Impacts Of The San Diego Photo Red Light Enforcement System On Traffic Safety

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ABSTRACT

The paper reports on the analysis of violation and crash data as part of an evaluation of the impact on traffic safety of the San Diego Photo Red Light Enforcement System. The system was found to have resulted in a statistically significant reduction in the number of red light running violations. The decreases in violations occurred at almost all camera enforced intersections and the decreases continued, at a diminishing rate, throughout the period the cameras were operated. The impact on traffic safety was more complex. For traffic traveling in the enforced direction at intersections with red light cameras, crashes attributable to red light running decreased after implementation to approximately 60 percent of pre-enforcement rates, while rear end crashes increased to approximately 140 percent of pre-implementation levels. These before-and-after changes in crash rates were statistically significant, while there were no significant changes in crash rates for traffic traveling in directions not covered by the red light cameras. In addition, it is concluded that photo enforcement was more effective in reducing crashes at intersections where through movement was enforced, than where left turns were enforced.

INTRODUCTION

This paper reports findings based on an evaluation of the City of San Diego Photo Red Light Camera Program. The focus of discussion is on original data that were analyzed and the contribution that the findings can make to the existing body of knowledge on red light photo enforcement.

Background

In 1998, the City of San Diego Police Department contracted with a vendor for the provision of "red light camera enforcement" technology and services at selected intersections throughout the City. The City's photo enforcement system was implemented under the provisions of California Vehicle Code (CVC) Section 21455.5, Traffic Signal Automated Enforcement. Frontal photo images are required so that the individual driving can be cited for a moving violation. The fine in California is $271. In June 2001, following negative publicity, the camera system was turned off to allow for a period of review. The results of that review are reported in the full study report (*1*). The camera system remains turned off at the time of writing.

The Deployed System

The deployed system uses equipment that has been widely deployed throughout the world to monitor both red light running and speeding violations. The system provides for the detection of motor vehicles entering the intersection being enforced by inductive loops, similar to the loops that are widely used for traffic signal control and freeway management purposes, and for the recording of red light violations by a high quality 35 mm camera wet film system. The logic required to identify red light running violations and then take two photographs of each violation at pre-determined locations is implemented on a processor situated in the camera unit enclosure or housing, using inputs from the vehicle detection loops and traffic signal yellow and red control circuits.

The first and second loops are installed at all but one location in the City inside the intersection or on the intersection side of the stop line. This is not a standard form of installation. The installation method means that the actual time of the violation, that is, the precise time when the motorists crossed the stop line facing a red traffic signal indication, needs to be estimated for each recorded violation. In order to establish the position of the vehicle when the signal turned red, a calculation is performed that uses the vehicle speed from the first loop to the second loop and applies that speed to the known distance of the leading edge of the second loop to the trailing edge of the stop line. A grace time period, that varies from intersection to intersection and according to the vehicle speed, is allowed before a citation is prepared. During the period of operation of the system, 83,931 motorists were cited for violations.

Red Light Running and Crashes

Two commonly applied criteria for evaluating the effectiveness of photo enforcement programs are: (a) reduction in the number of red light running violations, and (b) reduction in the number of intersection crashes after the installation and operation of photo enforcement cameras. Both of these criteria are important justifications for photo enforcement programs that may not otherwise be popular with the driving public. Studying data associated with these criteria can also lead to an understanding of how such programs may be improved in order to enhance their positive impact for traffic safety. Some of the findings suggest traffic engineering and signal timing improvements rather than enforcement.

VIOLATIONS

Data

It is necessary to establish whether the implementation of the program has indeed reduced red light running. Unfortunately, there is no photographic or other evidence that reflects the true "before" situation. The violations data is based on the monthly violations data reported for each photo-enforced intersection. The number of violations reported for each location is determined from the photographic record of drivers triggering the cameras according to the agreed-upon parameters for the operation of the cameras.

As shown in Table 1, nineteen intersections were made operational over a period of nearly three years. The length of the period of operation, which for all intersections extended until June 2001, varies from as long as 34 to as little as 12 complete months. When processing data, partial months at the beginning and end of each period were dropped.

