

Reducing red light running through longer yellow signal timing and red light camera enforcement: Results of a field investigation

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Abstract

Red light running is estimated to account for 900 intersection crash fatalities annually. Two principal methods used to reduce red light running involve lengthening the duration of yellow change intervals and automated red light enforcement. The present study evaluated the incremental effects on red light running of first lengthening yellow signal timing, followed by the introduction of red light cameras. At six approaches to two intersections in Philadelphia, Pennsylvania, yellow change intervals were increased by about 1 s, followed several months later by red light camera enforcement. The number of red light violations was monitored before changes were implemented, several weeks after yellow timing changes were made, and about 1 year after commencement of red light camera enforcement. Similar observations were conducted at three comparison intersections in a neighboring state where red light cameras were not used and yellow timing remained constant. Results showed that yellow timing changes reduced red light violations by 36%. The addition of red light camera enforcement further reduced red light violations by 96% beyond levels achieved by the longer yellow timing. This study shows that the provision of adequate yellow signal timing reduces red light running, but longer yellow timing alone does not eliminate the need for better enforcement, which can be provided effectively by red light cameras.

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1. Introduction

Traffic signals are intended to promote safe and efficient traffic flow at busy intersections. However, the level of safety achieved is largely dependent on drivers' compliance with the signals. Research shows that many drivers violate red signals, placing themselves and other road users at risk for serious collisions. In a nationwide survey of 880 licensed drivers, one in five respondents reported running one or more red lights when entering the last 10 signalized intersections (Porter and Berry, 2001). Analyses of red light violation data from 19 intersections in four states found that violation rates averaged 3.2/intersection/h (Hill and Lindly, 2003). Similarly, a study conducted during several months at five busy intersection approaches in Fairfax

City, Virginia, found that violation rates averaged 3/intersection/h (Retting et al., 1999a). During peak travel times, red light running was more frequent.

Crashes resulting from red light running are a frequent occurrence. Brittany et al. (2004) estimated that 20% of vehicles involved in fatal crashes at signalized intersections failed to obey the traffic lights. In 2005, more than 800 people were killed and an estimated 165,000 were injured in crashes that involved red light running (Insurance Institute for Highway Safety, 2006). About half of the deaths in these crashes were pedestrians and occupants in other vehicles who were hit by the red light runners.

Two principal countermeasures to red light running involve lengthening the duration of the yellow signal phase, which warns drivers of an imminent change in right-of-way, and the use of automated red light enforcement. The Manual on Uniform Traffic Control Devices (US Department of Transportation, 2006) indicates that yellow intervals should range from approximately 3 to 6 s and that longer intervals should be reserved for approaches with higher traffic speeds. Because drivers generally cannot predict the onset or duration of a yellow signal,

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the likelihood that a driver will stop on a red signal is related to vehicle speed and distance from the intersection when the signal changes to yellow. Although there is no universal practice for selecting the duration of the yellow signal phase, many state and local transportation agencies follow guidelines published by the Institute of Transportation Engineers (ITE, 1985) that consider site-specific criteria including traffic speeds and intersection geometry.

Numerous studies have found that longer yellow signal timing can reduce the frequency of red light running. A cross-sectional study of 20 intersections in three cities found that the frequency of red light running was higher at locations where yellow signal timing was shorter than the values associated with engineering guidelines (Bonneson and Son, 2003). Van Der Horst (1988) evaluated changes in red light violations 1 year after yellow signal timing was increased by 1 s (from 3 to 4 s at four urban intersections and from 5 to 6 s at two rural intersections) and found that red light violations were reduced by about half. Bonneson and Zimmerman (2004) evaluated changes in red light violations at six intersections 6 months after yellow signal timing was increased in accordance with the ITE (1985) guidelines. The authors concluded that an increase of 1 s in yellow duration (such that it did not exceed 5.5 s) decreased red light violations by at least 50%. Retting and Greene (1997) evaluated changes in red light violations 3 and 9 months after yellow signal timing was increased to values associated with the ITE guidelines. The authors found that red light violations had decreased significantly 3 months after signal timings were changed. After 9 months, red light running had increased at one of four study sites (possibly due to habituation of drivers to the longer yellow timing) but not at the other three intersections.

