A Before-and-After Study on Red-Light Camera Installation

THE IMPACTS OF INSTALLING AND OPERATING RED-LIGHT CAMERAS ARE REPORTED FOR THREE SIGNALIZED INTERSECTIONS IN SINGAPORE. RED-LIGHT RUNNING VIOLATIONS AND STOPPING CHARACTERISTICS WERE GATHERED BEFORE AND SHORTLY AFTER CAMERA INSTALLATION ALONG EACH INDIVIDUAL APPROACH. THE OPPOSING APPROACHES, WHICH WERE NOT INSTALLED WITH RED-LIGHT CAMERAS, ALSO WERE STUDIED.

BY K.M. LUM, PH.D., P.E. AND Y.D. WONG

INTRODUCTION

A driver approaching a signalized intersection at the onset of amber must decide whether to cross the intersection or to stop before the stop-line. The choice can be quite definite if the driver is near enough to the stop-line that proceeding straight through the intersection is necessary and possible or if the driver is far enough from the stop-line that braking is necessary and possible. The decision can be rather conflicting, however, if the driver is positioned in the option zone, where both choices are possible, or in the dilemma zone, where it is neither possible to proceed straight through at constant speed to clear the stop-line before red nor possible to brake comfortably.

Red-light cameras (RLC) can play a significant part in encouraging drivers to stop instead of violate the red light.[1] The impacts of RLC installation on drivers caught in the option or dilemma zone at the onset of amber were evaluated by carrying out a before-and-after study on red-running and stopping characteristics at signalized intersections.

LITERATURE

Red-running violations at signalized intersections have been studied by a number of researchers in recent years. Retting et al. examined red-running violation data captured before, shortly after (three to four months later) and, in one study, sometime after (one year later) RLC installation in Virginia and California, USA.[2,3] These studies involved camera sites as well as nearby non-camera sites to determine spillover RLC effects. They also involved control sites at a far distance from the camera sites, which controlled for factors that might affect red-light violations, such as weather and seasonal variability in travel patterns. No camera effect at these sites was expected. Compared to the control sites, reductions in red-running violations were observed at both the camera and the nearby non-camera sites. In studies conducted by Retting et al., red-light runners tended to be younger, be less likely to wear seat belts and have poor driving records.[4,5]

Studies also have been conducted on attitudes toward and acceptance of RLC programs. A postal survey of drivers in Norway, Spain and the Netherlands showed good acceptance of RLC as an enforcement tool.[6] Public-opinion surveys conducted in different parts of the United States indicated support for the use of RLC as a supplement to police efforts to reduce red-running violations.[2,3,7] The level of acceptance appeared to correlate with driver attitudes toward red-running violations and public awareness of RLC programs.

EXPERIMENT DESIGN

RLC first was installed in Singapore over a five-year period beginning in August 1986, when the bulk of the camera systems were installed. A before-and-after study was designed to evaluate the impacts of installing RLC on red-running violations. The violations before camera installation were compared to those obtained after installation along each individual approach installed with RLC (referred to as the camera approach), on a lane-by-lane basis. The opposing approach, which was not installed with RLC (referred to as the non-camera approach), also was included in the comparative study. Analysis of drivers choosing to stop up to 2 seconds (sec.) into the red was included.

BEFORE-AND-AFTER INTERSECTIONS

Three intersections operating with a 3-sec. amber signal (a standard practice in Singapore) were selected for the before-and-after study. The Clementi and Woodlands intersections are T intersections; the AMK intersection is a four-way (X) intersection. The major road for all studied sites is a two-way arterial comprising three lanes in each direction.

The approach facing opposing right turns (left turns in U.S. context) was installed with RLC at the median of the Clementi intersection while the approach comprising a storage pocket for right turns was installed with RLC at the roadside curb of the Woodlands intersection. These two sites were wired with RLC mainly due to high incidences of red-running violations; the AMK intersection was chosen mainly due to high incidences of serious injuries and fatal accidents. In addition, the AMK intersection is highly congested with traffic and pedestrian activities and it is situated in a locality with a high RLC penetration rate (defined as the proportion of intersections installed with RLC within a given locality).