Regression Models of Violation Rates Over Time

If the cameras have a deterrent effect on running of red lights, violations should be decreasing over time at the controlled intersections. Figure 1, a typical case, shows that violations decreased at almost every controlled intersection, and in most cases the rate of decrease also declines over time. The curve displayed in Figure 1 is a fitted exponential regression function. This function represents a uniform percentage change in the dependent variable:

$$y = \alpha e^{\beta x} \tag{1}$$

Where y is the number of violations per month, x is the number of months beyond the first month of implementation, and α and β are parameters to be estimated for each intersection. The uniform decrease in y (violations) per unit of x (per month) can be shown to be $1-e^{\beta}$.

Table 1. Controlled Intersection Locations with Effective Date of Operation

Code	Location	Movement enforced	Effective date
1404	WB El Cajon Boulevard at 43rd Street	Through	7/30/1998
1444	WB Harbor Drive at 32nd Street	Through	12/7/1998
1454[a]	WB Garnet Avenue at Ingraham Street	Through	12/7/1998
1484	WB Imperial Avenue at Euclid Avenue	Through	4/2/1999
1504[a]	WB F Street at 16th Street	Through	4/2/1999
1523	EB A Street at10th Avenue	Through	2/24/2000
1534[a]	WB Miramar Road at Camino Ruiz	Through	2/24/2000
1542[a]	SB Mission Boulevard at Garnet Avenue	Through	5/19/2000
1551	SB Black Mountain Road at Gemini Avenue	Through	4/20/2000
1553	EB Mira Mesa Boulevard at Scranton Road	Through	4/20/2000
1414	NB Bernardo Center Drive to WB Rancho Bernardo Road	Left turn	7/30/1998
1422	WB Aero Drive to SB Murphy Canyon Road	Left turn	7/30/1998
1462	SB College Avenue to Montezuma Road	Left turn	12/7/1998
1474	WB La Jolla Village Drive to Towne Center Drive	Left turn	12/7/1998
1492	SB Black Mountain Road to EB Mira Mesa Boulevard	Left turn	4/2/1999
1513	EB Garnet Avenue to NB Mission Bay Drive	Left turn	4/2/1999
1533[a]	SB Harbor Drive to EB Grape Street	Left turn	10/7/1999
1541[a]	NB Mission Bay Drive to WB Grand Avenue	Left turn	5/19/2000
1543	EB Carmel Mountain Road to NB Rancho Carmel Drive	Left turn	2/24/2000

[a] Signal timing changes made during period of enforcement

The regression results are listed in Table 2. For all but one of the intersections – Code number 1533, SB Harbor Drive to EB Grape Street – the coefficient representing a uniform percentage decrease per month is significantly different from zero at p = .01 (the 99% confidence level). Moreover, with only a few exceptions, the percent variance accounted for is high, indicating that the month-to-month variation from the regression trend is reasonable.

The median estimated percentage decrease per month is 3.2%. The intersection plotted in Figure 1 is typical. At half of the intersections violations decreased at a rate in excess of 3.2% per month. The maximum rate of decrease was 22.3% per month and the minimum rate was 0.0% per month; for the 18 of 19 intersections with a significant regression coefficient, the minimum rate of decrease in violations was 2.1% per month.

