16: Summary of statistics for speed by site

Site ID	Mean	Std. Dev.	Min.	Median	Max.	N (n_i)
1	70.40	6.46	46	71	83	288
2	75.17	5.35	43	75	90	288
3	70.83	4.90	62	70	87	384
4	77.27	4.51	52	78	91	384
5	70.67	6.14	40	72	83	288
6	73.22	7.70	31	74	87	288

It is important to note that the number of intervals at each site (n_i) depends on the number of lanes (i.e., n_i = number of lanes × 1,440/15). Before comparing the speed data of the *before* period to those of the *program* period, the relationship between speed and traffic flow in is examined.

3.2.2 The Speed-Flow Relationship and Level of Service

There are three commonly referenced macroscopic parameters to describe a traffic stream: speed, density, and rate of flow. They are related as follows:

$$V = S \times D$$

- V= Rate of flow (vehicle/hour/lane)
- S= Space mean speed (mph)
- D= Density (vehicles/mile/lane)

Density and speed are parameters for a specific section, while rate of flow is a parameter for a point. There have been a number of studies to reveal the shape of these relationships, but the relationship depends upon prevailing conditions. Figure 11 shows a recently depicted speed-flow relationship (Transportation Research Board, 2000), which is a typical of traffic patterns on uninterrupted flow facilities.

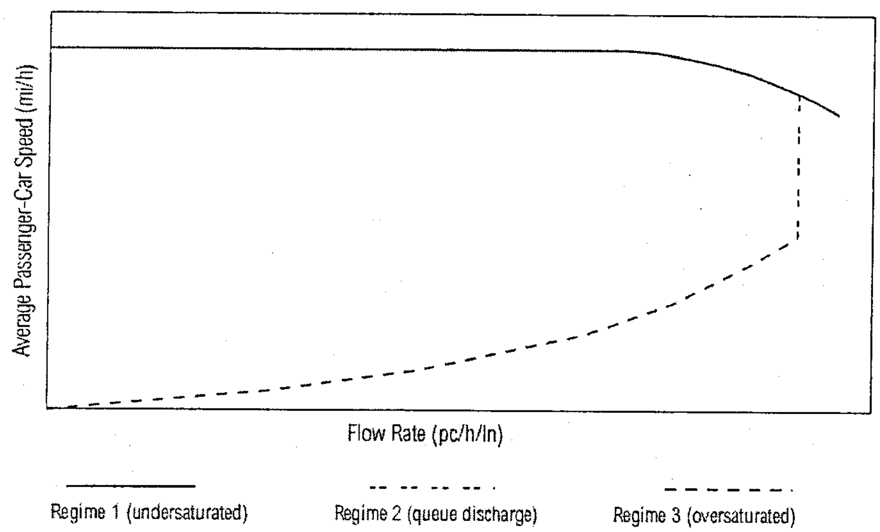


Figure 11: Speed-flow curve [Source: HCM 2000]

The three identified regimes of the speed-flow curve in Figure 11 can be described as follows (Roess *et al.*, 2004):

- Regime 1: This regime is in the stable (or undersaturated) condition where drivers can maintain a high speed that is unaffected by upstream or downstream conditions. The flat portion of the curves usually defines free-flow speed. Speed begins to decline in response to increasing flow rates. However, the total decline in speed from free-flow speed to the speed at capacity is often 5mi/h or less.

- The inflection point, which indicates the flow rate at which speed begins to decline, is often in the range of 1,500–1,700 pc/h/ln (passenger cars per hour per lane).
- Note that the path from free-flow speed to capacity is often associated with a relatively small increase in the flow rate.

- Regime 2: This portion of the curve is called "queue discharge." Once demand exceeds capacity, a breakdown occurs and a queue propagates upstream of the point of breakdown. Once the queue forms, flow is restricted to what is discharged from the front of the queue. The variable speed for Regime 3 reflects the fact that vehicles discharge from a queue into an uncongested downstream segment.
- Regime 3: This portion of the curve reflects the unstable operating conditions within the queue, upstream of the breakdown, in which traffic flow is influenced by the effects of a downstream condition. Traffic flow in the regime can vary over a broad range of flows and speeds depending on the congestion severity.

  Unlike a stable flow condition, queue discharge and congested flow have not been extensively studied. Thus, the speed-flow curve for the two regimes should be considered conceptual at best. Further research is needed to better define flow in these two regimes.

The modern speed-flow curve implies that the effects of traffic flow on speed are different across regimes. Since focus in this study is on the speed distribution in regime 1 rather than that in regimes 2 or 3, it is necessary to determine and classify regime 1. The concept of the level of service (LOS) is applied to identify regime 1 (undersaturated).

In general, LOS is characterized using three performance measures: density in terms of passenger cars per mile per lane, speed in terms of mean passenger-car speed, and the volume-to-capacity (v/c) ratio. Each of these measures is an indication of how well traffic flow is being accommodated by the freeway. For a basic freeway section, the LOS is defined by reasonable ranges using the 3 critical flow variables: speed, density, and flow rate. Figure 12 shows the speed-flow curves that depend on free-flow speeds. All curves have the same speed-flow relationship for regimes 1 and 2 as illustrated in Figure 11, but each curve has a different intercept that depends on free-flow speed. In addition, each LOS has the minimum or maximum values for the 3 parameters. The minimum or maximum values for the parameters are summarized in Table 17, which can be used to determine LOS.

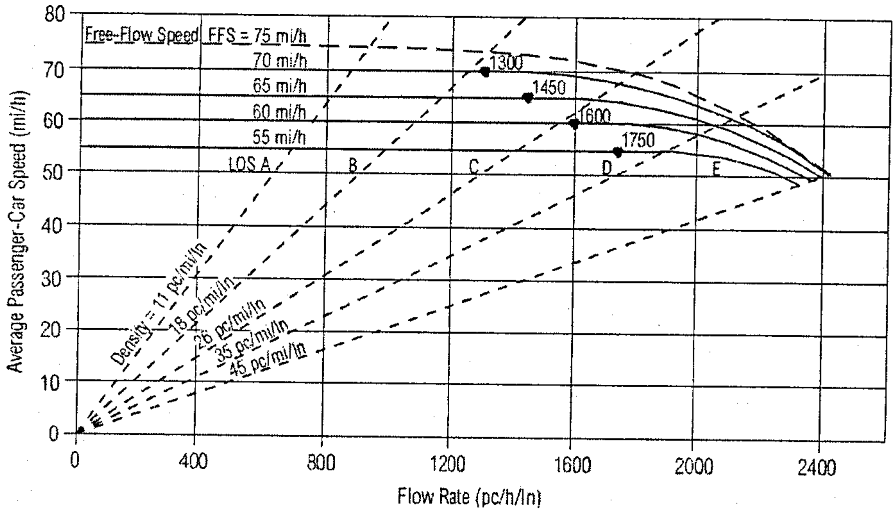


Figure 12: Speed-flow curves and LOS on a basic freeway segment [Source: HCM 2000]

Table 17: LOS criteria for basic freeway sections

Criteria	LOS				
	A	B	C	D	E
FFS = 75 mi/h					
Maximum density (pc/mi/ln)	11	18	26	35	45
Minimum speed (mi/h)	75.0	74.8	70.6	62.2	53.3
Maximum v/c	0.34	0.56	0.76	0.90	1.00
Maximum service flow rate (pc/h/ln)	820	1350	1830	2170	2400
FFS = 70 mi/h					
Maximum density (pc/mi/ln)	11	18	26	35	45
Minimum speed (mi/h)	70.0	70.0	68.2	61.5	53.3
Maximum v/c	0.32	0.53	0.74	0.90	1.00
Maximum service flow rate (pc/h/ln)	770	1260	1770	2150	2400
FFS = 65 mi/h					
Maximum density (pc/mi/ln)	11	18	26	35	45
Minimum speed (mi/h)	65.0	65.0	64.6	59.7	52.2
Maximum v/c	0.30	0.50	0.71	0.89	1.00
Maximum service flow rate (pc/h/ln)	710	1170	1680	2090	2350
FFS = 60 mi/h					
Maximum density (pc/mi/ln)	11	18	26	35	45
Minimum speed (mi/h)	60.0	60.0	60.0	57.6	51.1
Maximum v/c	0.29	0.47	0.68	0.88	1.00
Maximum service flow rate (pc/h/ln)	660	1080	1560	2020	2300
FFS = 55 mi/h					
Maximum density (pc/mi/ln)	11	18	26	35	45
Minimum speed (mi/h)	55.0	55.0	55.0	54.7	50.0
Maximum v/c	0.27	0.44	0.64	0.85	1.00
Maximum service flow rate (pc/h/ln)	600	990	1430	1910	2250

The general definitions of LOS are as follows (Transportation Research Board, 2000):

- LOS A describes free-flow operations. Free-flow speeds prevail. Vehicles are almost completely unimpeded in their ability to maneuver within the traffic stream. The effects of incidents or point breakdowns are easily absorbed at this level.
- LOS B represents reasonably free flow, and free-flow speeds are maintained. The ability to maneuver within the traffic stream is only slightly restricted, and the general level of physical and psychological comfort provided to drivers is still high. The effects of minor incidents and point breakdowns are still easily absorbed.
- LOS C provides for flow with speeds at or near the FFS of the freeway. Freedom to maneuver within the traffic stream is noticeably restricted, and lane changes require more care and vigilance on the part of the driver. Minor incidents may still be absorbed, but the local deterioration in service will be substantial. Queues may be expected to form behind any significant blockage.
- LOS D is the level at which speeds begin to decline slightly with increasing flows and density begins to increase somewhat more quickly. Freedom to maneuver within the traffic stream is more noticeably limited, and the driver experiences reduced physical and psychological comfort levels. Even minor incidents can be expected to create queuing, because the traffic stream has little space to absorb disruptions.
- LOS E describes operation at capacity. Operations at this level are volatile, because there are virtually no usable gaps in the traffic stream. Vehicles are closely spaced, leaving little room to maneuver within the traffic stream at speeds that still exceed 49 mi/h. Any disruption of the traffic stream, such as vehicles entering from a ramp or a vehicle changing lanes, can establish a disruption wave that propagates throughout the upstream traffic flow. At capacity, the traffic stream has no ability to dissipate even the most minor disruption, and any incident can be expected to produce a serious breakdown with extensive queuing. Maneuverability within the traffic stream is extremely limited, and the level of physical and psychological comfort afforded the driver is poor.
- LOS F describes breakdowns in vehicular flow. Such conditions generally exist within queues forming behind breakdown points.

3.2.3 Effect of the SEP on Mean Speeds

In order to control for the measurement date and day of week effects, the traffic volume and speed data obtained from the enforcement zone during the program period were carefully selected from the set of the speed and traffic flow data collected during the program period. Therefore, the speed and traffic flow data during the 3 identical times and days of the program period (Table 15) were selected: 4/13/2006 (Thursday), 4/19/2006 (Wednesday), and 6/27/2006 (Thursday). The descriptive statistics for the speed data during the *before* and *program* periods are summarized in Table 18.

Table 18: Summary statistics for the speed during the before and program periods

Period	Mean	Std.Dev.	Min	Max	N
Before	72.56	5.12	32.9	82	576
Program	63.17	4.42	19	68.33	1709
Total	65.54	6.15	19	82	2285

In order to analyze the effect of the SEP on mean speed, the analysis of covariance (ANCOVA) models were used. Note that the ANCOVA model is essentially the same as the general linear regression model, but the terminology ANCOVA model is consistently used in this analysis because our interest lies in testing whether of not the aggregated factors are significant. We used 6 ANCOVA models to test numerous assumptions. The results of the testing are summarized in Table 19.

The measurement date effects were tested by adding the variable *Date* and the interaction between *Date* and *Period* in Models I and II. The ANCOVA model results show that the measurement date effect is not significant, indicating that the speed and traffic flow data are independent random samples. In Model III, the interaction between *Period* and the covariate *Traffic Flow* are tested. The result shows that there is no significant evidence supporting an interaction between the variables. Figure 13 also shows that the interaction is not significant, but the mean speed has different intercepts for the 2 periods (the intercept for the before period is greater than that for the program period). However, the linear relationship does not hold because the data include the traffic volume and speed for regime 3 as well as regime 1 and 2, which were discussed in the previous section (see "The Speed-Flow Relationship and Level of Service" on page 39). Therefore, it is necessary to exclude the speed data from regime 3 in order to precisely estimate the effect of the SEP on mean speed.

In order to determine the borderline between regime 2 and regime 3, we used the concept of the LOS discussed in the previous section. The 70 mph speed was used as the free flow speed for determining the LOS, and the LOS A, B, C, and D are selected based on the given criteria in Table 17 (i.e., speed for LOS D: 61.5 mph). Consequently, the sample size was reduced from 1,560 intervals to 1,390 intervals, and the ANCOVA model was re-estimated. The result shown in Table 19 (Model V) indicates that the covariate traffic flow remains significant with the factor of interest *Period.*

Table 19: The ANCOVA model results

Model	Source	DF	Seq SS	Adj SS	Adj MS	F	P	Adj R^2
Model I	Traffic Flow	1	5950	6200	6200	432.21	<.0001	0.6076
	Period	1	28698.6	28688.2	28688.2	1999.87	<.0001	
	Date	2	35.8	35.8	17.9	1.25	0.287	
	Error	1555	22306.5	22306.5	14.3			
	Total	1559	56990.9					
Model II	Traffic Flow	1	5950	6149.5	6149.5	428.91	<.0001	0.6078
	Period	1	28698.6	3867.6	3867.6	269.75	<.0001	
	Date	2	35.8	61.3	30.6	2.14	0.118	
	Period* Date	2	40.4	40.4	20.2	1.41	0.245	
	Error	1553	22266.1	22266.1	14.3			
	Total	1559	56990.9					
Model III	Traffic Flow	1	5950	4576	4576	318.7	<.0001	0.6073
	Period	1	28699	7962	7962	554.57	<.0001	
	Traffic Flow*Period	1	3	3	3	0.21	0.648	
	Error	1556	22339	22339	14			
	Total	1559	56991					
Model IV	Traffic Flow	1	5950	6271	6271	436.98	<.0001	0.6075
	Period	1	28699	28699	28699	1999.96	<.0001	
	Error	1557	22342	22342	14			
	Total	1559	56991					
Model V	Traffic Flow	1	688	1829	1829	475.85	<.0001	0.8222
	Period	1	24011	24011	24011	6246.98	<.0001	
	Error	1387	5331	5331	4			
	Total	1389	30030					
Model VI	Traffic Flow	1	688.5	1962.2	1962.2	526.94	<.0001	0.8278
	Period	1	24010.6	8634.5	8634.5	2318.75	<.0001	
	Traffic Flow*Period	1	169.9	169.9	169.9	45.62	<.0001	
	Error	1386	5161.1	5161.1	3.7			
	Total	1389	30030					

In addition, the interaction between *Period* and the covariate *Traffic Flow* is significant as shown in Table 19 (see the results for Model VI) and Figure 14, when using the data on regime 1 and 2.