DATA COLLECTION USING AN AUTOMATIC LOGGING SYSTEM

A special purpose M660-type data logger, working in conjunction with inductance loop sensors, was conceptualized and developed for field data collection.[8] The M660 was deployed to gather the before-and-after (one to three months later) RLC data, which included traffic volumes, speeds and the timings and status of each signal phase.[9] Loop sensors were installed to detect vehicles on a lane-by-lane basis. All straight-through lanes of the camera approach were wired with sensors; the lanes of the non-camera approach were not. Two sensors were installed for each chosen lane—one before and one after the stop-line. The sensor placed before the stop-line acted as a detection point to monitor the movements of crossing and first-stopping vehicles with respect to signal timings. The sensor placed after the stop-line provided further details on crossing vehicles, including red-runners. The two sensors near the stop-line counterchecked the movement pattern and eliminated spurious signals from one sensor alone.

ANALYSIS OF RED-RUNNING VIOLATIONS

A red-running event was defined as an occurrence in which the front of a crossing vehicle passed the painted stop-line of a signalized intersection any time after the onset of the red signal. The average daily red-running violations for weekdays and weekends were gathered for the before-RLC and after-RLC periods, with identical durations of one continuous week of field data, unless otherwise stated (see footnotes in Table 1). Table 1 shows violation rates (enclosed in parentheses), which were normalized with respect to lane volumes and signal cycles. The normalization of violations to vehicles per lane per cycle was necessary to provide a more meaningful comparison among the various approaches. Normalization also can take into account differences in violation opportunities presented to drivers at intersection entrances. On the supply side, each cycle and each individual lane in the intersection approach provide an opportunity and a passage for violations

Table 1. Red-running violations at before-and-after intersections.

			Average daily red-running violations (violation rates)[a]					
			Curb lane		Middle lane		Median lane	
	Approach	Period[d]	Weekday	Weekend	Weekday	Weekend	Weekday	Weekend
Clementi intersection	Camera	Before RLC	64.4[b] (2.13)[c]	67.0 (5.80)	111.8 (2.60)	111.0 (6.73)	58.2 (2.01)	50.0 (5.05)
		After RLC	44.0 (1.43)	15.5 (3.24)	58.6 (1.42)	29.0 (4.16)	27.8 (0.99)	11.5 (2.75)
	Non-camera	Before RLC	70.7 (5.44)	37.5 (10.19)	112.3 (5.50)	54.5 (9.22)	58.7 (4.79)	22.0 (6.99)
		After RLC	137.6 (9.71)	78.5 (16.78)	217.3 (10.12)	104.5 (14.61)	105.0 (8.04)	46.0 (12.02)
Woodlands intersection	Camera	Before RLC	51.4 (4.37)	33.5 (9.77)	68.6 (3.42)	39.0 (6.79)	16.0 (1.78)	5.0 (2.38)
		After RLC	32.8 (2.83)	16.0 (4.90)	49.4 (2.05)	24.0 (3.33)	13.4 (1.23)	9.0 (3.53)
	Non-camera	Before RLC	—	—	—	—	58.5 (4.96)	—
		After RLC	—	—	—	—	46.0 (3.57)	—
AMK intersection	Camera	Before RLC	—	—	330.0 (32.73)	382.0 (38.23)	144.9 (19.35)	244.1 (37.42)
		After RLC		—	79.0 (9.41)	158.0 (18.13)	80.0 (18.54)	52.0 (13.99)
	Non-camera	Before RLC	—	—	—	—	228.2 (5.32)	220.0 (13.56)
		After RLC	—	—	—	—	72.6 (2.72)	70.0 (6.89)

a Values given are the average daily numbers of red-running violations in vehicles per day, except when enclosed in parentheses (these are normalized on the basis of vehicles per lane per cycle ($\times 10^{-6}$)).