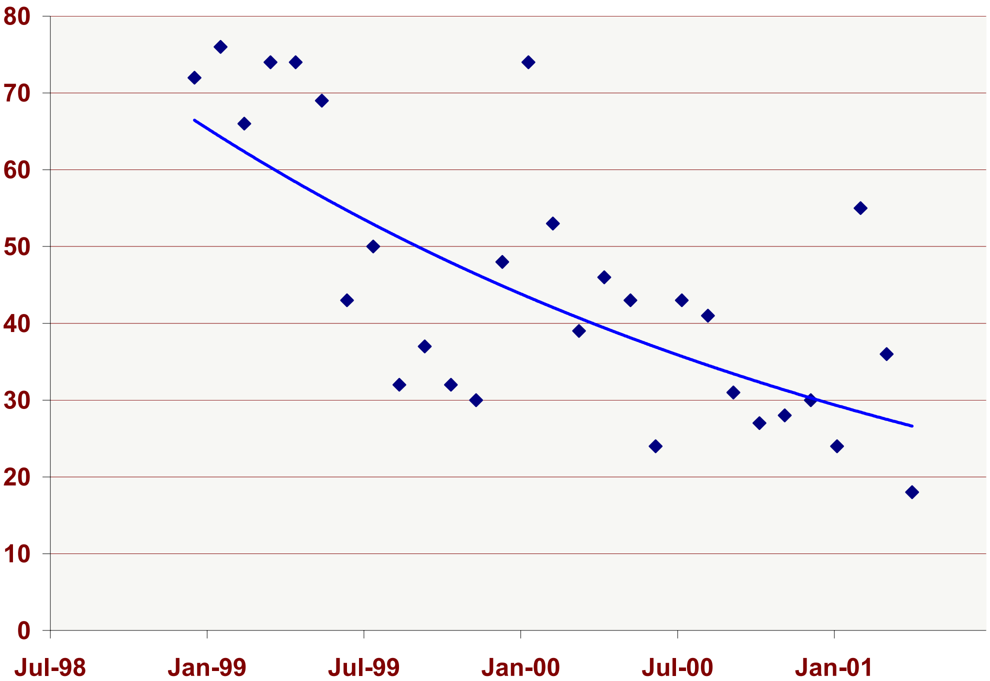

Figure 1. Violations By Month: West Bound Harbor Drive At 32nd St.

The regressions listed in Table 2 can be used to forecast the number of violations at various time horizons. Such a forecast was performed for time horizons up to two years commensurate with the extent of the data for each intersection. For the intersection with the median rate of decrease in violations – Code number 1444, WB Harbor Drive at 32nd Street – after six months the forecast violation rate is at approximately 82% of that of the initial month. After one year the forecast rate is at 68%, and after two years it is at 46%. Such forecasts could be used for monitoring violations at photo red light locations. If sudden aberrations occur then this would draw program management attention to the need to check for contributing circumstances such as malfunctioning equipment, accidental changes in signal timing, new visual hazards etc.

Two conclusions can be drawn based on these results:

1. Photo enforcement resulted in a significant reduction in the number of red light running violations; and,
2. The decrease in the number of red light running violations continued throughout the period that the cameras were operated at almost every controlled intersection, but the rate of decrease declined over time.

Table 2. Exponential Time Series Regressions of Violations by Month

Code	Months analyzed	adj. R^2	Constant (α)	Coefficient (β in equation 1) Estimate	t-statistic	Significance
1404	32	0.48	331	-0.0286	-5.53	0.000
1444	28	0.47	68	-0.0327	-5.08	0.000
1454	28	0.27	942	-0.0214	-3.38	0.002
1484	24	0.58	135	-0.0292	-5.81	0.000
1504	26	0.21	97	-0.0641	-2.73	0.012
1523	14	0.64	710	-0.0679	-5.14	0.000
1534	14	0.89	302	-0.0836	-10.81	0.000
1542	11	0.40	462	-0.1054	-2.87	0.017
1551	12	0.66	192	-0.0600	-4.92	0.001
1553	12	0.74	900	-0.1420	-5.86	0.000
1414	32	0.77	406	-0.0260	-10.50	0.000
1422	32	0.53	1535	-0.0212	-6.04	0.000
1462	28	0.25	273	-0.0217	-3.24	0.003
1474	28	0.33	755	-0.0255	-3.85	0.001
1492	24	0.38	449	-0.0214	-3.93	0.001
1513	24	0.67	1430	-0.0407	-7.07	0.000
1533	18	0.00	3102	-0.0023	-0.26	0.800
1541	11	0.37	860	-0.2529	-2.74	0.021
1543	14	0.59	637	-0.0551	-4.64	0.001

Violations and Signal Timing Changes

Studies have indicated that increasing the length of the yellow change interval significantly decreases the frequency of red light running (*2-5*). One study reported that between 70 and 82 percent of all red light violations happen in less than 1.5 seconds after the yellow signal indication (*5*). Longer yellow and all-red change intervals serve to reduce red light violations and the potential that they introduce for collisions.