Red light cameras automatically photograph vehicles whose drivers run red lights and increase drivers' perceptions of the risk of being caught for violations. A red light camera system is connected to the traffic signal and to sensors that monitor traffic flow. The system continuously monitors the traffic signal, and the camera is triggered by any vehicle entering the intersection, generally above a preset minimum speed, and following a specified time after the traffic signal has turned red. One or more photographs typically show the red light violator in the intersection. In some cases video cameras are used. Cameras record the date, time of day, time elapsed since the beginning of the red signal, and vehicle speed. Tickets are mailed to owners of violating vehicles, based on review of photographic evidence. Red light cameras have been shown to substantially reduce red light violations in US cities, from about 40% (Retting et al., 1999a,b) to 78% (Martinez and Porter, 2006). An evaluation in British Columbia, Canada, found a 69% reduction in red light violations 1 month after the introduction of red light cameras, and a 38% decline after 6 months (Chen et al., 2001). A review of international red light camera studies concluded that cameras generally reduce red light violations by about 40–50% (Retting et al., 2003).

Although appropriately timed yellow signals and red light camera enforcement both can reduce red light running, their



Fig. 1. Sign warning drivers of red light cameras.

relative contributions are unknown. No studies to date have evaluated both of these approaches implemented incrementally. The present study was designed to address this issue. Red light violation rates were measured at intersections before and after yellow signal timing was lengthened and again after red light cameras were in place.

2. Methods

The study was conducted in Philadelphia, Pennsylvania, where the use of red light cameras at several specific intersections was authorized by the state legislature in 2004. The legislation permitted photographing the rear license plates of vehicles entering intersections on a red signal. Drivers are not photographed. The registered vehicle owner is subject to a \$100 fine, but unlike violations resulting from traditional police enforcement, there are no driver's license penalty points for camera citations. The legislation required a 120-day warning period during which warning notices, rather than tickets, were mailed to registered owners of vehicles running red lights. In addition, conspicuous traffic signs were installed at all camera-equipped locations to warn drivers they were approaching intersections monitored by red light cameras (Fig. 1). The warning signs include an image of a traffic signal and the words "Red Light Photo Enforced"—features shown to be well understood by motorists (Carlson and Retting, 2001). Table 1 summarizes the study's timeline.

Table 1
Study timeline

Date	Event
November 2004	Baseline data collection at experimental and comparison sites (phase 1)
December 2004	Implementation of yellow signal timing changes at experimental sites
January 2005	Data collection at experimental and comparison sites after yellow signal timing changes (phase 2)
February 2005	Implementation of 120-day warning period for red light running violations
June 2005	Implementation of red light camera enforcement at experimental sites
June–July 2006	Data collection at experimental and comparison sites after camera enforcement (phase 3)

2.1. Study sites

Red light violations were monitored at the first two intersections designated for red light camera enforcement. Both intersections are located along Roosevelt Boulevard—a wide, high-volume urban arterial that includes two sets of northbound traffic lanes (main road and service road) separated by raised islands, and two sets of southbound lanes also separated by raised islands. The main road and service roads each have traffic signals controlling traffic flow. Both intersections were ranked among the highest crash locations in a systematic review of automobile insurance claims resulting from crashes at hundreds of thousands of US intersections (State Farm Mutual Automobile Insurance Company, 2001).

A total of six approaches at the two intersections formed the experimental sites. Four approaches were on Roosevelt Boulevard, and two were on side streets. Red light violations also were monitored at three comparison intersections located in Atlantic County, New Jersey, where red light cameras were not used and yellow signal timing remained constant. Selection of the comparison sites was based on two factors. One was proximity to experimental sites in Philadelphia. The distance between comparison and experimental sites was approximately 50 miles—close enough to expect similar patterns of changes associated with external factors such as weather, fuel prices, and economic conditions. The second factor was the ability to collect violation data using the same proprietary methods employed at the experimental intersections (the recording equipment, described later, required connection to the traffic signal system). Although it would have been preferable for comparison sites to have been located closer to Philadelphia and more closely matched with experimental sites in terms of traffic volume and geometric characteristics, time was limited given the imminent installation of red light cameras and related publicity. In addition, police officials in Atlantic County already had offered their assistance in documenting the prevalence of red light violations and had identified three specific intersections they would have prioritized for red light camera installation if given the legislative authority, which they were not. These were the three locations selected as comparison sites.