b The number of red-running vehicles for five weekdays (Monday to Friday) along the curb lane is 322 vehicles. Thus, the average daily red-running violations equal 322/5 or 64.4 vehicles per day.

c The number of red-running vehicles for five weekdays (Monday to Friday) along the curb lane is 322 vehicles. The total volume of vehicles for five weekdays (Monday to Friday) along the curb lane is 41,676 vehicles. The total number of signal cycles for five weekdays (Monday to Friday) is 3,631 cycles. Thus, the red-violation rates equal $322/(41{,}676 \times 3{,}631)$ or 2.13×10^{-6} vehicles per lane per cycle.

d The duration of data collection for the before-RLC period is the same as for the after-RLC period. Data were collected for one continuous week, except for the non-camera approach at the Clementi intersection (five days) and the Woodlands intersection (four weekdays) and the camera approach at the AMK intersection (two days).

Table 2. Statistical tests on red-running violations at before-and-after intersections.

Site	Approach	Test statistics[a] (computed by test of proportion)		
		Curb lane	Middle lane	Median lane
Clementi intersection	Camera	–2.75[b]	–4.37	–3.40
	Non-camera	5.29	6.67	4.35
Woodlands intersection	Camera	–2.12	–2.88	–0.67
	Non-camera	—	—	–1.83
AMK intersection	Camera	—	–10.87	–7.30
	Non-camera	—		–8.81

a test statistic = $\dfrac{p_1 - p_2}{\sqrt{p(1-p)}\sqrt{\dfrac{1}{n_1} + \dfrac{1}{n_2}}}$

where

p_1 is the proportion of daily red-violation numbers along each individual lane with respect to their lane volume per day in the after-RLC period;

p_2 is the proportion of daily red-violation numbers along each individual lane with respect to their lane volume per day in the before-RLC period;

p is the pooled estimate of the proportions; and

n_1 and n_2 are the lane volume per day in the after-RLC and before-RLC periods, respectively.

b Test statistics ($z \geq 1.96$) given in bold are statistically significant at a 95-percent confidence level. Negative values indicate a reduction in the after-RLC period.

Figure 1. Pictorial view of the Clementi intersection with RLC installed.

to occur. Traffic volume in itself constitutes the demand side, affecting the likelihood of vehicles approaching the intersection entrance during the critical phase-change period.

The average number of red-running violations across a respective approach per day was used as a performance index: The red signal at the AMK intersection was violated more frequently compared to the other two intersections. The fewest red-running violations occurred at the Woodlands intersection. This result can be expected because the AMK intersection is located along a heavily trafficked arterial in a bustling township where activities continue through the day and night.

A substantial drop in the number of violations can be observed along approaches installed with RLC; there were both increases and decreases along non-camera approaches. The pattern was repeated when the violations were expressed in terms of violation rates. The average reduction in violation rates along camera approaches was about 40 percent and ranged from as low as 4 percent to as high as 63 percent along the median lane of the AMK intersection during weekdays and weekends, respectively.

By proportioning the daily red-violation numbers along each individual lane with respect to lane volume per day, one can employ the test of proportion to assess the statistical significance of red violations before and after RLC installation. As shown in Table 2, the test results indicate that the reduction in red-running violations in the after-RLC period was statistically significant at a 95-percent (test statistic ≥ 1.96) confidence level. The median lane along the camera approach of the Woodlands intersection was not statistically significant at a 95-percent confidence level, but the violation rate did increase noticeably (49 percent) during weekends. This unusual observation should not be taken to mean that RLC was ineffective; there was a substantial reduction (about 31 percent) during weekdays. Because of the relatively low numbers of violations and volumes along this median lane, the violation rates obtained may have been rather unstable and may have inflated with a nominal increase in violation numbers.