However, “intentional violators” may not be deterred by the length of the yellow change interval. Red light running was found to be frequent at intersections where the yellow change interval is as much as 40 percent greater than those intervals recommended by the ITE guidelines (*6*). Intentional violators use the yellow change interval intentionally and recurrently as a part of the green interval. On the other hand, longer yellow change intervals do serve to reduce the number of violations by “unintentional” violators. Although compliance with the longer yellow change intervals may eventually deteriorate, it is believed that the reductions observed for unintentional violators are sustained over extended time periods.

For reasons unrelated to the enforcement program the yellow change intervals were modified at six photo-enforced intersections after the startup of the City's photo enforcement program (identified in Table 1). These modifications were performed as part of the City Traffic Engineering Department's on-going review and adjustment of the yellow change intervals throughout the City. A comparison of the numbers of red light running violations before and after the modifications in the yellow change intervals at the five photo enforced intersections confirms the previous findings of (3). The before and after violations data is shown in Figure 2.

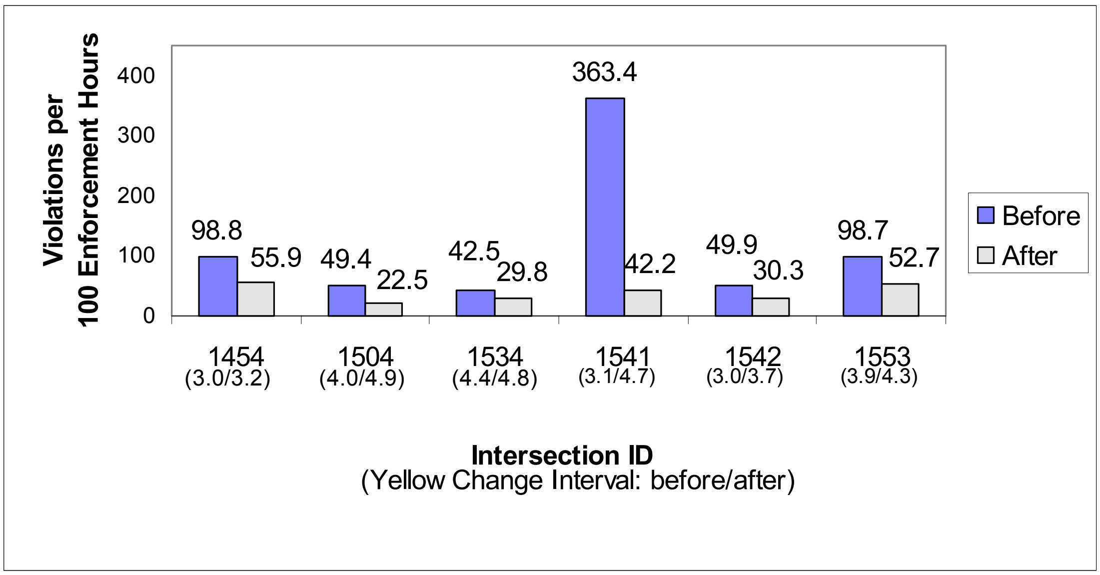

Figure 2. Violations Data For Photo Enforced Intersections Before And After Yellow Change Interval Modification

The most significant change in the number of violations occurred at the intersection of Mission Bay Drive and Grand (1541) where the yellow change interval was extended from 3.1 seconds to 4.7 seconds. This change resulted in an 88-percent decrease in the number of violations. At the five other intersections, the number of violations dropped significantly in response to longer yellow intervals. These findings support the view that adjustments of yellow and all-red intervals can reduce signal violations. Such traffic engineering solutions should be implemented, evaluated, and modified if necessary in advance of implementing automated enforcement of red light running.

TRAFFIC SAFETY

Crash Data

The overall objective of the City's photo enforcement program is to improve traffic safety at signalized intersections by reducing the number of red light running violations and collisions attributable to red light running. Before and after crash data was provided by the City's Traffic Engineering Department. Analysis of these data indicates that the number of crashes attributable to red light running has been significantly reduced for the photo-enforced intersection approaches.