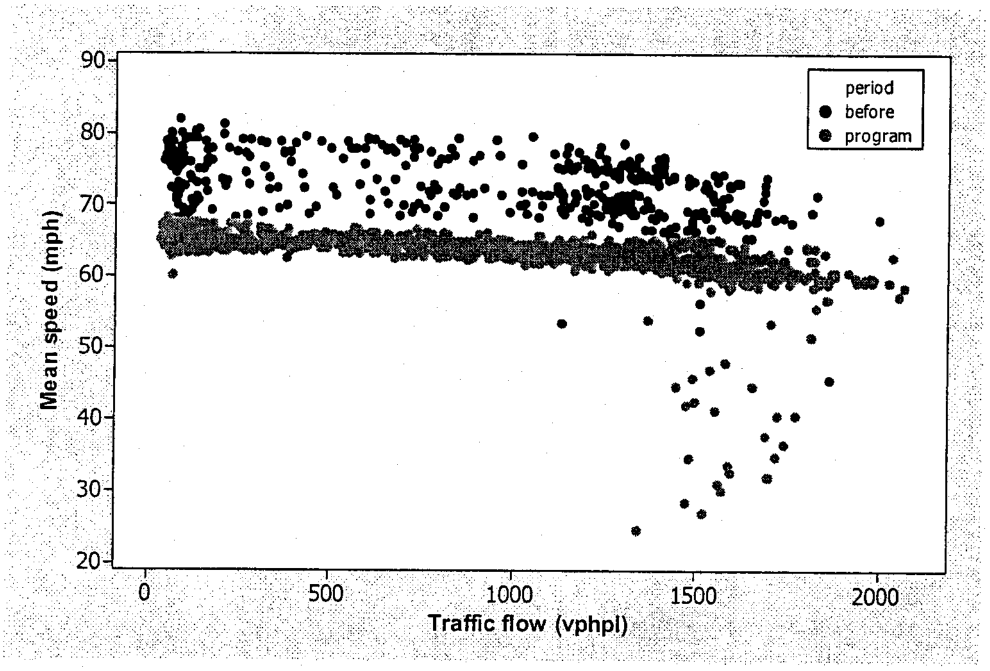


Figure 13: Speed-traffic flow relationship by period (all regimes)

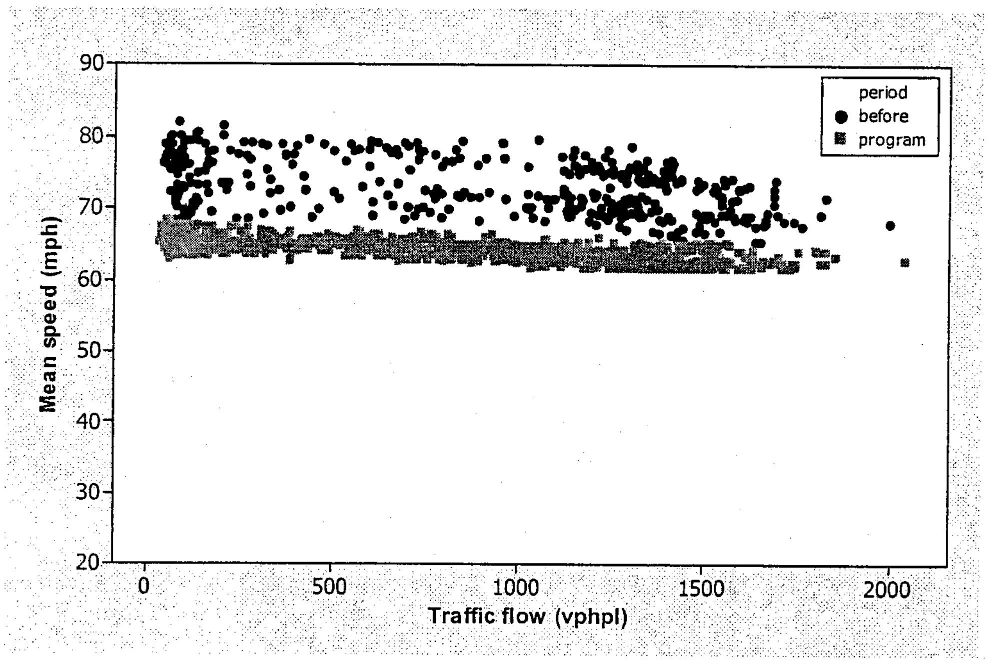


Figure 14: Speed-traffic flow relationship by period (regime 1 and 2)

Since Model VI shows a superior adjusted R^2 and smaller MSE, Model VI was used to estimate the effect of the SEP on mean speed. Table 20 shows the estimated factor level means (mean speeds) and associated statistics, which were derived from Model VI. By using the estimated mean speeds and MES of the Model VI, the difference in the mean speed between the before and program periods was estimated as shown in Table 20.

Table 20: Estimated factor level means and associated statistics

Period	Mean speed	Std.Err.	P-value	95% CIs	
				Lower	Upper
Before period (1)	73.57	0.0995	<.0001	73.377	73.767
Program period (2)	64.17	0.0611	<.0001	64.045	64.285
Difference	–9.407	0.1168	<.0001	–9.636	–9.178

Again, the percent change is obtained using these estimates. The estimated results reveal that:

- After the demonstration program was implemented, the mean speed decreased by 12.78% (9.4 mph) compared to that of the *before* period.
- The effect of the SEP on the mean speed is estimated to be between 12.48% (9.78 mph reduction) and 13.09% (9.64 mph reduction).
- It is very likely that most of this speed drop is due to compression of speeds of upper decile drivers (drivers with speeds in top 10%) because the speed data on regime 3 were eliminated from this analysis.

3.2.4 Changes in Mean Speed at the Comparison Site

In this subsection, the change in the mean speed at the comparison site during the before and program periods is analyzed. The same approaches employed in the previous subsection are used to analyze the change in the mean speed at the comparison site. Examining the change in mean speed at the comparison sites provides a test to determine if there is evidence of a spillover effect from the SEP on the comparison site. Note that international experience has not revealed significant spillover effects in this regard.

3.2.4.1 Data Description

The comparison site is located on the west side of SR 101 between Northern Ave. and Glendale Ave. (see Figure 15). The traffic volume and mean speed data used in this analysis were collected from October 2005 to September 2006, and the summary statistics for the mean speeds are summarized in Table 21 and Table 22.

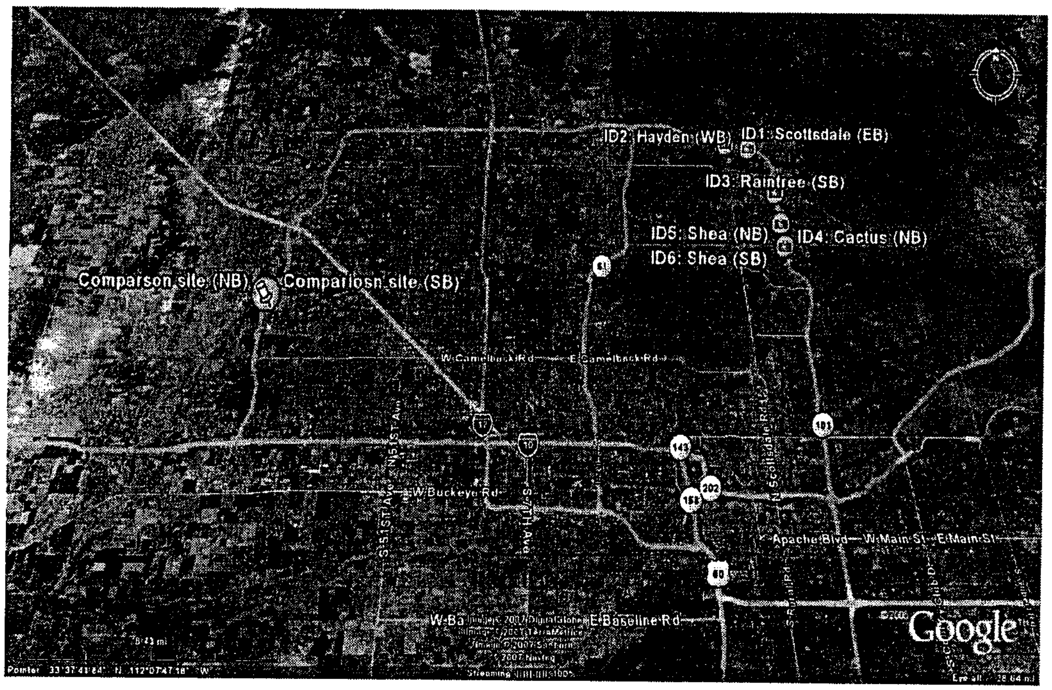


Figure 15: Location of the comparison site

Regardless of the direction, the mean speed fluctuated around 70 mph to 68 mph. The trend in the mean speed by month is shown in Figure 16 and Figure 17, in which LOS C based on the free-flow speed 70 mph was used to eliminate the mean speeds in regime 3. After eliminating the speed data in regime 3, the variance of the mean speeds is reduced, and the mean speeds are not remarkably different from those of all regimes. In the next subsection, the statistical difference in the mean speeds during the before and program periods is analyzed.

Table 21: Summary statistics for the mean speed at the comparison site for 9 months (all regimes)

Period	Month	North bound					South bound					All directions				
		Mean	Std. dev	Min	Max	N	Mean	Std. dev	Min	Max	N	Mean	Std. dev	Min	Max	N
Before	Oct-05	68.99	1.78	47.33	72.10	504	69.36	3.40	54.68	73.57	480	69.17	2.70	47.33	73.57	984
Warning	Feb-06	68.80	1.89	45.03	72.37	336	66.95	5.50	45.00	71.72	336	67.87	4.21	45.00	72.37	672
Program	Mar-06	67.82	3.09	45.06	70.91	336	68.26	1.40	62.41	71.18	336	68.04	2.41	45.06	71.18	672
	Apr-06	68.91	1.74	47.53	71.59	336	69.31	1.17	65.56	73.22	336	69.11	1.49	47.53	73.22	672
	May-06	68.02	0.91	63.70	70.79	360	67.65	3.97	45.00	71.86	360	67.84	2.88	45.00	71.86	720
	Jun-06	68.66	1.05	61.11	71.26	336	68.38	2.46	55.50	71.33	336	68.52	1.89	55.50	71.33	672
	Jul-06	68.77	1.33	53.70	71.19	336	67.16	2.67	45.19	70.14	336	67.96	2.26	45.19	71.19	672
	Aug-06	68.62	1.47	54.63	71.08	360	67.35	2.13	51.23	70.27	360	67.98	1.94	51.23	71.08	720
	Sep-06	68.96	1.55	47.33	71.66	336	67.89	1.78	57.59	71.63	336	68.43	1.75	47.33	71.66	672
Total		68.63	1.79	45.03	72.37	3240	68.09	3.15	45.00	73.57	3216	68.36	2.57	45.00	73.57	6456

Table 22: Summary statistics for the mean speed at the comparison site for 9 months (regime 1 and 2)

Period	Month	North bound					South bound					All directions				
		Mean	Std. dev	Min	Max	N	Mean	Std. dev	Min	Max	N	Mean	Std. dev	Min	Max	N
Before	Oct-05	69.43	0.76	68.21	72.10	416	70.17	1.83	61.58	73.57	445	69.81	1.47	61.58	73.57	861
Warning	Feb-06	69.35	0.73	68.21	72.37	270	69.36	0.77	68.23	71.72	199	69.35	0.74	68.21	72.37	469
Program	Mar-06	69.10	0.64	68.23	70.91	203	68.99	0.70	68.20	71.18	211	69.04	0.67	68.20	71.18	414
	Apr-06	69.43	0.82	68.21	71.59	261	69.63	0.98	68.21	73.22	282	69.53	0.91	68.21	73.22	543
	May-06	68.90	0.61	68.21	70.79	139	69.50	0.95	68.20	71.86	182	69.24	0.87	68.20	71.86	321
	Jun-06	69.15	0.71	68.21	71.26	232	69.51	0.77	68.23	71.33	234	69.33	0.76	68.21	71.33	466
	Jul-06	69.30	0.74	68.22	71.19	242	68.94	0.53	68.21	70.14	126	69.18	0.70	68.21	71.19	368
	Aug-06	69.04	0.60	68.22	71.08	286	69.02	0.57	68.24	70.27	103	69.04	0.59	68.22	71.08	389
	Sep-06	69.32	0.73	68.21	71.66	276	69.05	0.66	68.20	71.63	159	69.23	0.71	68.20	71.66	435
Total		69.26	0.73	68.21	72.37	2325	69.50	1.19	61.58	73.57	1941	69.37	0.98	61.58	73.57	4266

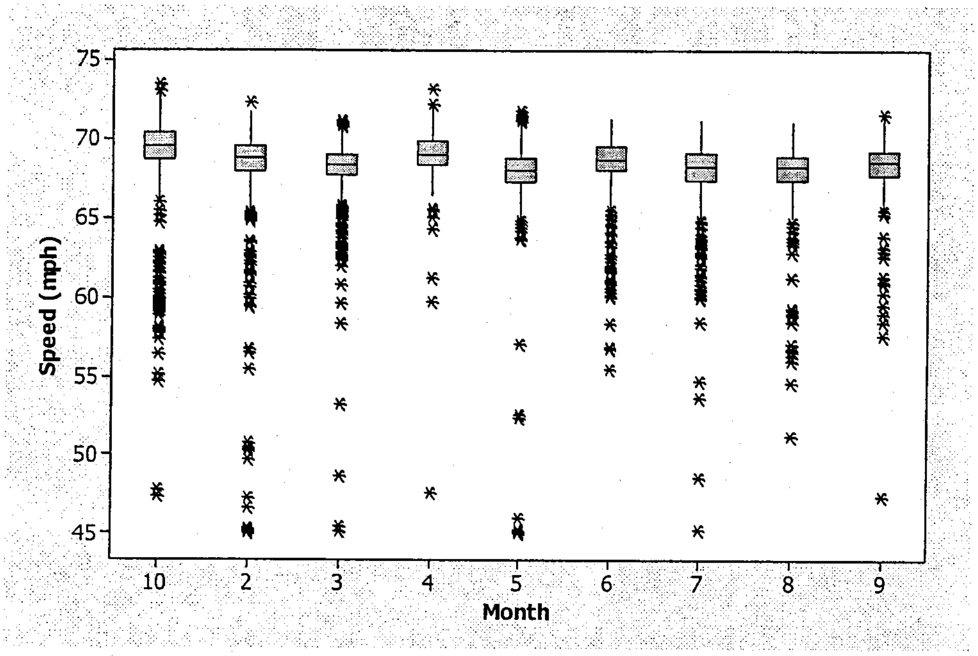


Figure 16: Box plot of the mean speed by month (all regimes)

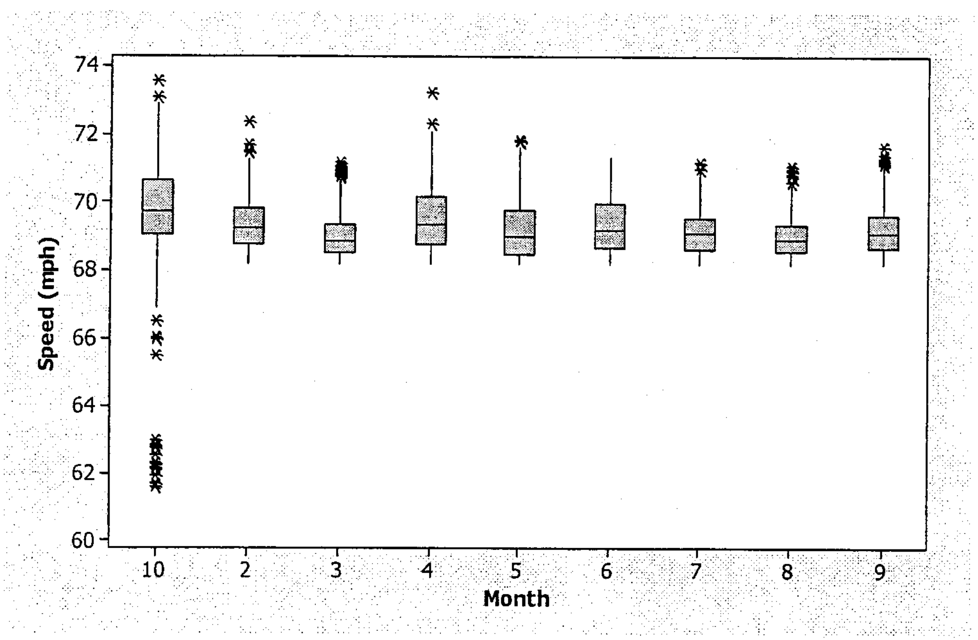


Figure 17: Box plot of the mean speed by month (regime 1 and 2)

3.2.4.2 Differences in the Mean Speeds during the 3 Periods

As with the analysis for the changes in mean speeds at the SEP site, the difference in mean speeds at the comparison zone by time period is analyzed using the data collected from flow regimes 1 and 2. Again, ANCOVA models were applied to reveal whether or not the mean speeds are different during the 3 periods, and the results of the ANCOVA models are summarized in Table 23.

In the Northbound direction there is no significant difference between the mean speeds during the 3 periods (Model 1). However, the effect of the period on the mean speeds is significant in Model II and III, indicating that the mean speeds during the 3 periods are different.

Table 23: Results of the ANCOVA models

Model	Source	DF	Seq SS	Adj SS	Adj MS	F	P	Adj R^2
Model I (North Bound)	Traffic Flow	1	0.33	0.33	0.33	0.62	0.432	0.016
	Period	2	19.28	0.28	0.14	0.27	0.767	
	Traffic Flow*Period	2	3.23	3.23	1.61	3.05	0.048	
	Error	2319	1227.41	1227.41	0.53			
	Total	2324	1250.26					
Model II (South Bound)	Traffic Flow	1	24.83	37.68	37.68	29.65	<.0001	0.11
	Period	2	274.47	25.57	12.79	10.06	<.0001	
	Traffic Flow*Period	2	11.89	11.89	5.94	4.68	0.009	
	Error	1935	2459.01	2459.01	1.27			
	Total	1940	2770.19					
Model III (All directions)	Traffic Flow	1	15.45	24.70	24.70	27.43	<.0001	0.06
	Period	2	217.15	12.70	6.35	7.05	0.001	
	Traffic Flow*Period	2	16.68	16.68	8.34	9.26	<.0001	
	Error	4260	3836.00	3836.00	0.90			
	Total	4265	4085.29					

Since the results do not indicate how the mean speeds at the comparison sites are different during the 3 periods, the Tukey's simultaneous comparison analysis was conducted for all ANCOVA models. The simultaneous comparison results summarized in Table 24 indicate that the difference in the mean speeds for the *north bound site* between the *before* and *warning* periods is 0, while the differences in the mean speed for other pairs are not 0 (the mean speeds during the *before* and *warning* periods are slightly greater than the mean speed during the *program* period: the differences are 0.153 mph or 0.221 mph).