Yellow signal timing was increased in December 2004 at the intersections where red light cameras were to be installed. Procedures for determining the duration of revised yellow signal timing incorporated traffic speeds and intersection geometry, as described in the ITE (1985) guidelines. Under these guidelines, intersection approaches with 30 miles/h speed limits, 85th percentile traffic speeds of approximately 35 miles/h, and no significant grade (characteristic of the side street approach legs in this study) were assigned a yellow interval of 3.6 s. Approaches with speed limits of 45 miles/h, 85th percentile traffic speeds of approximately 50 miles/h, and no significant grade (characteristic of the boulevard approach legs in this study) were assigned a yellow interval of 4.6 s. Philadelphia officials exceeded these values by increasing yellow intervals by about 1 s—from 3.0 to 4.1 s on the two side street approach legs, and from 4.0 to 4.9 s on the four Roosevelt Boulevard approaches. Yellow intervals at the comparison sites remained constant—5 s at one site with



Fig. 2. Typical video camera deployment.

a 45 miles/h speed limit, 4.4 s at one site with a 40 miles/h limit, and 4.0 s at another site with a 40 miles/h limit.

2.2. Data collection and coding

Violation data were recorded at the experimental and comparison sites using unattended video cameras mounted on existing poles located near the intersections (Fig. 2). These locations provided a view of vehicles approaching the monitored intersections and the traffic signals. Road tubes connected to traffic counters were used to estimate traffic volumes on the monitored intersection approaches.

Wireless communication between the traffic signal systems and the video cameras used in the evaluation enabled the cameras to record the first 5 s of each red light phase, thereby eliminating excess videotaping between signal cycles. When the video camera switched from a pause mode to a recording mode at the start of each red light phase, there was a delay of approximately 0.5 s during which vehicles entering the intersection on red were not recorded. Therefore, for the purpose of this study, red light violations at the experimental and comparison sites were limited to those vehicles that entered the intersection 0.5 s or more after onset of the red signal. To be counted as a red light violation, a vehicle's rear tires must have been positioned behind the crosswalk or stop line prior to entering on red. Vehicles already in the intersection when the camera began recording, as well as those turning right on red (whether or not they came to a stop) were not counted as red light violations.

One person coded all the data from videotapes. Coder reliability was checked by having a second coder independently code data from three 24-h periods at three separate intersections. Each observer was given the same video playback equipment and the same instructions. The level of interobserver agreement was greater than 96%.

Data were collected at each of the six experimental and three comparison approaches during three phases, for a total of 27 data collection sessions. Data collection occurred during a baseline period in November 2004 (phase 1), after extended yellow timings were in place in January 2005 (approximately 6 weeks after the signal timing changes were made) (phase 2), and in June and July 2006 (approximately 1 year after commencement of red light camera enforcement) (phase 3). Each data collec-

Table 2
Red light violation rates for experimental and comparison sites

Site	Baseline (phase 1)			After yellow signal timing changes at experimental sites (phase 2)				After yellow signal timing changes and camera enforcement at experimental sites (phase 3)			
	Number of violations	Number of vehicles	Violations per 10,000 vehicles	Number of violations	Number of vehicles	Violations per 10,000 vehicles	Percent change in violation rate from phase 1	Number of violations	Number of vehicles	Violations per 10,000 vehicles	Percent change in violation rate from phase 2
Experimental											
1	615	24,467	251.4	465	23,490	198.0	−21	5	27,225	1.8	−99
2	279	29,812	93.6	107	14,264	75.0	−20	18	29,935	6.0	−92
3	29	37,345	7.8	16	36,067	4.4	−43	1	39,861	0.3	−94
4	45	30,310	14.8	8	14,667	5.5	−63	0	33,532	0	−100
5	213	35,043	60.8	113	35,145	32.2	−47	2	34,405	0.6	−98
6	183	34,166	53.6	100	33,500	29.9	−44	16	41,054	3.9	−87
Comparison											
1	8	9,010	8.9	6	9,296	6.5	−27	8	10,563	7.6	17
2	30	14,468	20.7	25	7,536	33.2	60	44	16,069	27.4	−17
3	24	16,782	14.3	18	16,410	11.0	−23	31	29,405	10.5	−4

Experimental sites

1. Eastbound Grant Ave. at Roosevelt Blvd.
2. Westbound Grant Ave. at Roosevelt Blvd.
3. Southbound Roosevelt Blvd., main road at Red Lion Rd.
4. Southbound Roosevelt Blvd., service road at Red Lion Rd.
5. Northbound Roosevelt Blvd., main road at Red Lion Rd.
6. Northbound Roosevelt Blvd., service road at Red Lion Rd.