The crash data covered the time period from April 1995 through October 2001. Since the photo enforcement program was initially deployed in July 1998, crash data are available for the time periods before and after the startup of the photo enforcement program. No control data were available for intersections where photo enforcement was not deployed.

Two crash types, broadside or right angle (RA) and ran signal (RS), are the principal types of crashes associated with red light running. RS crashes are defined to be collisions of any type caused by red light running, as determined in the course of police investigation. The hypothesis is that photo enforcement reduces the likelihood of both RA and RS crashes. A corollary hypothesis is that photo enforcement increases the likelihood of rear end (RE) crashes.

The crash data are summarized in Table 3 on a per year basis, before and after implementation. This table shows that total crashes per year went down at 11 intersections and up at 8. RS/RA crashes went down at 12 intersections and up at 7, while RE crashes went down at 5 intersections and up at 14 intersections.

The review of crash rates by intersection in Table 3 also revealed that some locations in San Diego have very low crash rates. As an example, SB Harbor Drive to EB Grape Street (Code 1533) had less than 1.5 crashes per year before and 1.0 after the introduction of enforcement. Yet, this same location accounted for nearly one-quarter of the recorded violations and citations issued under the City's photo enforcement system. It is also a location that had no statistically significant change in the violation rate after the implementation of enforcement (Table 2). This would appear to indicate the violations are intentional. This suggests two things: firstly, a mismatch between crash rates and the deployment of photo enforcement. If the major criteria for such programs are their use for traffic safety enhancement then the highest number of RS/RA crashes should be considered first for photo enforcement. Secondly, if violations remain at such a high level this intersection leg would appear to be a high priority location for traffic engineering improvements. The criteria used for the original selection of the intersection are unknown.

Table 3 Crash Rates per Year for Responsible Traffic in Enforced Direction

		Before: 1996 to implementation				After: implementation to 9-10-2001			
Code	Date	Total	RS[a] & RA[b]	Rear end	All others	Total	RS[a] & RA[b]	Rear end	All others
1404	7/30/1998	2.41	0.90	0.90	0.60	0.94	0.31	0.63	0.00
1444	12/7/1998	0.82	0.54	0.27	0.00	0.69	0.34	0.00	0.00
1454	12/7/1998	3.81	1.36	2.18	0.27	3.43	0.34	2.40	0.69
1484	4/2/1999	2.50	1.00	1.25	0.25	2.38	0.00	1.98	0.40
1504	4/2/1999	5.25	2.25	2.00	1.00	3.97	0.00	2.78	1.19
1523	2/24/2000	2.86	2.66	0.20	0.00	4.32	3.70	0.62	0.00
1534	2/24/2000	3.68	1.84	0.82	1.43	6.17	0.62	4.93	6.78
1542	5/19/2000	1.37	0.39	0.59	0.20	0.00	0.00	0.00	0.00
1551	4/20/2000	2.58	1.98	0.00	0.59	2.04	1.36	0.68	0.00
1553	4/20/2000	4.36	1.59	1.98	0.79	4.08	0.00	2.04	2.04
1414	7/30/1998	0.30	0.00	0.30	0.00	1.25	0.63	0.63	0.00
1422	7/30/1998	1.81	0.30	1.51	0.00	2.50	1.25	0.63	0.63
1462	12/7/1998	1.36	0.00	1.09	0.27	2.11	0.70	1.41	0.00
1474	12/7/1998	8.43	2.45	5.71	0.27	9.14	0.35	7.74	1.05
1492	4/2/1999	3.25	1.00	1.75	0.50	1.19	0.00	1.19	0.00
1513	4/2/1999	5.75	1.00	3.00	1.75	5.55	1.19	3.17	1.19
1533	10/7/1999	1.42	0.47	0.47	0.47	1.00	0.00	0.50	0.50
1541	5/19/2000	1.37	0.59	0.20	0.59	2.87	0.72	2.16	0.00
1543	2/24/2000	2.25	0.20	1.63	0.41	2.47	0.62	1.85	0.00

[a] Ran Signal crashes
[b] Right Angle crashes

Statistical Comparison of Before and After Data

In order to analyze the potential effects of the red light cameras on traffic safety, we need to control for effect of external conditions, such as changes in overall traffic volumes, speeds, or changes in vehicle mix and driver characteristics. This is best done by analyzing the changes over time at the implemented intersections compared to changes over the same time at a control sample of similar intersections without cameras. However, such data were not available in this study. As a second best solution, we compared the before-and-after changes in crash rates for traffic in the enforced direction of each intersection with changes over the same periods in crash rates for the un-enforced directions. Assuming that changes in traffic characteristics are similar among the various directions of traffic at a particular intersection, this provides a means of controlling for external influences.