Although the mean speeds at the *south bound site* during the *before* and *warning* periods are also slightly greater than the mean speed during the *program* period, the difference in the mean speeds between the *warning* and *program* periods is insignificant. Therefore, there is not a decreasing speed trend in the mean speeds across the 3 time periods at the comparison site. As a result, there is no evidence for a spillover effect of the SEP on the comparison site, and the comparison site meets one of the requirements of a suitable site.

When aggregating the mean speeds from the 2 directions, all differences in the mean speeds between periods are statistically significant. Although the differences in the mean speeds are significant, the differences (0.125 mph to 0.575 mph) were substantially smaller than those within the enforcement zone (9.18 mph to 9.64 mph). In addition, it is necessary to note that the differences in speed might be attributed to unobserved effects such as a month effect although 2 factors and interaction terms were included in the ANCOVA model to reduce the variance of the error from such effects.

Table 24: Test results of the differences in the mean speed at the comparison sites

Direction	Pair	Difference (mph)	P-value	95% CIs	
				Lower	Upper
North bound	"Before"–"Warning"	*0.068*	0.4693	-0.068	0.203
	"Before"–"Program"	0.221	<0.0001	0.127	0.315
	"Warning"–"Program"	0.153	0.0049	0.039	0.268
South bound	"Before"–"Warning"	0.845	<0.0001	0.618	1.072
	"Before"–"Program"	0.926	<0.0001	0.780	1.073
	"Warning"–"Program"	*0.081*	0.611	-0.120	0.283
All directions	"Before"–"Warning"	0.450	<0.0001	0.321	0.579
	"Before"–"Program"	0.575	<0.0001	0.489	0.661
	"Warning"–"Program"	0.125	0.0239	0.013	0.237

Note: The italic differences are insignificant at α=0.05.

Chapter 4 Effects of the SEP on Traffic Safety

In this chapter, the effects of the SEP on traffic safety are comprehensively analyzed. Target crashes are first carefully determined by using the detection trend in terms of time of day. The evaluation methodologies used in the study are described in detail, and the results of each methodology are presented. In addition, the economic benefits obtained from the demonstration program are quantified using Arizona-specific crash costs.

4.1 Preliminaries: Target Crashes and Data Description

4.1.1 Determining Target Crashes

Before estimating the impacts of the SEP on traffic safety, it is necessary to define which crashes are materially affected by the speed enforcement cameras—referred to as "target" crashes. Since the crashes occurring during the peak travel periods are unlikely to be significantly affected by the photo enforcement cameras, target crashes are defined as crashes that occurred during the off-peak periods.

In order to define the off-peak periods, the time of day (TOD) was used in this analysis because traffic flow data were not available for all data pertaining to the *before* period. Figure 18 shows the detection frequencies by TOD, in which the detection frequency is the average number of detections per 15-minute interval at the enforcement sites for the program period. The detection frequencies by TOD indicate that detection frequencies decrease during peak hours for weekdays, while they are almost proportional to traffic flow for weekends and holidays. Therefore, TOD is generally related to speeding behaviors on weekdays.

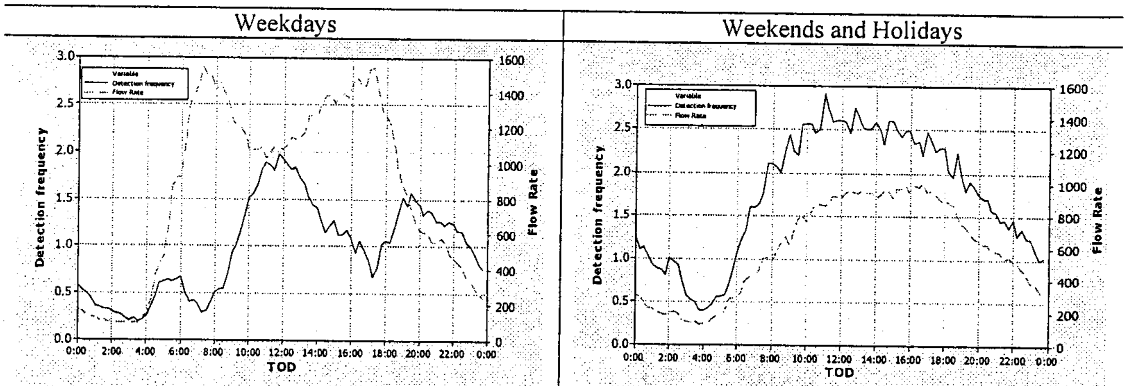


Figure 18: Detection frequencies by TOD

In addition, the relationships between TOD and detection rates shown in Figure 19 indicate that the detections could occur for weekends and holidays regardless of traffic flow, while the detections are related to the changes in traffic flow, in which the detection rate is the ratio of detection frequency to the average traffic volume per 15-minute interval at the enforcement sites for the program period. For example, the detection rates during peak hours for weekdays are remarkably low—less than 0.25% between 6:00 AM and 9:00 AM.

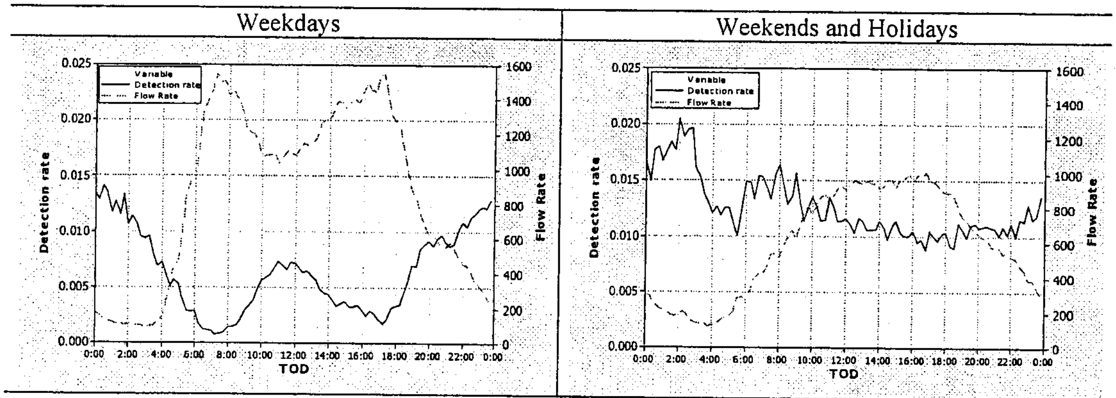


Figure 19: Detection rates by TOD

Since the detection trends by TOD suggest that TOD can be used to identify traffic flow regimes, two traffic flow regimes (peak and off-peak periods) are defined by using TOD.

- Peak periods (6 hours)
  - 06:00 AM — 09:00 AM
  - 16:00 PM — 19:00 PM
- Off–peak periods
  - The remaining 18 hours for weekdays
  - 24 hours for weekends and holidays

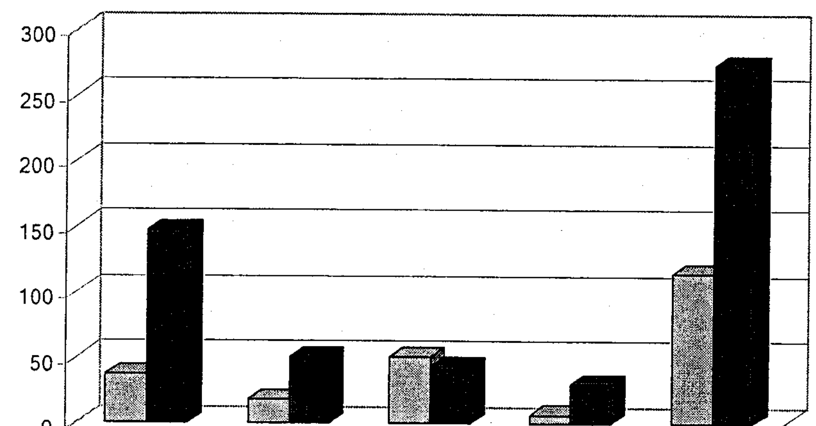
Consequently, the target crashes in this analysis are the crashes that occurred within the enforcement zone (MP 34.51 – MP 41.06: 6.5 miles) during the off-peak travel periods defined by TOD (because of the limited expected influence of the cameras on slow moving peak period traffic). Note that the target crashes are "mainline" crashes classified by ADOT, excluding crashes that occurred on SR 101 ramps and frontage roads. In the next subsection, the characteristics of the target crashes are discussed in detail.

4.1.2 Crash Data Description

In this subsection, the characteristics of the target crashes determined in the previous subsection are discussed. The durations of the target crash data are summarized below:

- Crash data during the *before* period
    - Duration: 2/22/2006 – 8/31/2006 (2001 through 2005)
- Crash data during the *program* period
    - Duration: 2/22/2006 – 8/31/2006 (191 days)

Note that the SEP ended October 22, 2006, but the current analysis is based on the limited crash data. Figure 20 shows the number of crashes that occurred within the enforcement zone during the *before* period. It contains target crashes as well as the crashes that occurred during the peak periods. Although the average number of crashes during the 2 periods (peak and off-peak periods) cannot be compared directly, three crash types are most frequent: single-vehicle, side-swipe (same), and rear-end crashes. Therefore, the remaining crash types such as angle, left-turn, side-swipe (opposite), head-on, and other crashes are aggregated as "other" in this analysis.



	Single-vehicle	Side-swipe (same)	Rear-end	Other	Total
Peak	38	19	51	7	115
Off-peak	148	51	44	31	274

Figure 20: Number of crashes that occurred at the enforcement zone during the before period

Figure 21 and Figure 22 show the percentage of the peak or off-peak crashes by crash type, which occurred during the *before* period. The most frequent crash type was single-vehicle crashes (54%) for the off-peak periods, while rear-end crashes (44%) was most frequent for the peak periods.

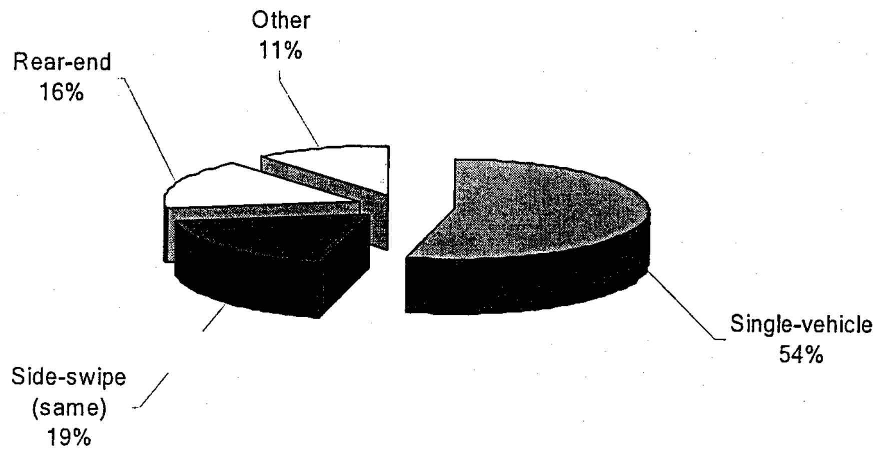


Figure 21: Percentage of off-peak crashes by crash type (before period)

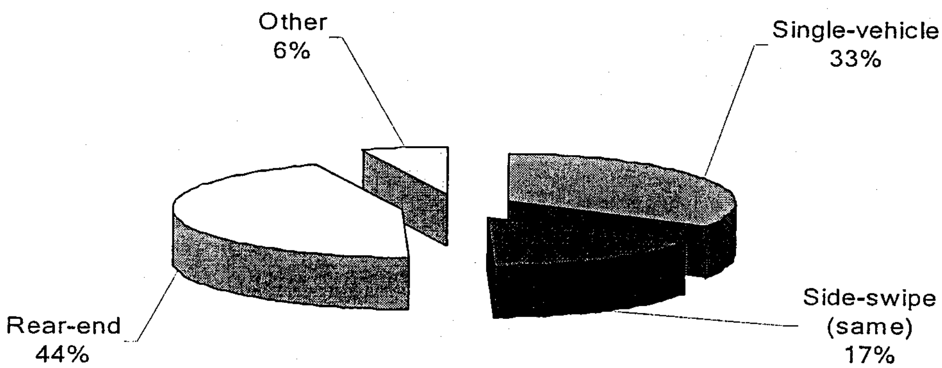


Figure 22: Percentage of peak-period crashes by crash type (before period)

Although it is evident that the characteristics of crashes are different for the 2 periods, the analysis using the target crashes is conservative because the peak period increases over time (the *before* to *program* period), therefore there is increasing constraint on speed over time, or lesser constraint on speed going back in time (the *before* period), resulting in target crashes in the *before* period being eliminated from the analysis (because they occurred during the 'peak' period). Fewer *before* crashes reduces the estimated effectiveness of a countermeasure; therefore this approach is conservative.

4.2 The Four-Step Procedures for Before and After Study

In this section, the basic concepts of the before-and-after (BA) study are described, and the basic 4-step procedure for estimating the effects of SEP is also provided. The analysis approach developed and described here is an expansion and mathematical formalization of the methods described by Hauer (Hauer, 1997; Hauer *et al.*, 2002).

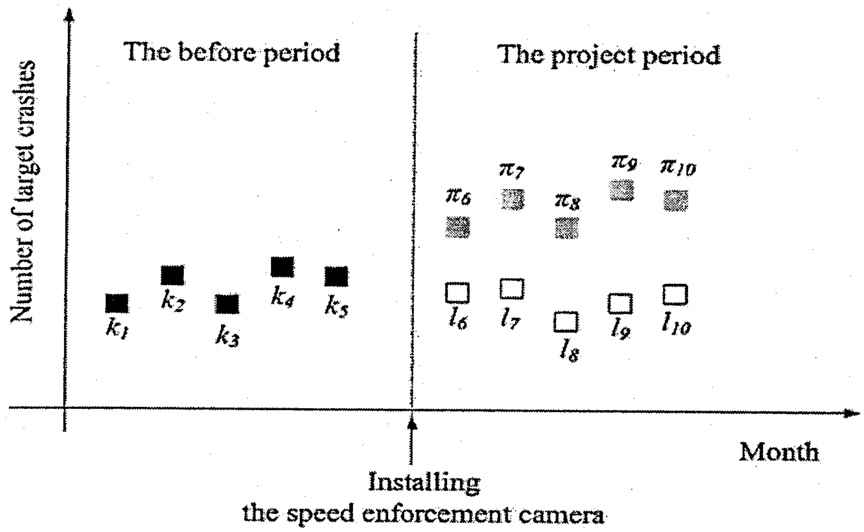
The key objective of the BA study is to estimate the change of safety in the program period as a result of the treatment. The key notations used are:

- π: Expected number of target crashes in the program period if the treatment had not been installed
- λ: Expected number of target crashes in the program period with the treatment in place
- $\delta = \pi - \lambda$: Change in safety due to the treatment
- $\theta = \lambda/\pi$: Index of the effectiveness of the treatment

If either δ is greater than 1 or θ is less than 1, then we conclude that the treatment is effective. The parameters π, λ, δ, and θ are unknown parameters and must be estimated using the available data. There are numerous arduous aspects of estimating these unknown parameters. Generally, the value of λ is being estimated using the observed number of crashes in the after period. It might seem that the observed number of crashes in the before period would be employed to predict the value of π.

Figure 23 illustrates the basic concept of the BA study. As discussed, the key objective of the analysis is to estimate the expected number of crashes in the program period if the SEP had not been implemented. If we do not assume any change from before to program periods, the estimates of the π's are the same as the observed target crash frequency during the before period (i.e., k's). However, it is insufficient to predict the value of π using the observed number of crashes in the before period. Problems arise because there are either potentially many recognizable and unrecognizable factors which may have changed from the before to after periods, or the regression to the mean bias that has resulted from sites being selected based on prior crash histories. Thus, often more rigorous evaluation methodologies are needed to obtain accurate estimates of π, which are described in detail in the following subsection.

Regardless of the corrections made to the BA study, a basic 4-step procedure is used (with modifications) to estimate the safety effect of a treatment. In the next subsections, we provide the 4-step procedure for the simple or naïve BA study approach.



k_i: The observed target crash frequency during the before period
l_j: The observed target crash frequency during the project period
π_j: The expected number of target crash frequency during the project period if the treatment had not been installed

Figure 23: Basic concept of the before-and-after study

Step 1: Estimate λ and predict π

The first step is to estimate λ and π. The estimate of λ is equal to the sum of the observed number of target crashes in the program period. Also, the predicted value of π is equal to the sum of the observed number of crashes in the before period. In the simple BA study, these estimates are:

$$\hat{\pi} = \sum_{i=1}^{b} k_i = K \quad (1)$$

and

$$\hat{\lambda} = \sum_{j=1}^{p} l_i = L, \quad (2)$$

where b and p are the number of durations for the before and program periods respectively, and k and l are the observed target crash frequencies during the before and program periods.