Comparison sites

1. Eastbound Wheat Rd. at Brewster Rd.
2. Northbound Fire Rd. at Washington Ave.
3. Southbound Tilton Rd. at Hingston Ave.

tion session at each intersection approach was designed to last approximately 48 h. However, due to equipment problems, three of the 27 data collection sessions yielded only 24 h of data (two sessions at experimental sites, and one session at a comparison site).

Violation rates per 10,000 vehicles were computed for each intersection approach and each time period. Logistic regression analyses were used to estimate the odds of a vehicle running a red light based on jurisdiction (Philadelphia versus Atlantic County), site within each jurisdiction, time period, and whether or not experimental changes (signal timing or camera enforcement) had occurred. One regression model estimated the odds of red light running at the experimental sites relative to the comparison sites following implementation of yellow timing changes. A second regression model estimated the odds of red light running at the experimental sites relative to comparison sites following installation of red light cameras.

3. Results

Table 2 provides a summary of the red light violation and exposure data collected at the experimental and comparison sites during the three study periods. Baseline violation rates ranged from 8 to 251 violations per 10,000 vehicles at the six experimental sites and from 9 to 21 violations per 10,000 vehicles at the three comparison sites. After yellow signal timing changes, violation rates at the experimental sites declined at each location, with reductions ranging from 21 to 63%. At the comparison sites, however, changes were inconsistent. Violation rates increased 60% at one comparison site but declined 23 and 27% at the other two comparison sites. After camera enforcement began, violation rates at the experimental sites declined an additional 87 to 100% beyond those observed during phase 2, whereas changes at the comparison sites again were inconsistent. Violation rates increased 17% at one comparison site but declined 4 and 17% at the other two comparison sites.

Based on the logistic regression model, the odds of a red light violation at the comparison sites increased an average of 9% between the first and second observation periods (95% confidence interval (CI) = 25% decline to 59% increase). After accounting for these changes in driver behavior at the comparison sites, the changes to yellow signal timing at the experimental sites were associated with a 36% decline in the odds of a red light violation (95% CI = 6–57% decline). Between the second and third observation periods, the odds of a red light violation at the comparison sites declined an average of 9% (95% CI = 36% decline to 30% increase). After accounting for these changes at the comparison sites, the logistic regression model estimated that camera enforcement at the experimental sites was associated with an additional 96% reduction in the odds of a red light violation (95% CI = 93–97% decline). Results of the logistic regression are summarized in Tables 3 and 4.

4. Discussion

The present study found large and highly significant incremental reductions in red light running associated with increased

Table 3

Logistic regression model of the effects of state, site, time, and yellow signal timing changes on red light violation rates

Effect	Odds ratio (95% CI)
State	
Pennsylvania vs. New Jersey	4.09 (2.79, 5.98)
Site	
Pennsylvania 1 vs. Pennsylvania 6	5.48 (4.80, 6.25)
Pennsylvania 2 vs. Pennsylvania 6	1.98 (1.70, 2.31)
Pennsylvania 3 vs. Pennsylvania 6	0.15 (0.11, 0.20)
Pennsylvania 4 vs. Pennsylvania 6	0.26 (0.20, 0.36)
Pennsylvania 5 vs. Pennsylvania 6	1.11 (0.95, 1.31)
New Jersey 1 vs. New Jersey 3	0.60 (0.33, 1.11)
New Jersey 2 vs. New Jersey 3	2.00 (1.34, 3.01)
Time	
January 2005 vs. November 2004	1.09 (0.75, 1.59)
Yellow timing changes	
Yes vs. No	0.64 (0.43, 0.94)

yellow signal timing followed by the introduction of red light cameras. Neither effect individually is surprising given the substantial prior research. However, the strong effects of red light cameras after having increased the duration of yellow signal timing provides evidence that provision of adequate yellow timing may not eliminate the need for or the potential benefits of red light camera enforcement.

Because measurements during phase 2 were made just 6 weeks after yellow signal timing was increased (due to imminent construction of red light cameras and the planned start of the warning period), longer term effects of yellow timing changes alone could not be assessed in this study. Prior research examining longer term effects of increased yellow timing found that reductions in red light violations were sustained at least 6 months to 1 year (Bonneson and Zimmerman, 2004; Retting and Greene, 1997; Van Der Horst, 1988) but that some drivers might adapt to increases in yellow duration and continue to run red lights (Bonneson and Zimmerman, 2004; Retting and Greene, 1997).