In Table 4 we show the results of paired-sample t-tests of differences in the mean crash rates per year, for total crashes and for three composite types of crashes, comparing before implementation to after implementation. The paired t-tests is a method with takes advantage of repeated measurements (panel data) to measure the statistical significance of the mean change in a variable by comparing this mean change to the variance of changes across the sample.

Table 4. Paired-sample t-tests of Changes in Crash Rates per Year

	Mean Before	Mean After	Change	Std. error of change	t-statistic	Significance of t-statistic[c]
Enforced direction (n=19)						
Total crashes	2.92	2.95	0.027	0.264	0.10	N.S.[d]
RS[a] and RA[b] crashes	**1.08**	**0.64**	**-0.442**	**0.223**	**-1.98**	**0.031**
Rear end crashes	**1.36**	**1.86**	**0.498**	**0.264**	**1.89**	**0.038**
Other types of crashes	0.49	0.76	0.267	0.306	0.87	N.S.[d]
Direction right of enforced (n=17)						
Total crashes	1.05	1.24	0.184	0.705	0.75	N.S.[d]
RS[a] and RA[b] crashes	0.43	0.26	-0.164	0.119	1.37	N.S.[d]
Rear end crashes	0.41	0.69	0.275	0.164	1.68	N.S.[d]
Other types of crashes	0.22	0.29	0.073	0.135	0.54	N.S.[d]
Direction left of enforced (n=17)						
Total crashes	1.72	1.47	-0.250	0.330	-0.76	N.S.[d]
RS[a] and RA[b] crashes	0.59	0.36	-0.233	0.142	-1.64	N.S.[d]
Rear end crashes	0.65	0.68	0.031	0.216	0.14	N.S.[d]
Other types of crashes	0.48	0.39	-0.088	0.131	-0.67	N.S.[d]
Direction opposite of enforced (n=17)						
Total crashes	2.52	2.39	-0.223	0.374	-1.01	N.S.[d]
RS[a] and RA[b] crashes	0.78	0.71	-0.070	0.218	-0.32	N.S.[d]
Rear end crashes	1.25	1.25	-0.006	0.252	-0.03	N.S.[d]
Other types of crashes	0.49	0.32	-0.167	0.155	-1.08	N.S.[d]

[a] Ran Signal crashes
[b] Right Angle crashes
[c] Based on 1-tailed tests for RS and RA crashes (decrease hypothesized) and rear end crashes (increase hypothesized); 2-tailed tests for total crashes and other types of crashes
[d] not significant at the 95% confidence interval

As shown in Table 4, the *decrease* (in the mean number of combined ran-signal and right-angle crashes per year for traffic traveling in the enforced direction is statistically significant at the p = .05 level (one-tailed test). There is a corresponding statistically significant *increase* in the number of rear-end crashes per year for traffic in the enforced direction. None of the other directions of traffic exhibit any significant changes in crash rates over the same before-and-after period. For traffic traveling in the enforced direction, ran-signal and right-angle crashes decreased after implementation to approximately 60% of pre-enforcement rates, while rear-end crashes increased to approximately 140% of pre-implementation levels.