On average, violation rates along the middle lanes were substantially higher than along the other lanes before RLC installation. After RLC implementation, violation rates still were higher, but to a much lesser extent. Weekend violation rates consistently were much higher than those of weekdays—about twofold on average for all approaches except the median lane at the AMK intersection. The differences ranged from a low of 1.17 times at the middle lane of the AMK intersection to a high of 2.93 times at the middle lane of the Clementi intersection. The ratios of weekend to weekday violation rates generally were lower for the non-camera approach lanes. Along the curb and median lanes of the camera approach at the Clementi intersection, the violation rates for weekdays were reduced by 33 percent and 45 percent, respectively. By dividing the percentage reduction in violation rates for weekdays by the weekend rates for the curb lane, a value of 0.73 times was obtained (a lower reduction during weekdays). However, values of 1.19 and 1.12 times were obtained for the middle and median lanes of the Clementi intersection, respectively.

The before-and-after results along the non-camera approach at the Clementi intersection had a reverse violation trend. In fact, the violation rates, as normalized to vehicles per lane per cycle, increased by an average of about 70 percent for weekdays and 60 percent for weekends in the after-RLC data. One possible explanation may be drivers' awareness of RLC operation being constrained to capture violations along the camera approach and not the whole intersection. This knowledge could be further rationalized by the fact that the orientation of the RLC housing installed along the median pointed along the camera approach, as shown in Figure 1. Violation rates in all lanes of the non-camera approach were much higher than in the corresponding lanes of the camera approach at the Clementi intersection. Facing a potential conflict with impending opposing right-turning vehicles, the straight-through vehicles along the camera approach at the Clementi intersection would choose to stop rather than to violate the red signal.

Table 3. Red stopping at before-and-after intersections.*

			Average daily red stopping (red-stopping rates)[a]					
			Curb lane		Middle lane		Median lane	
	Approach	Period[d]	Weekday[b]	Weekend[b]	Weekday	Weekend	Weekday	Weekend
Clementi intersection	Camera	Before RLC	6.2[b] (0.21)[c]	2.5 (0.22)	8.2 (0.19)	5.0 (0.30)	4.5 (0.19)	2.5 (0.25)
		After RLC	47.8 (1.55)	13.5 (2.83)	53.8 (1.30)	21.5 (3.08)	42.6 (1.52)	17.0 (4.07)
	Non-camera	Before RLC	15.3 (1.18)	3.0 (0.82)	23.3 (1.14)	6.5 (1.10)	15.7 (1.28)	3.5 (1.11)
		After RLC	16.7 (1.18)	1.5 (0.32)	10.3 (0.48)	4.5 (0.63)	7.3 (0.56)	1.0 (0.26)
Woodlands intersection	Camera	Before RLC	2.2 (0.19)	1.0 (0.29)	2.0 (0.10)	0.0 (0.00)	1.2 (0.13)	0.0 (0.00)
		After RLC	8.0 (0.69)	6.5 (1.99)	7.6 (0.32)	5.5 (0.76)	2.0 (0.18)	1.5 (0.59)
	Non-camera	Before RLC	—	—	—	—	0.8 (0.21)	—
		After RLC	—	—	—	—	2.8 (0.07)	—
AMK intersection	Camera	Before RLC	—	—	51.0 (5.06)	24.0 (2.40)	26.7 (3.56)	26.1 (3.99)
		After RLC	—	—	31.0 (3.69)	62.0 (7.11)	9.3 (2.15)	8.2 (2.21)
	Non-camera	Before RLC	—	—	—	—	20.8 (0.48)	19.5 (1.17)
		After RLC	—	—	—		6.8 (0.26)	6.0 (0.59)

* Note: Refer to Table 1 for footnotes.

Table 4. Statistical tests on red stopping at before-and-after intersections.*

		Test statistics[a] (computed by test of proportion)		
Site	Approach	Curb lane	Middle lane	Median lane
Clementi intersection	Camera	5.13[b]	5.46	5.08
	Non-camera	0.37	−1.29	−1.18
Woodlands intersection	Camera	1.86	2.24	0.78
	Non-camera	—	—	0.96
AMK intersection	Camera	—	1.04	−2.67
	Non-camera	—	—	−2.61

* Note: Refer to Table 2 for footnotes.