Step 2: Estimate $\hat{\sigma}^2[\hat{\lambda}]$ and $\hat{\sigma}^2[\hat{\pi}]$

The second step is to estimate the variance of $\hat{\lambda}$ and $\hat{\pi}$. Suppose that the number of target crashes is Poisson distributed (which is often the case at a single site), then the variance is equal to the mean.

$$\hat{\sigma}^2[\hat{\lambda}] = \lambda \tag{3}$$

and

$$\hat{\sigma}^2[\hat{\pi}] = \pi. \tag{4}$$

Of course, the estimate of variance of $\hat{\pi}$ will depend on the method chosen to consider various assumptions.

Step 3: Estimate δ and θ

The estimates of treatment effectiveness, δ and θ, can be estimated:

$$\hat{\delta} = \hat{\pi} - \hat{\lambda} = K - L. \tag{5}$$

The estimator of θ was obtained by using the well-known delta approximation, because θ is a non-linear function of two random variables. Since the applications of the delta method are necessarily brief, the interested reader can refer to two references for a full derivation and justification (Hauer, 1997; Washington and Shin, 2005) and consult two of a variety of references for the delta method (Greene, 2003;Hines *et al.*, 2003).

$$\hat{\theta} \cong \frac{\left(\hat{\lambda}/\hat{\pi}\right)}{\left\{1 + \widehat{Var}[\hat{\pi}]/\hat{\pi}^2\right\}} \tag{6}$$

Equation (6) shows that it is also necessary to estimate the variance of $\hat{\pi}$ in order to estimate the index of the effectiveness θ. The variance for $\hat{\pi}$ can be estimated by using the assumption that the number of target crashes is Poisson distributed.

Step 4: Estimate $\hat{\sigma}^2[\hat{\delta}]$ and $\hat{\sigma}^2[\hat{\theta}]$

The final step is to estimate the variance of the effects obtained by using four different methods, which can be used to approximate the "level of confidence" of the results. Equation (7) shows the unbiased estimators for the variances of $\hat{\delta}$ and $\hat{\theta}$, in which the variance of $\hat{\theta}$ is also obtained by using the delta method (Hauer, 1997; Washington and Shin, 2005).

$$\widehat{Var}[\hat{\delta}] = \hat{\pi} + \hat{\lambda}; \quad \widehat{Var}[\hat{\theta}] \cong \frac{\hat{\theta}^2 \cdot \left(\frac{\widehat{Var}[\hat{\lambda}]}{\hat{\lambda}^2} + \frac{\widehat{Var}[\hat{\pi}]}{\hat{\pi}^2} \right)}{\left(1 + \frac{\widehat{Var}[\hat{\pi}]}{\hat{\pi}^2} \right)^2}. \tag{7}$$

Table 25 shows the goal and formulas for each step in simple BA study 4 step process.

Table 25: The 4-step procedure for simple before-and-after study

Step	Goals	Formulas for simple before-and-after study
Step 1	Estimate λ and predict π	$\hat{\lambda} = L$ $\hat{\pi} = K$
Step 2	Estimate $\hat{\sigma}^2[\hat{\lambda}]$ and $\hat{\sigma}^2[\hat{\pi}]$	$\hat{\sigma}^2[\hat{\lambda}] = \hat{\lambda}$ $\hat{\sigma}^2[\hat{\pi}] = \hat{\pi}$
Step 3	Estimate δ and θ	$\hat{\delta} = \hat{\pi} - \hat{\lambda} = K - L$ $\hat{\theta} \cong \frac{\left(\frac{\hat{\lambda}}{\hat{\pi}}\right)}{\left(1 + \frac{\widehat{VAR}[\hat{\pi}]}{\hat{\pi}^2}\right)} = \frac{\left(\frac{L}{K}\right)}{\left(1 + \frac{K}{K^2}\right)}$
Step 4	Estimate $\hat{\sigma}^2[\hat{\delta}]$ and $\hat{\sigma}^2[\hat{\theta}]$	$\hat{\sigma}^2[\hat{\delta}] = \hat{\pi} + \hat{\lambda} = K + L$ $\hat{\sigma}^2[\hat{\theta}] \cong \frac{\hat{\theta}^2 \cdot \left[\frac{\widehat{VAR}(\hat{\lambda})}{\hat{\lambda}^2} + \frac{\widehat{VAR}(\hat{\pi})}{\hat{\pi}^2}\right]}{\left[1 + \frac{\widehat{VAR}(\hat{\pi})}{\hat{\pi}^2}\right]^2} = \frac{\hat{\theta}^2 \cdot \left[\frac{L}{L^2} + \frac{K}{K^2}\right]}{\left[1 + \frac{K}{K^2}\right]^2}$

Correcting for Traffic Volume Differences

The four-step BA procedure can be modified in many ways to account for corrections needed across observation periods. Examples are the duration of the observation period, the number of wet pavement days, or traffic volumes. The only correction we make in this current analysis is for increases in traffic volumes over the demonstration site. At this stage some assumptions needed to be made regarding traffic volume increases from 2005 to 2006. Conservatively, it is estimated that traffic volumes in the section (off-peak) increased by

15% from 2005 to 2006 on average. At the same section of the 101, from 2004 to 2005 traffic volumes increased on average 16%, and increased by 26% from 2003 to 2004. If and when more current traffic volumes for 2006 become available the real increase will be used instead of the assumed 15%. Making this assumption, traffic volumes at 6 locations within the 101 demonstration site are used to compute average correction factors over the site, corrections for increases in traffic exposure over time are incorporated into the BA analysis results. The traffic correction factors, r(tf) for the five years of the *before* period are shown in Table 26.

Table 26: Observed Traffic Volumes (AADT) in Scottsdale 101 Section: 2001 through 2005

Traffic Volume Count Station	2001	2002	2003	2004	2005	2006*
Exit 34 Scottsdale Rd	65,000	67,600	69,400	100,000	142,000	163300
Exit 36 Princess Dr	-	-	80,000	103,000	124,000	142600
Exit 37 Frank Lloyd Wright Blvd	85,000	88,400	90,700	105,000	123,000	141450
Exit 39 Raintree Dr	81,000	84,200	86,400	110,000	115,000	132250
Exit 40 Cactus Rd	90,000	93,600	96,000	118,000	123,000	141450
Exit 41 Shea Blvd	90,000	93,600	96,000	119,000	131,000	150650
Correction Factor, r(tf)	2.12	2.04	1.68	1.33	1.15	1.00

* 2006 volumes estimated assuming a conservative growth of 15%

Correction for exposure to risk, or traffic, is essential to account for the increased number of opportunities for conflict and interaction on a roadway. The correction factors are used to inflate the number of observed crashes in prior years to account for the reduced exposure. For example, crashes that occurred in 2001 are increased by a factor of 2.12 in order to make a meaningful comparison with crashes that occurred in 2006 (since exposure increased by this factor over that same time period). In the simple BA analysis approach, this correction simply modifies the estimate of what would have been the crash counts to $\hat{\pi} = Kr_{(tf)}$. In the case of multiple years, it becomes $\hat{\pi} = \sum_{i=2001}^{2005} K_i r_{(tf)i}$, where crashes are summed over the period 2001 to 2005 using the corrections shown in Table 26.

4.3 The Simple or Naïve Before After Study

The first analysis method is the simple BA study. This approach is based on the following assumptions:

- Traffic volume, roadway geometry, road user behavior, weather, and many other factors have not significantly changed from the *before* to the *program* period.
- There are no treatments or improvements other than the installation of the speed enforcement cameras during the *program* period.
- The probability that crashes are reported is the same in both periods, and the reporting threshold has not changed.

4.4.1 Overview of the Before and After Study with a Comparison Group

The basic concept of the before and after study with a comparison group is illustrated in Figure 25, in which k_i and l_j represent the observed number of target crashes at the enforcement zone during the before and program periods respectively, while m_i and n_j represent the observed number of target crashes at the comparison zone during the before and program periods respectively.

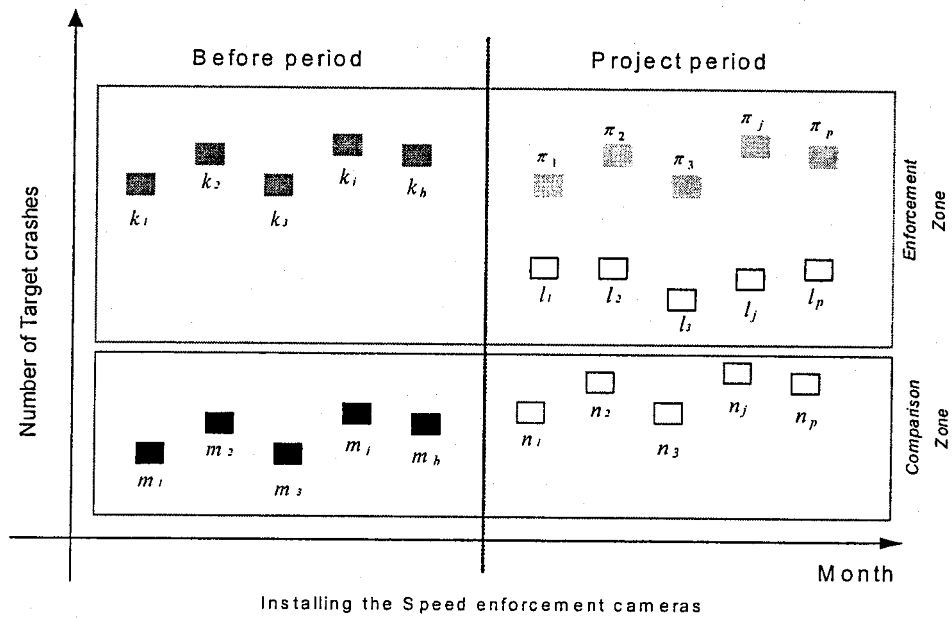


Figure 25: Basic concept of the before and after study with comparison group

Again, K, L, M, and N represent the sums of the observed number of crashes during each period. Table 28 shows the observed counts of crashes and the expected crash counts (Greek letters). These quantities are used to obtain the estimates in the before-and-after study with a comparison group.

Table 28: Key notations used in the before and after study with a comparison group

	Target crashes at treated Sites	Target crashes at comparison sites
Before	K (κ)	M (μ)
After	L (λ)	N (ν)

Step 1: Estimate λ and predict π

The first step is to estimate λ and predict π. Again, the estimate of λ is equal to the sum of the observed number of crashes during the program period. Unlike the simple before-and-after study approach, the comparison ratio can be used in order to estimate π:

$$\left(r_T = \frac{\pi}{\kappa}\right) = \left(r_C = \frac{\nu}{\mu}\right), \tag{8}$$

where these two ratios (r_T and r_C) are identical under the comparison group method assumption. Since the ratio r_C is a random variable consisting of a non-linear combination of two random variables (μ and ν) and the observed counts of target crashes at comparison sites are Poisson distributed, the estimate of π can be represented as Equation (9):

$$\hat{\pi}_C = \hat{r}_T \cdot K = \hat{r}_c \cdot K = \frac{\left(\frac{N}{M}\right)}{\left(1 + \frac{1}{M}\right)} \cdot K. \tag{9}$$

Step 2: Estimate $\hat{\sigma}^2[\hat{\lambda}]$ *and* $\hat{\sigma}^2[\hat{\pi}]$

Due to the property of the Poisson distribution, the variance is equal to the mean. Thus, the estimate of variance for $\hat{\lambda}$ is L, and the estimate of variance for $\hat{\pi}$ can be obtained by using the delta approximation:

$$\begin{aligned}\hat{\sigma}^2[\hat{\pi}] &= r_T{}^2 \cdot \hat{\sigma}^2[K] + K^2 \cdot \hat{\sigma}^2[\hat{r}_T] \\ &= \hat{\pi}^2 \cdot \left[\frac{1}{K} + \frac{\hat{\sigma}^2[\hat{r}_T]}{\hat{r}_T{}^2}\right].\end{aligned} \tag{10}$$

For convenience, the ratio of r_T and r_C is defined as the odds ratio.

$$\omega = r_C / r_T \tag{11}$$

Therefore, the variance for $\hat{r}_T$ is:

$$\hat{\sigma}^2[\hat{r}_T] \cong \hat{r}_C{}^2 \cdot \left(\frac{1}{M} + \frac{1}{N} + \frac{VAR[\omega]}{E^2[\omega]}\right). \tag{12}$$

By plugging Equation (12) into Equation (10), the estimate of variance for $\hat{\pi}$ can be rewritten:

$$\hat{\sigma}^2[\hat{\pi}] = \hat{\pi}^2 \cdot \left\{\frac{1}{K} + \left(\frac{1}{M} + \frac{1}{N} + \frac{VAR[\omega]}{E^2[\omega]}\right)\right\}. \tag{13}$$

With these corrections to the 4 step process, the remaining steps (step 3 and step 4) continue as before.

Table 29 shows the corrected 4-step used in the comparison method.

Table 29: Corrected 4-step for the before-after study with comparison group

Step	Goals	Formulas for before-and-after study with comparison group
Step 1	Estimate λ and predict π	$\hat{\lambda} = L;\ \hat{\pi} = \hat{r}_T \cdot \hat{\kappa} = \hat{r}_C \cdot \hat{\kappa} = \frac{\left(\frac{N}{M}\right)}{\left(1+\frac{1}{M}\right)} \cdot K$
Step 2	Estimate $\hat{\sigma}^2[\hat{\lambda}]$ and $\hat{\sigma}^2[\hat{\pi}]$	$\widehat{VAR}[\hat{\lambda}] = L;\ \widehat{VAR}[\hat{\pi}] \cong \hat{\pi}^2 \cdot \left[\frac{1}{K} + \left(\frac{1}{M} + \frac{1}{N} + \frac{VAR[\omega]}{E^2[\omega]}\right)\right]$
Step 3	Estimate δ and θ	$\hat{\delta} = \hat{\pi} - \hat{\lambda};\ \hat{\theta} \cong \frac{\left(\frac{\hat{\lambda}}{\hat{\pi}}\right)}{\left(1+\frac{\widehat{VAR}[\hat{\pi}]}{\hat{\pi}^2}\right)}$
Step 4	Estimate $\hat{\sigma}^2[\hat{\delta}]$ and $\hat{\sigma}^2[\hat{\theta}]$	$\hat{\sigma}^2[\hat{\delta}] = \hat{\pi} + \hat{\lambda};\ \hat{\sigma}^2[\hat{\theta}] \cong \frac{\hat{\theta}^2 \cdot \left[\frac{\widehat{VAR}(\hat{\lambda})}{\hat{\lambda}^2} + \frac{\widehat{VAR}(\hat{\pi})}{\hat{\pi}^2}\right]}{\left[1+\frac{\widehat{VAR}(\hat{\pi})}{\hat{\pi}^2}\right]^2}$

4.4.2 Estimating Comparison Ratio

Figure 26 shows the comparison zone used in this analysis, which is 6.5 miles section on SR 101 west side. There are 2 assumptions in employing the comparison zone. First, the past crash trends within the comparison zone are similar to those within the enforcement zone. Second, the comparison zone is not affected by the SEP (i.e., not influenced by spillover effect).