We can conclude that photo enforcement has led to a significant *decrease* in RS/RA crashes for responsible vehicles traveling in the enforced direction. Concurrently, there has been a significant *increase* in the rate of RE crashes for this same traffic flow direction. There were no other significant changes in accident rates for non-enforced traffic flow directions at the same intersections. The changes in the two accident rates are approximately the same. However, RE crashes are on average less severe than RS/ RA crashes. Evidence of the difference in crash severity is provided by two years of data from the Traffic Accident Surveillance and Analysis System (TASAS) (*7*) for intersections in neighboring Orange County (the authors did not have access to San Diego County data). There were 1780 crashes at intersections on the arterial state highways in Orange County during 1997 and 1998, and 424 of these were rear end crashes and 806 were angle (broadside) crashes. Of the rear end crashes, 33.7% resulted in injuries (as opposed to property damage only), versus 46.4% of the angle crashes that were injury crashes, a difference in severity rates which is highly statistically significant. Similar differences in severity have been observed in other studies (*8-9*).

The issue of mitigating rear end crashes and the identification of successful countermeasures is clearly an area for further study. Treatments aimed at mitigating rear end crashes should accompany photo red light enforcement. Monitoring changes in crashes at enforced intersections over longer periods of time is clearly vital. If rear end crashes do not decline despite serious efforts to mitigate, then the validity of the traffic safety justification should be questioned.

Crash Rate Changes By Type of Movement Enforced

The accident data were analyzed to determine if there were differences in the crash rate changes for photo-enforced intersections where the through movement (THM) is enforced in comparison with intersections where left turn movement (LTM) is enforced. As shown in Figure 3, before photo enforcement, the average rate for right angle and ran signal (RA/RS) crashes for the enforced direction at the ten THM intersections was 1.45 per year; after photo enforcement, the average RA/RS crash rate dropped to 0.67 crashes per year, a decrease of more than fifty percent. Even with the small sample size, this change is significant at the p = .010 level for one-tailed paired-sample t-tests. Rear end (RE) crashes for THM intersections increased from 1.02 per year to 1.61 per year. However, due to the small sample size and high variations, this increase in RE crashes is not statistically significant (p = .098).

For the nine LTH intersections, average RA/RS crash rates dropped from 0.67 to 0.61 crashes per year, while rear end crashes increased from 1.74 to 2.14 crashes per year. Neither of these changes in crash rates for LTM intersections was significant at the *p* = .05 level (*p* = .427 for RA/RS crashes and *p* = .131 for RE crashes). It can be concluded that photo enforcement was more effective in reducing the rate of crashes at intersections where the through traffic movements was enforced. This finding would appear to be of importance when considering criteria for the selection of locations for photo red light enforcement cameras.

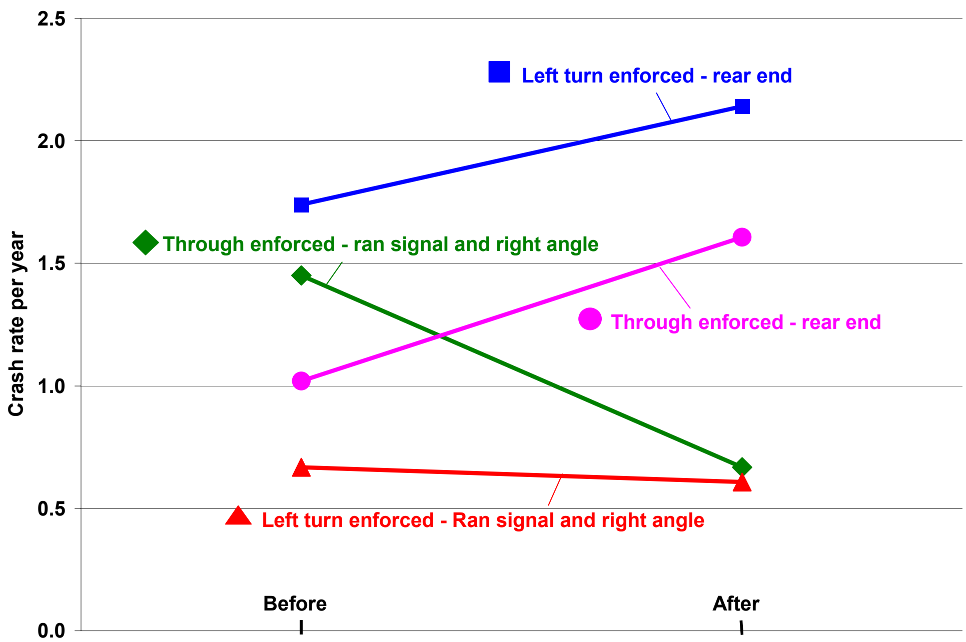

Figure 3. Average Crash Rates Before and After Enforcement for Intersections by Type of Movement Enforced and Type of Crash