Table 4

Logistic regression model of the effects of state, site, time, and camera enforcement on red light violation rates

Effect	Odds ratio (95% CI)
State	
Pennsylvania vs. New Jersey	2.91 (1.95, 4.35)
Site	
Pennsylvania 1 vs. Pennsylvania 6	5.88 (4.80, 7.21)
Pennsylvania 2 vs. Pennsylvania 6	2.46 (1.91, 3.17)
Pennsylvania 3 vs. Pennsylvania 6	0.14 (0.08, 0.23)
Pennsylvania 4 vs. Pennsylvania 6	0.15 (0.07, 0.31)
Pennsylvania 5 vs. Pennsylvania 6	0.95 (0.74, 1.24)
New Jersey 1 vs. New Jersey 3	0.65 (0.36, 1.18)
New Jersey 2 vs. New Jersey 3	2.75 (1.90, 3.97)
Time	
June 2006 vs. January 2005	0.91 (0.64, 1.30)
Camera enforcement	
Yes vs. No	0.04 (0.03, 0.07)

These prior studies suggest that effects of increased yellow timing in the present study would have been evident, although possibly smaller, long after implementation of yellow timing changes had the effects been measured without the confounding influence of red light cameras.

The present study found larger reductions in red light violations from camera enforcement than have been reported in prior evaluations (Aeron-Thomas and Hess, 2005; Chen et al., 2001; Retting et al., 1999a,b). The effectiveness of camera enforcement may relate to the way in which programs are structured, although no research to date has teased out the importance of specific factors such as publicity about camera enforcement. The unusually large reductions observed in this study could result in part from particular characteristics of Philadelphia's red light camera program. The Pennsylvania legislation authorizing red light cameras restricted enforcement to nine specific intersections in one city, Philadelphia, thus helping to narrowly focus media interest and highlight public awareness. The legislation mandated a 120-day warning period prior to enforcement and the installation of warning signs at all camera-equipped locations to warn drivers they were approaching intersections monitored by red light cameras. By comparison, some jurisdictions install warning signs at jurisdictional boundaries rather than specific photo-enforced intersections. The \$100 fine in Philadelphia is somewhat higher than those imposed by red light camera programs in nearby states, including Delaware (\$75), Maryland (\$75), New York (\$50), and Virginia (\$50 when red light cameras were in use). Because this was the first red light camera program in Pennsylvania, there was extensive news coverage in the local newspapers and other news media. These factors may have contributed to larger reductions in red light violations than have been reported in prior evaluations.

In addition to reducing red light violations, longer traffic signal change intervals and red light cameras can reduce potential intersection conflicts and injury crashes, based on results of prior research. Stimpson et al. (1980) reported that increases in yellow signal timing duration of 1.3 s significantly reduced potential intersection conflicts. A study of modified traffic signal change interval timing at urban intersections reported that injury crashes were reduced by 12% at experimental sites relative to control sites (Retting et al., 2002). Numerous studies report significant crash reductions associated with red light camera enforcement. In Oxnard, California, injury crashes at intersections with traffic signals were reduced by 29% following the introduction of red light cameras (Retting and Kyrychenko, 2002). Front-into-side collisions – the crash type most closely associated with red light running – also were reduced by 32% overall, and front-into-side crashes involving injuries were reduced by 68%. Analyses of police reported crashes in seven US cities found that, overall, right-angle crashes decreased by 25% following the introduction of red light cameras (Council et al., 2005). Reviews of international red light camera studies concluded that red light cameras reduce right-angle crashes by 24% (Aeron-Thomas and Hess, 2005) and reduce injury crashes by 25–30% (Retting et al., 2003).

Some studies have reported that although red light cameras reduce front-into-side collisions and overall injury crashes, they

can increase rear-end crashes—at least in the short run. Because the types of crashes prevented by red light cameras tend to be more severe than rear-end crashes, research shows a positive aggregate benefit. Council et al. (2005) reported a 15% increase in rear-end collisions concurrent with a 25% decrease in right-angle crashes, but estimated a positive aggregate economic benefit of more than \$18.5 million during 370 site years, which translates into a crash reduction benefit of approximately \$39,000 per site year. Not all studies have reported increases in rear-end crashes. The international review by Aeron-Thomas and Hess (2005) did not find a statistically significant change in rear-end crashes.

Overall, results from the present study confirm that providing motorists with adequate yellow signal timing is important for reducing red light running. However, even with proper yellow timing in place, red light running remains a problem that can be further reduced through the use of camera enforcement.

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