(1) Enforcement zone: MP 34.51– MP 41.06 (Approximately 6.5 miles)
(2) Comparison zone: MP 3.5 – MP 10 (6.5 miles)

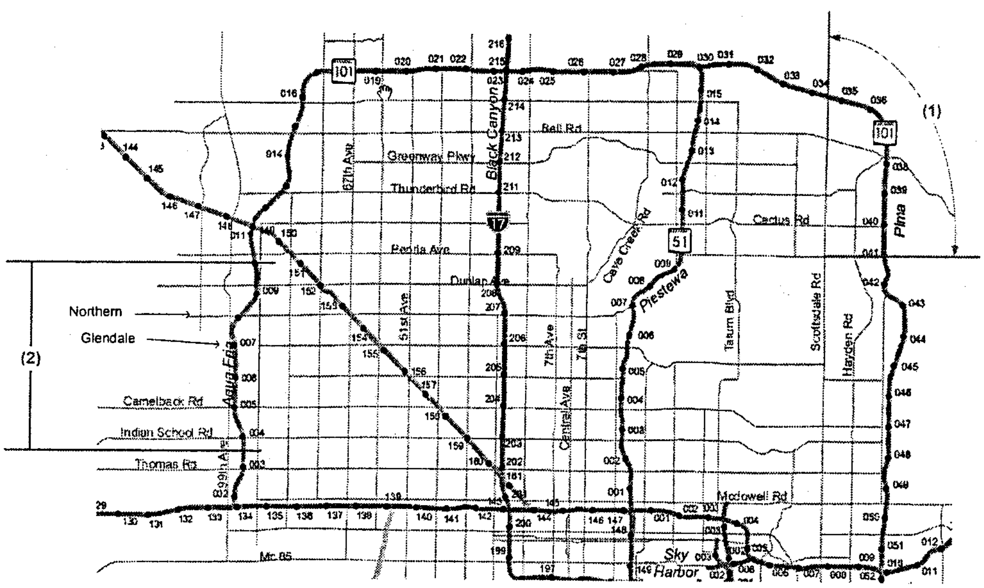


Figure 26: Enforcement and comparison zones

The first assumption can be statistically tested by the odds ratio (Hauer, 1997;Wong *et al.*, 2005). If the past crash trends within the comparison site are similar to those at the enforcement site, the odds ratio defined in Equation (11) should be equal to 1. Since the estimate of the odds ratio is also non-linear, an unbiased estimator is obtained using the delta approximation:

$$\widehat{\omega}_i = \frac{m_{i+1} \cdot k_i}{k_{i+1} \cdot m_i} \cdot \left(1 + \frac{1}{k_{i+1}} + \frac{1}{m_i}\right)^{-1}, \qquad (14)$$

where $\widehat{\omega}_i$ is the estimate for the odds ratio during period i and the rest of the notation is as defined previously. Therefore, the average of the estimates for the odds ratios is

$$\overline{\widehat{\omega}} = \frac{1}{b-1} \cdot \sum_{i=1}^{b-1} \widehat{\omega}_i, \qquad (15)$$

and the variance of the mean of the odds ratios is

$$S^2[\bar{\hat{\omega}}] = \frac{1}{b-1} \cdot \left[\frac{1}{b-2} \left\{ \sum_{i=1}^{b-1} \hat{\omega}_i^2 - (b-1)\bar{\hat{\omega}}^2 \right\} \right]. \qquad (16)$$

If the confidence interval of the odds ratios does not include 1, the comparison zone should not be employed in the BA study with a comparison group. Table 30 shows the odds ratio test results for the comparison site illustrated in Figure 26. Since the estimates for the odds ratios are close to 1 and all 95% CIs contains the expected value 1 under the assumption of the BA study with a comparison group, the comparison zone is a suitable candidate. In addition, we assumed that the comparison zone was not affected by the SEP since there was no significant change (decrease) in speed from the before to the program period at the comparison zone (0.125 mph decrease; see 3.2.4 Changes in Mean Speed at the Comparison Site on page 47).

Table 30: Estimates for the odds ratios and 95% CI for the estimates

Collision type	$\bar{\hat{\omega}}$	95% confidence interval	
		Lower	Upper
Single Vehicle	1.17	0.41	1.93
Side-swipe (same)	1.30	-0.65	3.25
Rear-end	1.01	-0.60	2.63
Other	1.89	-3.65	7.44
Total	1.21	0.19	2.23

Consequently, we estimated the comparison ratios from the comparison zone illustrated in Figure 26. The comparison ratio, (N/M)/(1+1/M), is the ratio of crashes before to program. Note that it is possible that the comparison ratios can be updated if there are other comparison zones whose variance of the odds ratios is relatively small. Table 31 shows the estimated comparison ratios and associated standard deviations. Comparison ratios greater than 1 indicate an increase, while ratios less than 1 indicate a decrease. For example, total crashes increased by 54% at the comparison zone.

Table 31: Estimates of the comparison ratio

Collision type	Comparison ratio (γ)	Std.Dev. (γ)
Single-vehicle	1.03	0.21
Side-swipe (same)	1.67	0.48
Rear-end	1.28	0.37
Other	3.80	0.67
Total	1.54	0.18

4.4.3 Results of the Before and After Study with a Comparison Group

Using the estimated comparison ratios shown in Table 31, the predicted values of π are obtained (see Equation (9)). Table 32 shows the estimated values for π, λ, δ, and θ as well as the estimated standard deviation for δ and θ.

Table 32: Results of before and after study with comparison group

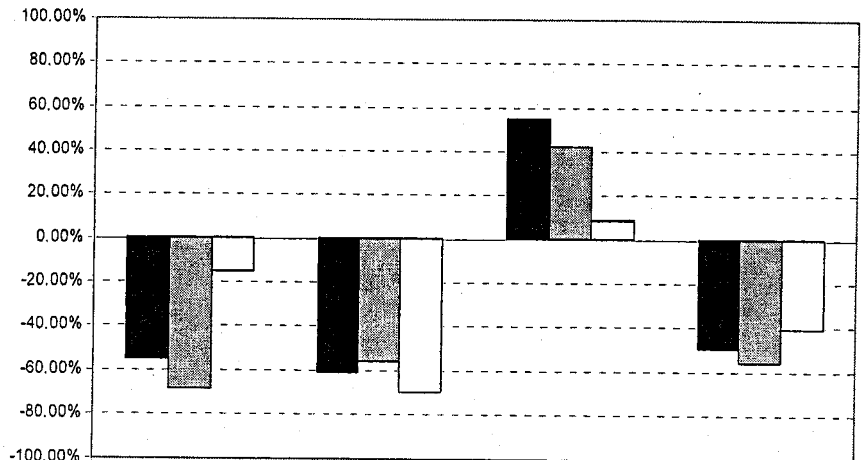
	Collision Type	Crash Estimates		Delta		Theta	
		Phi	Lambda	Estimate	Std.dev	Estimate	Std.dev
Total Crashes	Single Vehicle	30.53	14	**16.53**	6.67	**0.44**	0.21
	Side-swipe (same)	17.00	7	**10.00**	4.90	**0.39**	0.26
	Rear-end	11.30	19	-7.70	5.50	1.55	0.43
	Other	23.59	2	**21.59**	5.06	**0.08**	0.20
	Total	82.41	42	**40.41**	11.15	**0.50**	0.13
PDO Crashes	Single Vehicle	24.55	8	**16.55**	5.71	**0.31**	0.22
	Side-swipe (same)	12.67	6	**6.67**	4.32	**0.44**	0.30
	Rear-end	7.45	12	-4.55	4.41	1.42	0.49
	Other	15.98	1	**14.98**	4.12	**0.06**	0.24
	Total	60.64	27	**33.64**	9.36	**0.44**	0.15
Total Injuries	Single Vehicle	7.22	7	**0.22**	3.77	**0.85**	0.43
	Side-swipe (same)	5.67	2	**3.67**	2.77	**0.30**	0.38
	Rear-end	8.22	10	-1.78	4.27	1.09	0.44
	Other	11.41	1	**10.41**	3.52	**0.08**	0.27
	Total	32.52	20	**12.52**	7.25	**0.60**	0.21

* Bold numbers indicate crash reduction.

Since the comparison ratio for the rear-end crashes is greater than 1, the predicted values ($\hat{\pi}$) for the rear-end crashes are slightly greater than those from the simple before and after study.

Figure 27 illustrates the percent changes in target crash for each collision type and category. Again, the percent changes are $(\hat{\theta} - 1) \times 100$. Under the assumptions for the BA study with a comparison group, the results suggest:

- Total target crash frequency was reduced by 50%. Total PDO crashes and total injuries were also reduced by 56% and 40% respectively.
- Total crashes, PDO crashes, and total injuries of single-vehicle and side-swipe (same) crashes were reduced (15% to 70%).
- Total crashes, PDO crashes, and total injuries of rear-end crashes increased (9% to 55%).
  - Although rear-end crashes increased, the magnitudes of the increases are reduced when compared to those from the simple BA study.



	Single Vehicle	Side-swipe (same)	Rear-end	Total
■ Crash Frequencies	-55.60%	-61.11%	54.51%	-49.65%
▨ PDO Crashes	-68.69%	-56.10%	42.08%	-56.20%
□ Total Injuries	-14.84%	-70.00%	8.50%	-40.33%

Figure 27: Results of before and after study with a comparison group

It should be noted that more comparison sites are needed to improve trend estimates, although the current comparison zone satisfies all of the assumptions required for a suitable comparison group.

4.5 Empirical Bayesian Before and After Study

In the previous approach the observed crash count in the before period (K) plays a key role in estimating π with the correction factor. However, it is also necessary to consider the possible regression-to-the-mean (RTM) bias in safety studies. In this section, the empirical Bayesian before and after study approach is applied to the crash data in order to correct the RTM bias.

4.5.1 Overview of Empirical Bayesian Method

In an observational study there is likely to be a link between the decision to treat an entity and its crash history. This link causes so called Regression-to-mean bias (RTM bias). If an entity is treated because its "before" accident count (K) was abnormally high or unusually low, then the same K can not be a good estimate of π (Hauer, 1997; Hauer *et al.*, 2002). In such circumstances, the best estimate of π is conditionally defined as $E[\kappa|K]$, in which the observed crash K and the expected value κ are thought of as a *sample* and as a *prior* respectively in the Bayesian model. Then, the Bayesian theorem is expressed:

$$f(\kappa \mid K) = \frac{f(K \mid \kappa) \cdot f(\kappa)}{f(K)}, \quad (17)$$

where $f(\kappa \mid K)$ is the posterior density of parameter κ given sample K, $f(\kappa)$ is the prior density of parameter (κ) in which κ is considered as a random variable, and $f(K \mid \kappa)$ is the likelihood of sample K. Suppose that the distribution of sample K and parameter κ are Poisson and Gamma distributed respectively. Then, the posterior density of κ given K is calculated using the Bayesian theorem.

For a random sample of one segment, the likelihood of the sample element given κ, is

$$f(K \mid \kappa) = \frac{e^{-\kappa} \cdot \kappa^K}{K!}.$$

The prior distribution for κ is a Gamma distribution with parameters a and b,

$$f(\kappa) = \frac{a^b}{\Gamma(b)} \cdot \kappa^{b-1} \cdot e^{-a\kappa},$$

where a and b are chosen depending on the exact knowledge or the degree of belief we have about the value of κ. In addition, the parameters are denoted:

$$a = \frac{E[\kappa]}{V[\kappa]}, \quad b = \frac{E^2[\kappa]}{V[\kappa]} \quad (18)$$

The joint density of the sample (K) and κ is

$$f(K \mid \kappa) \cdot f(\kappa) = \frac{a^b \cdot e^{-(a+1)\kappa} \cdot \kappa^{(K+b-1)}}{K! \cdot \Gamma(b)}$$

and the marginal density of the sample (K) is

$$f(K) = \frac{a^b \cdot \Gamma(K+b)}{K! \cdot \Gamma(b) \cdot (a+1)^{K+b}}$$

In conjunction with "the joint density of the sample (K) and κ" and "the marginal density of the sample (K)", the posterior density for κ is

$$f(\kappa \mid K) = \frac{(a+1)^{K+b}}{\Gamma(K+b)} \cdot \kappa^{(K+b-1)} \cdot e^{-(a+1)\kappa},$$

and we see that the posterior density for κ is a Gamma distribution with parameters a+1 and K+b. As a result, the Bayesian expected value of κ and the Bayesian variance of κ are obtained:

$$E[\kappa \mid K] = \frac{K+b}{a+1}, \quad V[\kappa \mid K] = \frac{K+b}{(a+1)^2}$$

By plugging parameters a and b expressed by E[κ] and V[κ] in the prior distribution of κ (Equation (18)), they can be rewritten:

$$\begin{aligned} E[\kappa \mid K] &= w \cdot E[\kappa] + (1-w) \cdot K \\ V[\kappa \mid K] &= (1-w) \cdot E[\kappa \mid K], \end{aligned} \quad (19)$$

where the term w is a weight between 0 and 1.

$$w = \frac{E[\kappa]}{E[\kappa] + V[\kappa]} \quad (20)$$

In Equation (19), E[κ|K] is interpreted as the expected count of crashes for a segment given observed crash frequency K, and E[κ] is the average crash frequency of the reference group, which is similar to the comparison group, but the reference group should have data about crashes as well as other covariates for the safety performance functions used in the EB method (will be discussed in the next subsection). In addition, V[κ|K] is the variance of crashes for a segment given observed crash frequency K. They are determined after obtaining the weight term shown in the Equation (20). The weight (w) consists of the average crash frequency of the reference group (i.e., E[κ]) and the variation around E[κ] (i.e., V[κ]). If w is estimated to be near 1, then the E[κ|K] of the segment of interest is close to the mean of its reference group (E[κ]). On the contrary, if w is estimated to be near 0, then the E[κ|K] of the intersection of interest is mainly affected by the observed crash frequency (K).

The two components E[κ] and V[κ] play a pivotal role in obtaining the Bayesian estimator E[κ|K] as shown in Equation (20). In fact, the two components can be expressed by using the two parameters for the *prior*, which can be empirically estimated by the actual data (Carlin and Louis, 2000). In the Empirical Bayesian approach, it is common to assume that the crash frequency serves as data from a negative binomial distribution (Hauer, 1997;Hauer *et al.*, 2002). By using a negative binomial regression model, the two pivotal components can be estimated:

$$\widehat{E}[\kappa] = f(\text{covariates}); \; \widehat{Var}[\kappa] = \widehat{E}^2[\kappa] \cdot \alpha; \;\; \widehat{w} = \frac{\widehat{E}[\kappa]}{\widehat{E}[\kappa] + \widehat{Var}[\kappa]}, \qquad (21)$$

where the estimate of E[κ] and an over-dispersion parameter α can be obtained by using the safety performance functions for the EB correction, which are discussed in the next subsection. Again, the 4-step to estimate the impacts of the SEP on safety can be corrected by using the results of the empirical Bayesian estimates.

Step 1: Estimate λ and predict π

The first step is to estimate λ and predict π. Again, the estimate of λ is equal to the sum of the observed number of crashes during the program period, and the EB estimate of π is given by:

$$\hat{\pi} = \widehat{E}[\kappa \mid K] = \widehat{w} \cdot \widehat{E}[\kappa] + (1 - \widehat{w}) \cdot K. \qquad (22)$$

Step 2: Estimate $\hat{\sigma}^2[\hat{\lambda}]$ and $\hat{\sigma}^2[\hat{\pi}]$

The estimate of variance for $\hat{\lambda}$ is $\widehat{V}[\hat{\lambda}] = L$ under the assumption it is a Poisson distribution, and the estimate of variance for $\hat{\pi}$ is equal to the estimate of variance of EB estimate,

$$\widehat{Var}[\hat{\pi}] = (1 - \widehat{w}) \cdot \hat{\pi}_{EB}. \qquad (23)$$

The remaining steps (steps 3 and 4) proceed as previous. Table 33 shows the corrected 4-step used in EB method.

Table 33: Corrected 4-step for EB before-after study

Step	Goals	Formulas for before-and-after study with EB
Step 1	Estimate λ and predict π	$\hat{\lambda} = L$ $\hat{\pi} = \widehat{E}[\kappa \mid K] = \widehat{w} \cdot \widehat{E}[\kappa] + (1 - \widehat{w}) \cdot K$
Step 2	Estimate $\hat{\sigma}^2[\hat{\lambda}]$ and $\hat{\sigma}^2[\hat{\pi}]$	$\widehat{VAR}[\hat{\lambda}] = L$ $\widehat{VAR}[\hat{\pi}] = \widehat{V[\kappa \mid K]} = (1 - \hat{w}) \cdot \widehat{E[\kappa \mid K]}$
Step 3	Estimate δ and θ	$\hat{\delta} = \hat{\pi} - \hat{\lambda}$ $\hat{\theta} \cong \dfrac{\left(\dfrac{\hat{\lambda}}{\hat{\pi}}\right)}{\left(1 + \dfrac{\widehat{VAR}[\hat{\pi}]}{\hat{\pi}^2}\right)}$
Step 4	Estimate $\hat{\sigma}^2[\hat{\delta}]$ and $\hat{\sigma}^2[\hat{\theta}]$	$\hat{\sigma}^2[\hat{\delta}] = \hat{\pi} + \hat{\lambda}$ $\hat{\sigma}^2[\hat{\theta}] \cong \dfrac{\hat{\theta}^2 \cdot \left[\dfrac{\widehat{VAR}(\hat{\lambda})}{\hat{\lambda}^2} + \dfrac{\widehat{VAR}(\hat{\pi})}{\hat{\pi}^2}\right]}{\left[1 + \dfrac{\widehat{VAR}(\hat{\pi})}{\hat{\pi}^2}\right]^2}$

4.5.2 Developing Safety Performance Functions

In this section, we described the modeling approaches for developing the safety performance functions (SPFs), which need to be developed in order to obtain an estimate of the weight (w) in the empirical Bayesian before and after study. The SPFs were developed using negative binomial regression models, which are provided in the last subsection.