COMPARISON WITH OTHER PHOTO ENFORCEMENT PROGRAMS

Red Light Running Violations

A recent comprehensive review of photo enforcement programs (*10*) concluded that violation reductions ranged from 20 percent to 87 percent. Time periods are unspecified and the authors remark on the variability in the quality of sources. Similar impacts on red light running were detected in several other program reviews (*11-14*). We show here that such a wide range of impacts can be due to two factors: (a) a continual decrease in violations over time, and (b) to variations in the rate of decline in violations across different intersections. We were able to fit exponential decay functions for enforced intersections using monthly data on red light running. The regression decay coefficient was significant for eighteen out of nineteen intersections in the San Diego program. The median estimated percentage decrease per month is 3.2%. This represents a 32% decrease after one year, and a 54% decrease after two years. Violation rates declined at higher rates than this for half of the intersections in the program.

Crash rates

The comprehensive review sponsored by the U.S. Federal Highway Administration and published in 2001 concludes that the reported results concerning impacts of automated enforcement of traffic signal compliance on traffic safety are mixed and inconclusive (*10*). Indeed, opponents and proponents of automated enforcement systems can select among contradictory results in citing evidence of the effects of red light cameras on traffic safety (e.g., *15* and *16*).

A recent report from the California State Auditor (*17*) documents a series of analyses using data collected from the California Highway Patrol (CHP). The CHP maintains the Statewide Integrated Traffic Records System (SWITRS), a centralized crash database containing all fatal, injury and property damage collisions, including those caused by motorists running red lights, as reported by police and sheriff's departments throughout the State. The report indicates that following the introduction of the California red light camera law crashes attributable only to red light running, per month declined statewide by an average of 3 percent per month, and for all local governments with red light camera installations by 10 percent per month. Overall declines for five cities with red light programs ranged from 3 to 21 percent. In only one instance was an overall increase of five percent found. However, at intersections equipped with red light cameras, all cities experienced reductions ranging from 11 to 55 percent per month. The study also collected supplementary data from the City of San Diego for crash reports following the suspension of the red light camera program. Four months of data indicated red light crashes increased by 14 percent citywide and by 30 percent at formerly camera enforced intersections.

Our analyses of the San Diego program indicate that there is a statistically significant decrease, estimated to be 60% of pre-enforcement rates, in ran signal and right angle crashes for traffic traveling in the enforced directions. Correspondingly, rear-end crashes increased to approximately 140% of pre-implementation levels. In our analysis we lacked data for a suitable control sample of separate intersections, so we used traffic traveling through the program intersections in directions not covered by the red light cameras as a pseudo control. Crash rates for this control sample did not change significantly before and after implementation.

FINDINGS

These analyzes have demonstrated the following:

- Intersections in San Diego with photo enforcement experienced a statistically significant reduction in red light running violations.
- These decreases in violations continued throughout the period of enforcement, with diminishing rates of decrease over time.
- Just as in other studies, there is supporting evidence that extending yellow signal intervals reduces violations, independent of enforcement.
- Crashes classified as ran signal and right angle (RS/RA) crashes were significantly reduced following implementation of the project.
- Reductions in RS/RA crash rates were greater for intersections where through vehicle movements were enforced than for intersections where left turn movements were enforced.
- Rear end crashes increased significantly following photo enforcement implementation.
- Attention to the avoidance of rear end crashes through advance warning signs and public information campaigns are indicated as a necessary part of a photo enforcement program.
- Consistent monitoring of violation rates and crash rates at enforced and un-enforced intersections should be used to evaluate impacts of such programs over time.
- Specific locations with relatively low crash rates but high levels of continued violations suggest evidence of consistent red light running. Such situations suggest the need for traffic-engineering solutions.

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DISCLAIMER

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