ANALYSIS OF RED-STOPPING CHARACTERISTICS

Stopping up to 2 sec. into the red was selected as an upper bound to gather statistics of those drivers who chose to stop instead of cross the intersection.[10] Both crossing and stopping are viable alternatives in the option zone; therefore, the majority of drivers may have found it difficult to decide between stopping and crossing actions. This 2-sec. upper bound also would cater to a wide range of speeds, driver reaction times and deceleration characteristics.

The average daily number of drivers choosing to stop during weekdays and weekends is shown in Table 3. Red-stopping rates (enclosed in parentheses) as normalized to a per lane volume per cycle basis also were computed. The statistical test results, based on the test of proportion to assess the statistical significance of red stopping before and after RLC installation, are shown in Table 4.

Red-stopping rates along all camera approaches except the AMK intersection were relatively low prior to RLC installation. The higher rates at the AMK intersection, especially along the median lane, were a direct consequence of drivers' inability to clear the intersection due to heavy traffic more than a result of any other factors.

In the after-RLC period, stopping rates increased during weekdays by an average of 7.4 times and 2.7 times along the camera approaches at the Clementi and Woodlands intersections, respectively. The results were significant at a 95-percent confidence level at the Clementi intersection but not at the Woodlands intersection. The increase was even higher during weekends—by 13.1 and 6.8 times (the latter for the curb lane only) for the respective intersections examined. However, the change in stopping rate was not distinctly apparent at the AMK intersection; that is, a reduction was observed along the median lane but an increase was observed along the middle lane during weekends.

In further comparison, by taking the average rate of both lanes computed for all days, the stopping rates in the after-RLC period were slightly higher than in the before-RLC period (3.81×10^{-6} compared to 3.74×10^{-6}). For non-camera approaches, red-stopping rates in the after-RLC period generally were reduced at the Clementi intersection but increased at the Woodlands and AMK intersections. These results were not significant at a 95-percent confidence level except at the AMK intersection.

In a lane-by-lane comparison, the impact of RLC on stopping actions was not conclusive. For the stopping-rate ratio of weekends over weekdays, a value greater than unity was obtained along camera approaches in the after-RLC period. This difference was not always the case for the before-RLC period, while there was no vehicle stopping along either the middle or the median lanes at the Woodlands intersection during weekends. On the other hand, the calculated ratio generally was less than unity along the non-camera approach of the Clementi intersection. Collectively speaking, RLC encouraged drivers to stop more readily during weekends along camera approaches.

CONCLUSIONS

Violation rates were reduced significantly—by an average of about 40 percent—across camera approaches after RLC installation but they were rather inconclusive for opposing non-camera approaches. Violation rates during weekends generally were higher; however, it is uncertain whether RLC is more effective during weekdays or weekends. Although not statistically significant at a 95-percent confidence level, the findings indicate that red-stopping rates increased along camera approaches in the after-RLC situation. Drivers were more ready to stop during weekends along the camera approaches.

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K.M. LUM,

Ph.D., P.E., is a principal research scientist in the Centre for Transportation Studies and an associate professor in the School of Civil and Environmental Engineering at Nanyang Technological University, Singapore. He graduated with first class honors in civil engineering and a master of science in industrial engineering from the National University of Singapore. He also holds a master of science in engineering from the University of Texas-Austin and a Ph.D. from Nanyang Technological University. Lum is a member of ITE.

Y.D. WONG

is a principal research scientist in the Centre for Transportation Studies and an associate professor in the School of Civil and Environmental Engineering at Nanyang Technological University, Singapore. He graduated with a bachelor's degree and a Ph.D. in civil engineering from the University of Canterbury, New Zealand.