4.5.2.1 Data Description

In order to establish SPFs, a total of 52 sections on SR 101 were used. The number of sections may appear small but it covers more than 95% of the SR 101, which represents a total length of 60.19 miles. Traffic crash data during the same program period from 2001 to 2005 (a total of 3,495.6 total crashes) were used in the analysis in addition to the total PDO crash frequencies and total injuries. Therefore, the data used in the analysis have the pooled panel data structure.

Table 34: Summary Statistics for Variables in the Full Model (N=256)

Variable	Mean	Std. Dev.	Min	Q1	Q2	Q3	Max
Total crash frequency per section per 191 days	13.65	8.55	1.05	7.33	11.51	19.10	46.05
Total PDO crash frequency per section per 191 days	9.78	6.08	0	5.49	8.37	13.61	31.40
Total injuries per section per 191 days	5.90	4.69	0	2.35	4.71	8.37	27.21
AADT (vehicles/day)	113,561	33,999	52,000	83,200	115,000	142,000	196,000
Total length per section (miles)	1.15	0.41	0.50	0.99	1.03	1.22	2.53
Total Number of ramps per section	3.80	1.10	0	4.00	4.00	4.00	8.00
Average length of weaving area per section (miles)	0.31	0.25	0	0.19	0.25	0.35	1.40
Peak hourly volume (vehicles/hour)	6,482	1,127	4,284	6,127	6,342	6,468	10,278
Ratio of volume to service flow rate	0.98	0.18	0.63	0.87	0.95	1.07	1.56
Junction (1 or 0) : 1 if junction area	0.21	0.41	0	0	0	0	1.00
Lane reduction (1 or 0) : 1 for lane reduction	0.06	0.24	0	0	0	0	1.00

For each study section, a total of 8 possible explanatory variables were considered: average annual daily traffic (AADT), geometric features including total length, weaving section length, two variables related to congestion such as peak hourly volume and V/C ratio, and 2 dummy variables for junction-related and lane reduction. Table 34 shows the summary statistics for the variables listed above.

4.5.2.2 Count Models for Developing SPFs

The general approach used to develop SPFs involves the use of count based models. A common mistake is to model count data as continuous data by applying standard least squares regression. This is not strictly correct because regression models yield predicted values that are non-integers and can also predict values that are negative, both of which are inconsistent with count data. These limitations make standard regression analysis inappropriate for modeling count data without modifying the dependent variables. Count data are properly modeled using a number of methods, the most popular of which are Poisson and negative binomial regression models (Washington *et al.*, 2003).

Poisson regression model is often used to fit models of the number of occurrences of an event. Let $y_i, i = 1, 2, \cdots, N$ be the observations of a discrete and non-negative integer variable, which is assumed to be independently Poisson distributed, with the conditional mean specified as:

$$E[y_i \mid \mathbf{x}_i] = \lambda_i = \exp(\mathbf{x}_i'\boldsymbol{\beta}) \tag{24}$$

where $\mathbf{x}_i$ is a $k \times 1$ vector of explanatory variables associated with the ith observation and $\boldsymbol{\beta}$ is a $k \times 1$ vector of unknown parameters. Equation (24) is called the exponential mean function. The model comprising the Poisson probability distribution and the exponential mean function is typically referred to as the Poisson regression model although more precisely it is the Poisson regression model with exponential mean function (Cameron and Trivedi, 1998).

The density function of y_i given $\mathbf{x}_i$ is:

$$f(y_i \mid \mathbf{x}_i) = \frac{e^{-\lambda_i}\lambda_i^{y_i}}{y_i!}. \qquad y_i = 0, 1, 2, \ldots \tag{25}$$

Therefore, the likelihood function can be obtained by multiplying the density function of y_i across all observations as follows:

$$L(\boldsymbol{\beta}) = \prod_{i=1}^{n} \frac{e^{-\lambda_i}\lambda_i^{y_i}}{y_i!} \tag{26}$$

and the log-likelihood function is

$$\begin{aligned} \ln L(\boldsymbol{\beta}) &= \sum_{i=1}^{n}[-\lambda_i + y_i \ln \lambda_i - \ln(y_i!)] \\ &= \sum_{i=1}^{n}\Big[-\exp(\mathbf{x}_i'\boldsymbol{\beta}) + y_i\mathbf{x}_i'\boldsymbol{\beta} - \ln(y_i!)\Big]. \end{aligned} \tag{27}$$

The unknown parameters $\boldsymbol{\beta}$ can be estimated by maximizing the log-likelihood function. The maximizing value for $\boldsymbol{\beta}$ denoted as $\hat{\boldsymbol{\beta}}_{ML}$, is derived by computing the first derivatives of the log-likelihood function:

$$\frac{\partial \ln L(\boldsymbol{\beta} \mid y)}{\partial \boldsymbol{\beta}} = \sum_{i=1}^{n} [-\mathbf{x}_i' \exp(x_i'\boldsymbol{\beta}) + y_i \mathbf{x}_i'] \tag{28}$$

and then solving the first order conditions for a maximum

$$\sum_{i=1}^{n} [-\mathbf{x}_i' \exp(\mathbf{x}_i'\boldsymbol{\beta}) + y_i \mathbf{x}_i'] = 0. \tag{29}$$

The standard errors of the unknown parameters are obtained from the inverse of the Hessian matrix of the log-likelihood function. The Hessian matrix is obtained from the second derivatives of the log-likelihood function with respect to $\boldsymbol{\beta}$.

$$H(\boldsymbol{\beta}; y, x) = \frac{\partial^2 \ln L(\boldsymbol{\beta} \mid y)}{\partial \boldsymbol{\beta}\, \partial \boldsymbol{\beta}'} = \sum_{i=1}^{n} \left[-\mathbf{x}_i' \mathbf{x}_i \exp(\mathbf{x}_i'\boldsymbol{\beta}) \right] \tag{30}$$

and then the variance of $\hat{\boldsymbol{\beta}}_{ML}$ is given by

$$\begin{aligned} Var(\hat{\boldsymbol{\beta}}_{ML}) &= \left(-E\left(\frac{\partial^2 \ln L(\boldsymbol{\beta} \mid y)}{\partial \boldsymbol{\beta}\, \partial \boldsymbol{\beta}'} \right) \right)^{-1} \\ &= \left(\sum_{i=1}^{n} -\mathbf{x}_i' \mathbf{x}_i \exp(\mathbf{x}_i'\boldsymbol{\beta}) \right)^{-1} \end{aligned} \tag{31}$$

It is necessary to note that the conditional mean $\lambda_i = \mu_i t_i$, in which μ_i is the incidence rate (probability of a new event per tiny time interval) and t is often referred to as the exposure. Therefore, Equation (24) can be rewritten:

$$E[y_i \mid \mathbf{x}_i] = \lambda_i t_i = t_i \exp(\mathbf{x}_i'\boldsymbol{\beta}), \tag{32}$$

where the coefficient of t_i is 1. However, the coefficient of t_i can also be estimated by inserting it into the exponential mean function: $E[y_i \mid \mathbf{x}_i] = \exp(\gamma t_i + \beta_1 + \cdots + \beta_k x_{ik})$. Notice that if t_i is the same for every observation, this term can be absorbed into the intercept.

The Poisson regression model rarely fits in practice since the conditional variance is greater than the conditional mean in many applications. If this equality ($E[y_i] = VAR[y_i]$), which is assumed in the Poisson regression model, does not hold, the data are said to be under dispersed ($E[y_i] > VAR[y_i]$) or over-dispersed ($E[y_i] < VAR[y_i]$). The most common is the negative binomial model, which arises from a natural formulation of unobserved heterogeneity (Greene, 2003). By introducing the unobserved heterogeneity into the conditional mean, Equation (24) can be rewritten:

$$E[y_i \mid \mathbf{x}_i, v_i] = \lambda_i^* = \lambda_i v_i = \exp(\mathbf{x}_i'\boldsymbol{\beta} + u_i), \tag{33}$$

where v_i is $\exp(u_i)$ and u_i reflects either specification error or the kind of the unobserved heterogeneity (Greene, 2003). Therefore, the conditional density of y_i is:

$$f(y_i \,|\, \mathbf{x}_i, v_i) = \frac{e^{-\lambda_i^*} \lambda_i^{*y_i}}{y_i!} = \frac{e^{-\lambda_i v_i} (\lambda_i v_i)^{y_i}}{\Gamma(y_i + 1)}. \tag{34}$$

Since it is impossible to condition on the unobserved v_i, the marginal density of $f(y_i \mid \mathbf{x}_i)$ is obtained by integrating the joint distribution over v_i:

$$f(y_i \,|\, \mathbf{x}_i) = \int_0^\infty f(y_i \,|\, \mathbf{x}_i, v_i) g(v_i) dv_i, \tag{35}$$

where v_i>0. Thus, a specific choice of $g(\bullet)$ defines the marginal density of $f(y_i \mid \mathbf{x}_i)$.

There have been three distributions for $g(\bullet)$: the gamma distribution, the inverse Gaussian distribution, and the log-normal distribution (Winkelmann, 2003). In this analysis, we chose the gamma mixture that is widely used in traffic safety studies. In the gamma mixture model, the density function of v_i is $\text{Gamma}(a,b)$:

$$g(v_i) = \frac{v_i^{a-1} \cdot \exp(-v_i / b)}{b^a \cdot \Gamma(a)}, \quad \text{for} \quad v_i > 0 \tag{36}$$

where a is the shape parameter and b is the scale parameter of the gamma distribution. In order to reduce the number of parameters from two to one (for mathematical convenience), the model usually assumes that $v_i \sim \text{Gamma}(1/\alpha, \alpha)$.

$$g(v_i) = \frac{v_i^{\frac{(1-\alpha)}{\alpha}} \cdot \exp(-v_i / \alpha)}{\alpha^{1/\alpha} \cdot \Gamma(1/\alpha)}, \quad \text{for} \quad v_i > 0 \tag{37}$$

As a result, the gamma distribution can be expressed by one parameter, and the mean and variance of the gamma distribution of the v_i are $E[v] = 1$ and $Var[v] = \alpha$.

By using Equations (35) and (37), the marginal density of $f(y_i \mid \mathbf{x}_i)$ can be obtained:

$$f(y_i \,|\, \mathbf{x}_i) = \frac{\Gamma(1/\alpha + y_i)}{\Gamma(y_i + 1)\Gamma(1/\alpha)} \left(\frac{1}{1 + \alpha\lambda_i}\right)^{1/\alpha} \left(\frac{\alpha\lambda_i}{1 + \alpha\lambda_i}\right)^{y_i}, \tag{38}$$

which is one form of the negative binomial distribution (Winkelmann, 2003) and it is defined as NB2. Therefore,

$$E[y_i \mid \mathbf{x}_i, v_i] = \lambda_i \tag{39}$$

and

$$Var[y_i \mid \mathbf{x}_i, v_i] = \lambda_i(1 + \alpha\lambda_i) \tag{40}$$

Under this model, the ratio of the variance to the mean is $(1 + \alpha\lambda_i)$, which can vary by individuals. The log-likelihood function is

$$\begin{aligned} \ln L(\theta \mid y) = \sum_{i=1}^{n} \big[& \ln\Gamma(\alpha^{-1} + y_i) - \ln\Gamma(\alpha^{-1}) - \ln\Gamma(y_i + 1) \\ & + y_i \ln\alpha + y_i x_i'\beta - (\alpha^{-1} + y_i)\ln(1 + \alpha\lambda_i)\big]. \end{aligned} \tag{41}$$

The unknown parameters, $\boldsymbol{\beta}$ and α (over-dispersion parameter), can be estimated by maximizing the log-likelihood function and derived by computing the first derivatives of the log-likelihood function with respect to $\boldsymbol{\beta}$ and α:

$$\frac{\partial \ln L(\boldsymbol{\beta} \mid y)}{\partial \boldsymbol{\beta}} = \sum_{i=1}^{n} \left[\frac{(y_i - \lambda_i)}{1 + \alpha\lambda_i} \mathbf{x}_i' \right] \tag{42}$$

$$\begin{aligned} \frac{\partial \ln L(\boldsymbol{\beta} \mid y)}{\partial \alpha} = \sum_{i=1}^{n} \Bigg[& -\frac{1}{\alpha^2}\Psi\left(\frac{1}{\alpha} + y_i\right) + \frac{1}{\alpha^2}\Psi\left(\frac{1}{\alpha}\right) + \frac{y_i}{\alpha} \\ & + \frac{1}{\alpha^2}\ln(1 + \alpha\lambda_i) - \left(\frac{1}{\alpha} + y_i\right)\frac{\lambda_i}{1 + \alpha\lambda_i} \Bigg] \end{aligned} \tag{43}$$

where $\lambda_i = \exp(\mathbf{x}_i'\boldsymbol{\beta})$ and $\Psi(x)$ is a digamma function:

$$\Psi(x) = \frac{d \ln\Gamma(x)}{dx} = \frac{\Gamma'(x)}{\Gamma(x)}.$$

The standard errors of the parameters $\hat{\boldsymbol{\beta}}_{ML}$ and $\hat{\alpha}_{ML}$, are obtained from the inverse of the Hessian Matrix. The Hessian matrix is obtained from the second derivatives of the log-likelihood function with respect to $\boldsymbol{\beta}$ and α. The (2×2) Hessian matrix is given by:

$$H(\boldsymbol{\beta}, \alpha; y, \mathbf{x}) = \begin{bmatrix} \dfrac{\partial^2 \ln L(\boldsymbol{\beta} \mid y)}{\partial\boldsymbol{\beta}\,\partial\boldsymbol{\beta}'} & \dfrac{\partial^2 \ln L(\boldsymbol{\beta} \mid y)}{\partial\boldsymbol{\beta}\,\partial\alpha} \\ \dfrac{\partial^2 \ln L(\boldsymbol{\beta} \mid y)}{\partial\alpha\,\partial\boldsymbol{\beta}} & \dfrac{\partial^2 \ln L(\boldsymbol{\beta} \mid y)}{\partial\alpha\,\partial\alpha'} \end{bmatrix}. \tag{44}$$

In addition to Poisson regression model (PRM) and negative binomial regression model (NBRM), some researchers have proposed that zero-inflated models fit crash data better than NBRM in some cases. However, the zero-inflated model assumes an underlying dual-state process. Although fit may be improved, the theoretical support for a dual-state process is lacking. Inherently, "safe" locations do not agree with our understanding of crash causation. Thus, PRM and NBRM were employed to find SPFs comprising AADT and the number of crashes.

4.5.2.3 Modeling Results

Table 35 shows the developed SPFs estimated by using the NBRM. All estimated coefficients of independent variables and the log-likelihood ratio test for global test (H_0: the estimated model is not appropriate) are significant at $\alpha=0.05$. In addition, the log-likelihood ratio tests for the over-dispersion is 0 in the negative binomial regression model, indicating that the negative binomial regression model is preferable to the Poisson regression model. Note that the SPFs for each crash type could not be developed due to the relatively small sample size.

Table 35: Developed SPFs for EB application

	Variable	Estimate	Std.Err.	P-value
Total Crashes	AADT (vehicles/day)	0.0000118	0.0000008	<0.0001
	Log of total length (miles)	1.058238	0.0960107	<0.0001
	Ave. length of weaving area (miles)	-0.3308705	0.1220948	0.007
	Junction	-0.1557225	0.066867	0.02
	Constant	1.209892	0.1029637	<0.0001
	Likelihood for the estimated model (χ^2 statistics and associated p-value)		-772.94 (χ^2=211.61; <0.0001)	
	Over-dispersion parameter α (standard error)		0.0892064 (0.0154967)	
	Likelihood ratio test statistics for H_0: α=0 (associated p-value)		χ^2=101.36 (<0.0001)	
	Variable	Estimate	Std.Err.	P-value
Total PDO Crashes	AADT (vehicles/day)	0.0000118	0.0000008	<0.0001
	Log of total length (miles)	1.059809	0.0969112	<0.0001
	Ave. length of weaving area (miles)	-0.3274636	0.1203517	0.007
	Junction	-0.1547298	0.0671788	0.021
	Constant	0.8791145	0.1044735	<0.0001
	Likelihood for the estimated model (χ^2 statistics and associated p-value)		-691.934 (χ^2=210.11; <0.0001)	
	Over-dispersion parameter α (standard error)		0.0599316 (0.0151396)	
	Likelihood ratio test statistics for H_0: α=0 (associated p-value)		χ^2=31.87 (<0.0001)	
	Variable	Estimate	Std.Err.	P-value
Total Injuries	AADT (vehicles/day)	0.0000122	0.0000011	<0.0001
	Log of total length (miles)	1.087034	0.1380414	<0.0001
	Ave. length of weaving area (miles)	-0.3890718	0.1716208	0.023
	Constant	0.2994693	0.1475718	0.042
	Likelihood for the estimated model (χ^2 statistics and associated p-value)		-636.236 (χ^2=128.39; <0.0001)	
	Over-dispersion parameter α (standard error)		0.1716398 (0.0312429)	
	Likelihood ratio test statistics for H_0: α=0 (associated p-value)		χ^2=86.73 (<0.0001)	

In all estimated models, the signs for AADT and length are positive, while the coefficients for average length of weaving area and the dummy variable junction are negative. Using these estimated SPFs, the EB weight (w) and the EB estimates ($E[\kappa|K]$) can be obtained as discussed in Equation (21), and Table 36 shows the estimated EB weight and the EB estimates. The enforcement zone was not the 'least safe' on SR 101 prior to the SEP program since the expected crash counts from the reference group are greater than the observed crash counts. Therefore, the EB estimate is greater than the observed crash count, but less than the expected crash count.

Table 36: EB weight and EB estimates

	Expected crash count (E[κ])	Observed crash count (K)	EB weight (w)	EB estimate (E[κ|K])
Total crashes	76.67	54.80	0.15	58.00
Total PDO crashes	55.07	41.40	0.30	45.54
Total Injuries	31.36	19.80	0.19	21.95

4.5.3 EB Before and After Study Results

Table 37 shows the EB before and after study results. After adjusting the RTM bias, the impacts of the SEP on safety slightly increased since the 101 Scottsdale enforcement zone was 'safer than average' prior to the SEP.

Table 37: EB before and after study results

	Crash Estimates		Delta		Theta	
	Phi	Lambda	Estimate	Std.Dev	Estimate	Std.Dev
Total crashes	58.00	42	15.00	10.05	0.73	0.17
Total PDO crashes	45.54	27	18.54	8.52	0.58	0.18
Total Injuries	21.95	20	0.95	6.55	0.92	0.28

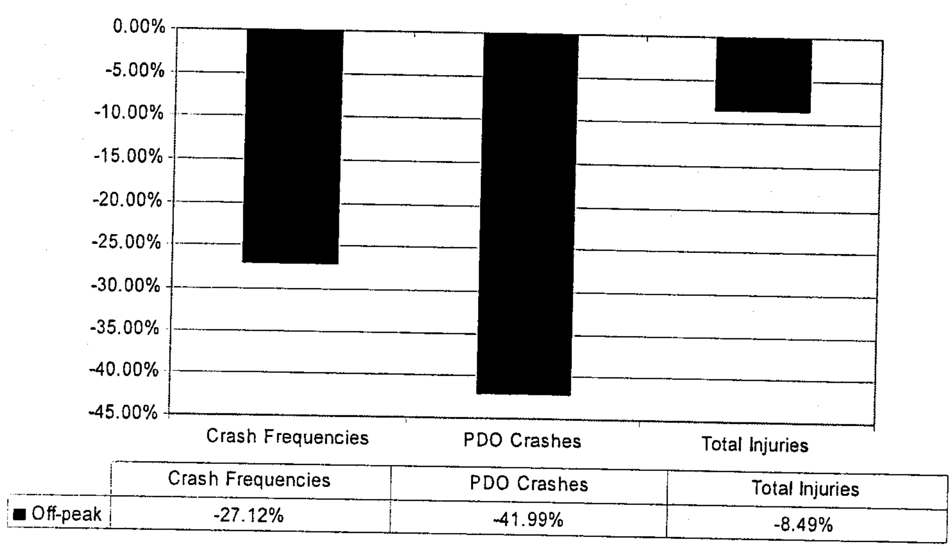


Figure 28: EB before and after study results

Figure 28 illustrates the percent changes in target crash for each analysis category. Again, the percent changes are $(\hat{\theta}-1)\times 100$. The EB before and after study results suggest:

- The impacts of the SEP on safety are larger than those from the simple before and after study when accounting for the RTM bias. Specifically,
  - Total target crash frequency was reduced by 27%. Total PDO crashes and total injuries were also reduced by 41% and 8% respectively.
  - However, the reduction percentages are less than those from the before and after study with a comparison group.

4.6 Economic Analysis

In this section, the estimated changes in safety due to the SEP are translated into economic impacts. The conversion of crashes to crash costs is extremely beneficial and insightful because different crash types have different cost implications, with some crash types costing more than others. In order to quantify the economic impacts, the Arizona-specific crash costs were developed based on the crash costs obtained from several Arizona freeways, and the economic benefits from the SEP were estimated by using the crash costs and the estimated changes in safety (δ).

4.6.1 Arizona-specific Crash Costs

Crash costs are obtained from extensive national research on full costs of motor vehicle crashes (Blincoe *et al.*, 2002). In this analysis, the crash costs are updated to reflect Arizona -specific costs such as hospital charges by injury severity category and to reflect crashes on Arizona high-speed freeways. We utilized inflation adjusted costs from National Hospital Discharge Survey, National Health Interview Survey, AZ hospital cost/charge information, CHAMPUS data on physician costs, National Medical Expenditure Survey, National Council on Compensation Insurance, and Crashworthiness Data System.

Table 38: Estimated Arizona-specific crash costs

Collision type	Crash severity	Final Medical Cost	Total Other Cost	Quality of Life Cost	Total Cost
Single-vehicle	K	$162,870	$1,340,063	$2,111,828	$3,614,761
	A	$122,790	$200,291	$361,020	$684,101
	B	$24,104	$61,295	$88,104	$173,503
	C	$13,545	$34,771	$45,343	$93,659
	O	$15,527	$41,402	$50,277	$107,206
Side-swipe (same direction)	K	$119,065	$1,651,039	$2,496,842	$4,266,946
	A	$133,636	$301,959	$442,205	$877,801
	B	$27,504	$80,482	$86,291	$194,277
	C	$16,354	$65,398	$64,673	$146,425
	O	$15,826	$62,247	$50,530	$128,604
Rear-end	K	$71,037	$1,608,206	$2,441,687	$4,120,929
	A	$70,820	$162,469	$239,725	$473,013
	B	$39,899	$100,244	$152,827	$292,971
	C	$28,785	$77,037	$113,695	$219,517
	O	$30,643	$77,278	$117,022	$224,942
Other Crashes	K	$77,949	$1,200,900	$1,784,243	$3,063,092
	A	$97,374	$236,524	$310,713	$644,611
	B	$15,431	$62,216	$60,957	$138,604
	C	$8,557	$42,965	$43,917	$95,439
	O	$3,421	$34,919	$11,019	$49,359

All crash costs for each crash type are estimated by using a large sample of crashes that occurred on Arizona high-speed freeways (SR 101, 202, and 51). Table 38 shows the estimated Arizona-specific crash costs for each target crashes by severity level, in which the crash severity is classified by using the KABCO severity scale (K = killed; A = disabling injury; B = evident injury; C = possible injury; O = property damage only). The crash costs have 3 cost items:

- Medical Costs: Professional, hospital, emergency department, drugs, rehabilitation, long-term care
- Other Costs: Police/ambulance/fire, insurance administration, loss of wages, loss of household work, legal/court costs, property damage
- Quality of Life Costs: Based on Quality Adjusted Life Years (approximately $92k/QALY)

4.6.2 Economic Benefits

The economic benefits from SEP are quantified using the unit costs and the changes in safety (δ). The estimated changes in safety derived from the simple before and after study and before and after study with a comparison group are shown in Table 39. Note that the economic benefits from the EB before and after study are not quantified in this preliminary report because the estimates could not be obtained in terms of crash type and crash severity due to the small sample size.

Table 39: Changes in safety by severity

Analysis method	Collision type	Crash severity				
		K	A	B	C	O
Simple before and after study with traffic correction	Single Vehicle	0.23	-0.18	5.08	-1.58	29.91
	Side-swipe (same)	0.00	0.00	1.74	1.36	5.51
	Rear-end	0.00	-1.59	-0.14	-0.52	-3.49
	Other	0.41	0.23	0.50	0.84	5.96
Before and after study with a comparison group	Single Vehicle	0.21	-0.97	3.09	-2.35	16.55
	Side-swipe (same)	0.00	0.00	2.00	1.33	6.67
	Rear-end	0.00	-1.74	-0.46	-0.95	-4.55
	Other	0.76	0.76	1.52	3.57	14.98

By multiplying the unit costs by the changes in safety, the economic benefits ($) are obtained. Table 40 shows the economic benefits per the program period (i.e., 191 days). The total benefit from the simple BA study is $6.0 M per 191 days, while the BA study with comparison group yields an estimated benefit of $5.5 M per 191 days, which is larger than that from the simple before and after study. On a annualized basis the benefits are estimated to be $11.5 M and $10.6 M respectively for the two methods.

Table 40: Summary of economic benefits per the program period ($1,000)

Analysis method	Collision type	Crash severity K	A	B	C	O	Total
Simple before and after study with traffic flow correction	Single Vehicle	$831	-$122	$882	-$148	$3,207	$4,651
	Side-swipe (same)	$0	$0	$337	$199	$709	$1,245
	Rear-end	$0	-$753	-$42	-$114	-$785	-$1,693
	Other	$1,250	$148	$69	$80	$294	$1,841
	Total	$2,081	-$727	$1,246	$18	$3,425	$6,044
Before and after study with a comparison group	Single Vehicle	$746	-$663	$537	-$220	$1,774	$2,174
	Side-swipe (same)	$0	$0	$389	$195	$857	$1,441
	Rear-end	$0	-$825	-$135	-$208	-$1,024	-$2,191
	Other	$2,331	$490	$211	$340	$739	$4,112
	Total	$3,076	-$997	$1,002	$108	$2,346	$5,535

Table 41: Summary of economic benefits per year ($1,000)

Analysis method	Collision type	Crash severity K	A	B	C	O	Total
Simple before and after study with traffic flow correction	Single Vehicle	$1,589	-$233	$1,686	-$282	$6,128	$8,888
	Side-swipe (same)	$0	$0	$645	$380	$1,355	$2,380
	Rear-end	$0	-$1,439	-$80	-$217	-$1,499	-$3,235
	Other	$2,388	$283	$131	$154	$562	$3,519
	Total	$3,977	-$1,388	$2,382	$34	$6,546	$11,551
Before and after study with a comparison group	Single Vehicle	$1,425	-$1,266	$1,026	-$421	$3,390	$4,154
	Side-swipe (same)	$0	$0	$743	$373	$1,638	$2,754
	Rear-end	$0	-$1,576	-$257	-$397	-$1,958	-$4,187
	Other	$4,454	$937	$403	$650	$1,413	$7,857
	Total	$5,879	-$1,905	$1,914	$206	$4,484	$10,578

Under the assumption that the changes in safety during the 191 days are the same as those during a year, the economic benefits are annualized as shown in Table 41. The annualized economic benefits range from $11,551,000/year to $10,578,000/year, and the positive values indicate that the increase in rear-end crashes does not nullify the impacts of SEP on safety. Detailed costs assessments of economic benefits quantified by each crash cost item are summarized in Tables 42 and 43.

Table 42: Economic benefit from the simple BA with traffic correction per 191 days

Collision type	Severity	Medical cost	Total other cost	Quality of life cost	Total
Single Vehicle	K	$37,460	$308,214	$485,720	$831,395
	A	-$21,857	-$35,652	-$64,262	-$121,770
	B	$122,546	$311,623	$447,920	$882,089
	C	-$21,348	-$54,798	-$71,461	-$147,607
	O	$464,443	$1,238,418	$1,503,894	$3,206,755
Side-swipe (same)	K	$0	$0	$0	$0
	A	$0	$0	$0	$0
	B	$47,747	$139,717	$149,801	$337,265
	C	$22,209	$88,810	$87,826	$198,845
	O	$87,265	$343,233	$278,624	$709,122
Rear-end	K	$0	$0	$0	$0
	A	-$112,745	-$258,650	-$381,642	-$753,037
	B	-$5,666	-$14,235	-$21,701	-$41,602
	C	-$14,911	-$39,905	-$58,894	-$113,710
	O	-$106,881	-$269,544	-$408,173	-$784,599
Other	K	$31,803	$489,967	$727,971	$1,249,741
	A	$22,396	$54,400	$71,464	$148,260
	B	$7,654	$30,859	$30,234	$68,748
	C	$7,205	$36,176	$36,978	$80,360
	O	$20,382	$208,047	$65,650	$294,080
Total		$587,703	$2,576,682	$2,879,951	$6,044,336

Table 43: Economic benefit from the before and after study with a comparison group per 191 days

Collision type	Severity	Medical cost	Total other cost	Quality of life cost	Total
Single Vehicle	K	$33,597	$276,425	$435,624	$745,646
	A	-$118,936	-$194,004	-$349,688	-$662,627
	B	$74,582	$189,657	$272,608	$536,848
	C	-$31,829	-$81,703	-$106,547	-$220,079
	O	$256,926	$685,083	$831,943	$1,773,952
Side-swipe (same)	K	$0	$0	$0	$0
	A	$0	$0	$0	$0
	B	$55,008	$160,964	$172,581	$388,554
	C	$21,806	$87,197	$86,231	$195,233
	O	$105,507	$414,983	$336,869	$857,359
Rear-end	K	$0	$0	$0	$0
	A	-$123,456	-$283,222	-$417,898	-$824,577
	B	-$18,332	-$46,058	-$70,218	-$134,608
	C	-$27,229	-$72,873	-$107,549	-$207,651
	O	-$139,548	-$351,927	-$532,925	-$1,024,399
Other	K	$59,309	$913,728	$1,357,576	$2,330,613
	A	$74,089	$179,964	$236,412	$490,465
	B	$23,483	$94,677	$92,760	$210,920
	C	$30,509	$153,179	$156,574	$340,262
	O	$51,240	$523,026	$165,043	$739,309
Total		$326,725	$2,649,097	$2,559,397	$5,535,219

Chapter 5 Conclusions, Limitations, and Further Work

This report presents the preliminary analysis results of the speed enforcement camera demonstration program (SEP) that was implemented on Arizona state route 101 from January 2006 to October 2006. This study estimated the impacts of the SEP on traffic safety, speed, and speeding behavior. Note that the conclusions are based on incomplete data, and thus the conclusions are likely to be revised once the data are updated and additional analyses are completed.

Conclusions

This preliminary study—based on the analysis of a variety of limited datasets—suggests the following:

1. Detection frequencies (speeds > 76 mph) increased by about 836% after the SEP ended. The Scottsdale 101 SEP appears to be an effective deterrent to speeding in excess of 75 mph.
2. The SEP reduced average speeds in the enforcement zone by about 9.5 mph.
3. All crashes appear to have been reduced except for rear-end crashes. Increases in rear-end crashes are traded for reductions in other crash types. Also, severity of crashes decreased within all crash types.
4. Swapping of crash types are common for safety countermeasures—many countermeasures exhibit the 'crash swapping' phenomenon observed in this study (left-turn channelization, red-light cameras, conversion of stop signs to signals, etc.).
5. Total estimated SEP benefits range from $11 M to $10 M per year, depending on the analysis type and associated assumptions, which suggests that the increase in rear-end crashes does not nullify the effects of the SEP on safety.
6. Estimated benefits are conservative because the Scottsdale 101 site was safer than average prior to the SEP.
7. Results are conservative because additional costs and benefits have not been considered: incident related congestion, reduced manual enforcement costs, risk to officers, and travel time costs.
8. It is not clear which results are more reliable, the BA with correction for traffic, the comparison group BA, or the Empirical Bayesian analysis results. At this point all three results should be weighed and considered. All three methods predict benefits, and only one predicts injury increases by a very small amount. Additional analysis should shed light on which analysis outcome is likely to be more reliable.

Limitations

The results of this analysis should be treated with caution for a variety of important reasons:

1. The results are based on small and incomplete samples. The demonstration program, which was implemented on a 6.5 section over a period of 6 months, none-the-less results in a relatively small sample of crashes. Small numbers of crashes results in large variability and uncertainty surrounding the analysis results, especially fatal and severe crashes which have high associated crash costs. In addition, approximately 7 of the 9 months of the program are evaluated in this analysis. More complete analysis will yield more reliable results.
2. Random fluctuations in crashes are commonly observed, and can influence the results significantly. In particular, severe crashes including fatal crashes will significantly influence the benefit estimates associated with the analysis.
3. Taking into account traffic exposure increases over time will increase the estimate of the effectiveness—translating to increased benefits.
4. Trends in crashes on the 101 are based on a small sample obtained at the comparison site. Analysis of the entire 101 set of crashes will yield more reliable estimates of crash trends on the 101 from the *before* to *program* periods. Also, comparison crashes will be used to expand the analysis (i.e. crashes during peak periods).
5. Detailed analysis of specific crashes has not been conducted as part of this analysis, and may reveal trends in crashes that have not been revealed in this analysis, such as crashes caused by drivers under the influence of drugs or alcohol, crashes as a result of preceding incidents, or crashes as a result of construction projects.
6. The entire set of costs and benefits have not been included in this analysis. The costs of reduced travel times (lost productivity of drivers) have not been included. The additional benefits of reduced risk to law enforcement personnel, of reduced incident-related congestion, and reduced 'secondary' crashes have not been included.

Planned Further Work

Since the current analyses were conducted by using incomplete data, the analysis result will be updated during the spring of 2007, and presented in the Final Report. The planned further work includes:

- Analyze priority 3 crashes (i.e., all SR 101 crashes in 2006)
- Examine additional comparison sites and comparison crashes
- Examine car-following effects
- Update databases (detections and speed)

- Increase sample size of comparison sites to improve analysis consistency
- Focus on implementation recommendations and guidelines
- Compute additional costs and benefits of program, including travel time losses, incident related congestion costs, reduced enforcement costs, and reduced officer risk.

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Attachment #4

<u>Photo Enforcement Attitude Study</u>

PHOTO-BASED TRAFFIC ENFORCEMENT ATTITUDE STUDY

January 2007

Prepared for

City of Scottsdale
Scottsdale, Arizona

Prepared by

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INTRODUCTION

This report was commissioned by the City of Scottsdale and conducted by Behavior Research Center (BRC). The purpose of the study was to measure attitudes about the use of photo-based traffic enforcement statewide, and follows a similar study conducted in March 2006.

The information contained in this report is based on 795 in-depth interviews with adult heads of household throughout Arizona and an additional 407 heads of household in Scottsdale. Interviewing was conducted in November and December 2006 by professional interviewers at BRC's state-of-the-art Computer-Assisted Telephone Interviewing (CATI) facility in Phoenix, where each interviewer worked under the direct supervision of BRC supervisory personnel. Interviews were conducted during a cross-section of late afternoon, evening and weekend hours to ensure that all households had a roughly equal opportunity of being called. A basic sample of 800 interviews were conducted statewide, proportionate to population in each region. In addition, because the City of Scottsdale wanted a specific understanding of how residents of Scottsdale feel about photo enforcement, an oversample of 407 interviews were conducted in Scottsdale. In this report, the data for overall (statewide) results were mathematically weighted to represent the entire state population distribution to ensure that the feelings of Scottsdale residents do not receive disproportionate weight.

Prior to beginning the interviewing, each interviewer received a thorough briefing on the particulars of the study. During the briefing, the interviewers were trained on (a) the purpose of the study, (b) sampling procedures, (c) administration of the questionnaire, (d) probing protocols for open-ended questions and (e) other project-related issues. In addition, each interviewer completed a series of practice interviews to ensure that all procedures were understood and followed.

When analyzing the results of this survey, it should be kept in mind that all surveys are subject to sampling error. Sampling error, simply stated, is the difference between the results obtained from a sample and those that would be obtained by surveying the entire population under consideration. The overall sampling error for this survey at a 95 percent confidence interval is approximately +/-3.5 percent and the sampling error for Scottsdale alone is approximately +/-5.0 percent.

Behavior Research Center has presented all of the data germane to the basic research objectives of the project. However, if City of Scottsdale management requires additional data retrieval or interpretation, we stand ready to provide such input.

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DETAILED FINDINGS

Effects of Photo Enforcement

Arizonans appear more certain now than they were earlier in the year that the use of photo enforcement technology has had a positive effect on overall traffic safety, cutting down speeding, reducing the number of collisions and even saving taxpayer dollars. In each case, those feeling photo enforcement has done "a great deal" has increased three percentage points since last March, and the percentage of those feeling the program has done "nothing at all" has dropped between two and four points.

TABLE 1

"As you may know, photo enforcement technology is now in use in several Arizona cities. If you have not heard about them, photo enforcement detection sites can be either fixed – that is, pole mounted – or mobile – vehicle mounted – systems. Depending on the technology used, the systems may use either radar or in-road electronic sensors to calculate speed. From what you know or may have heard, has this program done a great deal, some, only a little or nothing at all to. . ."

	A Great Deal	Some	Only a Little	Nothing at All	Not Sure
Improve overall traffic safety in cities where it is operating	**26%**	**32%**	**16%**	**13%**	**13%**
Cut down on speeding in cities where it is operating	29	32	15	11	13
Reduce the number of collisions	23	28	12	16	21
Save taxpayer dollars	15	22	13	26	24

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Table 2 displays the results to the question of the effect of photo enforcement on improving overall traffic safety by demographic groups. Most notable in this table is that Scottsdale residents – arguably those with the most experience with, and exposure to, photo enforcement – are overwhelmingly convinced this technology has had a positive effect on traffic safety, with almost half (46%) stating it has done "a great deal" to improve safety.

TABLE 2 : IMPROVE TRAFFIC SAFETY – DETAIL

"As you may know, photo enforcement technology is now in use in several Arizona cities. If you have not heard about them, photo enforcement detection sites can be either fixed – that is, pole mounted – or mobile – vehicle mounted – systems. Depending on the technology used, the systems may use either radar or in-road electronic sensors to calculate speed. From what you know or may have heard, has this program done a great deal, some, only a little or nothing at all to...?"

	A Great Deal	Some	Only a Little	Nothing at All	Not Sure
TOTAL	26%	32%	16%	13%	13%
GENDER					
Male	24	29	20	14	13
Female	28	34	13	12	13
AGE					
Less than 35	20	32	18	20	10
35 to 54	25	33	17	12	13
55 or over	35	30	13	8	14
ETHNICITY					
Caucasian	26	35	16	11	12
Hispanic	29	24	19	13	15
Other	28	19	15	24	14
COUNTY					
Maricopa	30	31	16	13	10
Pima	21	21	19	13	26
Rural	19	41	14	12	14
Scottsdale	46	28	11	9	6

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Effect of Photo Enforcement on Respondent Behavior

Little changed from the March study, eight in ten (80%) Arizonans admit they are more careful to observe speed limits where photo enforcement is operating, and this percentage is remarkably consistent across demographic groups.

TABLE 3

"Would you say you would be more careful to observe speed limits when you are driving in cities that have photo enforcement operating?"

	% Yes
Total	80%
Gender	
Male	79
Female	81
Age	
Less than 35	78
35 to 54	84
55 or over	78
Ethnicity	
Caucasian	79
Hispanic	86
Other	84
County	
Maricopa	79
Pima	77
Rural	84
Scottsdale	84

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SUPPORT FOR PHOTO ENFORCEMENT

In another indication that the publicity surrounding Scottsdale's demonstration freeway photo enforcement project has had a positive effect on public opinion, we note in Table 4 that the net of support to opposition to the use of photo enforcement has grown by eleven points since March. Moreover, an increase in support can be seen in every demographic group – even among men and those under 35, the most negative demographics.

TABLE 4

"In general, do you strongly support, support, oppose or strongly oppose the use of photo enforcement?"

	Strongly Support	Support	Oppose	Strongly Oppose	Not Sure	**Net – Support/ Oppose**
TOTAL	28%	45%	13%	8%	6%	**+52**
GENDER						
Male	25	40	18	11	6	**+36**
Female	30	50	9	5	6	**+66**
AGE						
Less than 35	16	51	17	11	5	**+39**
35 to 54	28	45	14	8	5	**+51**
55 or over	39	41	8	4	8	**+68**
ETHNICITY						
Caucasian	27	46	13	8	6	**+52**
Hispanic	27	49	15	4	5	**+57**
Other	30	40	15	11	4	**+44**
COUNTY						
Maricopa	30	43	14	8	5	**+51**
Pima	15	58	13	4	10	**+56**
Rural	31	42	11	9	7	**+53**
Scottsdale	39	36	14	8	3	**+53**

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Table 5 shows that support for the use of photo enforcement *on freeways* is very strong among those who support the technology in general. Indeed, while 73 percent of the total support photo enforcement in general (Table 4), 62 percent overall support its use on freeways.

TABLE 5

"Do you strongly support, support, oppose or strongly oppose the use of photo enforcement on freeways?"

AMONG THOSE WHO SUPPORT PHOTO ENFORCEMENT IN GENERAL

(Percentages shown are of total respondents)

	Strongly Support	Support	Oppose	Strongly Oppose	Not Sure	**Total Support**
TOTAL	28%	34%	7%	2%	2%	**62%**
GENDER						
Male	26	31	7	1	1	**57**
Female	30	38	8	2	2	**68**
AGE						
Less than 35	19	34	9	3	3	**53**
35 to 54	27	35	9	2	1	**62**
55 or over	40	34	4	1	2	**74**
ETHNICITY						
Caucasian	28	36	7	1	2	**64**
Hispanic	26	34	9	7	0	**60**
Other	30	30	7	4	0	**60**
COUNTY						
Maricopa	28	35	7	2	1	**63**
Pima	21	41	7	2	2	**62**
Rural	30	29	9	1	2	**59**
Scottsdale	43	27	3	1	0	**70**

Totals do not add to 100% due to photo enforcement opponents not being asked the question.

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SHOULD THE STATE OR THE CITY ADMINISTER PHOTO ENFORCEMENT?

Respondents are generally divided on the question of whether freeway photo enforcement should be administered by the state or by the city through which the freeway runs.

TABLE 6

"Whether or not you support photo enforcement, when it is used on freeways, do you feel it should be administered by the State or by the city or county in which the freeway is located?"

	State	City/ County	Either/ Does Not Matter	Neither	Not Sure
TOTAL	45%	39%	7%	2%	7%
GENDER					
Male	48	36	8	3	5
Female	43	40	6	2	9
AGE					
Less than 35	43	48	3	2	4
35 to 54	45	36	8	2	9
55 or over	48	34	8	2	8
ETHNICITY					
Caucasian	45	38	7	2	8
Hispanic	48	45	5	0	2
Other	51	32	5	5	7
COUNTY					
Maricopa	44	37	7	3	9
Pima	49	35	10	1	5
Rural	46	45	3	2	4
Scottsdale	40	34	12	3	11

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Perception of the Feelings of Others

Even on the "reverse" question – where we ask respondents how they think other drivers feel about photo enforcement – we can see evidence that the media attention to the subject in the past several months has had a positive effect on public opinion. The percentage who believe most oppose it has fallen from 31 to 25 percent since March.

TABLE 7

"And thinking about other drivers around the state, which of the following best describes how you think they feel about photo enforcement?"

Most everyone supports it	3%
A majority supports it	17
Net – support	**20%**
Evenly divided between supporters and opponents	44
A majority opposes it	18
Almost everyone opposes it	7
Net – oppose	**25%**
Not sure	11

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Awareness of Scottsdale Demonstration Project on Loop 101

Two-thirds (66%) statewide were aware of the Scottsdale demonstration project on a portion of the Loop 101 before our interviewer mentioned it. This reinforces the evidence that this project has resulted in greater public awareness of the issue.

TABLE 8

"As you may know, the City of Scottsdale recently conducted a demonstration photo enforcement program on a section of the Loop 101. Before I just mentioned it, were you aware of this demonstration program?"

	% Yes
TOTAL	66%
GENDER	
Male	68
Female	63
AGE	
Less than 35	64
35 to 54	65
55 or over	68
ETHNICITY	
Caucasian	68
Hispanic	63
Other	52
COUNTY	
Maricopa	77
Pima	33
Rural	58
Scottsdale	89

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The effect of the Scottsdale demonstration project on public support for photo enforcement may be found in Table 9, where we note that the project caused over four in ten (43%) to become more supportive, while making only 15 percent less supportive. The project had its maximum positive impact on Scottsdale (59%) and other Maricopa County (46%) residents.

TABLE 9

"Did that program make you more supportive of photo enforcement on freeways, less supportive, or did it make no difference to you?"

	More Supportive	No Difference	Less Supportive	Not Sure
TOTAL	43%	41%	15%	1%
GENDER				
Male	40	40	19	1
Female	45	42	12	1
AGE				
Less than 35	24	49	27	0
35 to 54	40	44	15	1
55 or over	64	31	3	2
ETHNICITY				
Caucasian	43	41	15	1
Hispanic	45	43	12	0
Other	37	41	20	2
COUNTY				
Maricopa	46	39	14	1
Pima	25	60	15	0
Rural	38	42	18	2
Scottsdale	59	26	14	1

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EFFECT OF COLLISION STATISTICS ON PHOTO ENFORCEMENT SUPPORT

Knowing that the number of collisions drop by 20 percent when photo enforcement is in place makes almost two-thirds (63%) more supportive of the technology. This argument is most influential among women and older residents.

TABLE 10

"Studies show that where photo enforcement is in use, the number of collisions drops 20 percent. Does this make you more favorable toward photo enforcement, less favorable, or does it make no difference?"

	More Favorable	No Difference	Less Favorable	Not Sure	**Net - More/Less Favorable**
TOTAL	63%	29%	5%	3%	**+58**
GENDER					
Male	57	34	6	3	**+51**
Female	69	25	3	3	**+66**
AGE					
Less than 35	57	34	6	3	**+51**
35 to 54	62	30	6	2	**+56**
55 or over	75	22	1	2	**+74**
ETHNICITY					
Caucasian	65	28	4	3	**+61**
Hispanic	56	35	8	1	**+48**
Other	62	31	1	6	**+61**
COUNTY					
Maricopa	60	31	5	4	**+55**
Pima	60	32	7	1	**+53**
Rural	73	23	2	2	**+71**
Scottsdale	72	22	4	2	**+68**

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Effect of Speed on Collisions

Virtually identical results, in terms of support for photo enforcement, may be found when respondents are told that 35 percent of collisions are due to speed.

TABLE 11

"Statistics also show that 35 percent of collisions are due to speeding. Does this fact make you more favorable toward photo enforcement, less favorable, or does it make no difference?"

	More Favorable	No Difference	Less Favorable	Not Sure	**Net - More/Less Favorable**
TOTAL	62%	32%	4%	2%	**+58**
GENDER					
Male	53	41	5	1	**+48**
Female	70	25	2	3	**+68**
AGE					
Less than 35	53	42	5	*	**+48**
35 to 54	63	33	3	1	**+60**
55 or over	74	21	2	3	**+72**
ETHNICITY					
Caucasian	63	33	3	1	**+60**
Hispanic	62	34	2	2	**+60**
Other	63	30	4	3	**+59**
COUNTY					
Maricopa	61	32	4	3	**+57**
Pima	56	43	1	*	**+55**
Rural	70	25	4	1	**+66**
Scottsdale	72	23	4	1	**+68**

*Indicates less than ½ of one percent

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Seriousness of Speeding

Next, we asked respondents whether they think speeding is a problem on freeways, on surface streets, in residential areas, in construction and school zones. Two-thirds or more feel speeding is a serious problem in each.

TABLE 12

"Would you say that speeding is a very serious problem, a somewhat serious problem, not a very serious problem or not a problem at all on each of the following:"

	Freeways	Major Surface Streets	Residential Areas	Construction Zones	School Zones
Very serious	49%	47%	46%	42%	45%
Somewhat serious	32	33	30	27	22
Net – Serious	**81%**	**80%**	**76%**	**69%**	**67%**
Not very serious	10	13	14	15	15
Not a problem at all	7	5	8	11	14
Net – Not a problem	**17%**	**18%**	**21%**	**26%**	**29%**
Unsure	2	2	2	5	4

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Support for Holding the Vehicle Owner Responsible for Citations

Finally, we asked respondents whether they would support holding the vehicle owner responsible for a citation issued through photo enforcement, knowing that many offenders avoid responsibility because the vehicle owner refuses to identify the driver. Six in ten (58%) support such a measure. As may be seen in Table 13, strongest levels of support are found among women, residents over 55, Hispanics and Pima County residents.

TABLE 13

"As you may know, current Arizona law provides that the driver of a vehicle cited for speeding through photo enforcement is charged with the offense, which results in many offenders avoiding responsibility because the vehicle's owner will not identify the driver. In some states, unless the owner identifies the driver, the vehicle owner is responsible for the citation. In general, do you strongly favor, favor, oppose or strongly oppose holding vehicle owners responsible unless they identify the driver?"

	Strongly Favor	Favor	Oppose	Strongly Oppose	Not Sure	**Net - Favor/ Oppose**
TOTAL	30%	28%	22%	15%	5%	**+21**
GENDER						
Male	28	28	24	17	3	**+15**
Female	32	28	20	13	7	**+27**
AGE						
Less than 35	21	37	20	15	7	**+23**
35 to 54	30	26	23	18	3	**+15**
55 or over	41	23	22	8	6	**+34**
ETHNICITY						
Caucasian	28	29	23	15	5	**+19**
Hispanic	38	27	17	11	7	**+37**
Other	38	22	20	15	5	**+25**
COUNTY						
Maricopa	28	26	22	17	7	**+15**
Pima	26	43	20	9	2	**+40**
Rural	38	23	25	11	3	**+25**
Scottsdale	30	23	21	21	5	**+11**

*Indicates less than ½ of one percent

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Attachment #5

Proposed Photo Enforcement Intersections And Directions

PROPOSED PHOTO ENFORCEMENT LOCATIONS