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Changes in crash risk following re-timing of traffic signal change intervals

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Abstract

More than 1 million motor vehicle crashes occur annually at signalized intersections in the USA. The principal method used to prevent crashes associated with routine changes in signal indications is employment of a traffic signal change interval — a brief yellow and all-red period that follows the green indication. No universal practice exists for selecting the duration of change intervals, and little is known about the influence of the duration of the change interval on crash risk. The purpose of this study was to estimate potential crash effects of modifying the duration of traffic signal change intervals to conform with values associated with a proposed recommended practice published by the Institute of Transportation Engineers. A sample of 122 intersections was identified and randomly assigned to experimental and control groups. Of 51 eligible experimental sites, 40 (78%) needed signal timing changes. For the 3-year period following implementation of signal timing changes, there was an 8% reduction in reportable crashes at experimental sites relative to those occurring at control sites ($P = 0.08$). For injury crashes, a 12% reduction at experimental sites relative to those occurring at control sites was found ($P = 0.03$). Pedestrian and bicycle crashes at experimental sites decreased 37% ($P = 0.03$) relative to controls. Given these results and the relatively low cost of re-timing traffic signals, modifying the duration of traffic signal change intervals to conform with values associated with the Institute of Transportation Engineers' proposed recommended practice should be strongly considered by transportation agencies to reduce the frequency of urban motor vehicle crashes.

Keywords: Traffic signal re-timing; Motor vehicle crashes; Red light running

1. Introduction

USA traffic engineers rely heavily on traffic signals to control and separate conflicting traffic movements at busy intersections. However, safe signal operation requires a high degree of voluntary driver compliance, and many drivers do not comply with red lights (Porter and England, 2000). When drivers disregard red lights there is a risk of collisions between intersecting vehicles, as well as to other road users, including pedestrians and bicyclists. On a national basis, red light running contributes to substantial numbers of motor vehicle crashes and injuries. Drivers who run red lights are responsible for an estimated 260 000 crashes each year, of which approximately 750 are fatal (Retting et al., 1999a). The number of fatal motor vehicle crashes at traffic signals increased 18% between 1992 and 1998, far outpacing the 5% rise in all other fatal crashes (US Department of Transportation, 1993, 1999). Motorists are more likely to be injured in crashes involving red light running than in other types of crashes, according to analyses of police-reported crashes from four urban communities; occupant injuries occurred in 45% of the red light running crashes studied, compared with 30% for all other crashes in the same communities (Retting et al., 1995).

The principal method used to prevent crashes associated with routine changes in signal indications is the use of a so-called change interval, which consists of a steady yellow signal warning of an imminent change in the right-of-way, and at many intersections is followed by an all-red phase during which traffic approaching the intersection is required to stop and conflicting traffic is delayed from entering the intersection. No universal practice exists for selecting the duration of

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change intervals or for determining whether to use an all-red phase. The *Manual on Uniform Traffic Control Devices* (US Department of Transportation, 1988) indicates that yellow change intervals normally range from 3 to 6 s, with longer intervals generally appropriate where traffic speeds are higher. The Institute of Transportation Engineers (1985) *Proposed Recommended Practice for Determining Vehicle Change Intervals* computes yellow interval timing as a function of approach speed and grade, along with assumed values for perception–reaction time, deceleration rate, and acceleration due to gravity. The Institute of Transportation Engineers (1999) *Traffic Engineering Handbook* states that the decision to use an all-red clearance interval is determined by intersection geometry, collision experience, pedestrian activity, approach speeds, local practices, and engineering judgment. The Institute of Transportation Engineers proposed recommended practice computes the length of the all-red interval, when used, as a function of approach speed and width of the intersecting roadway that must be cleared.

Prior research indicates that the duration of signal change intervals can affect the chance of red light running and potential intersection conflicts, which in turn may influence the risk of motor vehicle crashes. For example, Zador et al. (1985) reported that deficient change interval timing — particularly short yellow signals — increased the proportion of drivers who entered intersections and did not clear them during the clearance interval. Retting and Greene (1997) reported that red light running and potential right-angle vehicle conflicts were reduced at urban intersections when yellow and/or all-red signal timings were modified to values computed using the Institute of Transportation Engineers (ITE) proposed recommended practice. In a cross-sectional study, Stein (1986) reported that intersections with inadequate change interval timing relative to the ITE proposed recommended practice had higher crash rates than intersections with adequate timing.

Although these and similar studies indicate potential safety benefits of modifying the duration of signal change intervals, there is no direct evidence that such changes reduce the risk of motor vehicle crashes. The purpose of this study was to estimate potential crash effects of modifying the duration of traffic signal change intervals to conform with values associated with the ITE proposed recommended practice.

2. Methods

The study was conducted using standard four-leg signalized intersections located on roads under the jurisdiction of the New York State Department of Transportation (NYSDOT) in Nassau and Suffolk counties. Intersections were considered ineligible if the traffic signals had been recently installed, or if during the study period there was any major road construction that would remove signals from operation or substantially alter traffic flow for a prolonged period of time. A total of 122 intersections were identified for inclusion in the study. Half were randomly chosen to have their signals re-timed, and half had no changes made to their signal timing. Traffic engineering technicians visited the experimental sites to obtain geometric measurements and to sample traffic speeds for use in computing the duration of yellow and all-red change intervals. This information was not collected for control sites as they were not visited. Of the 61 experimental sites, ten were eliminated from the study due to possible errors in implementing timing changes, most often related to confusion over similarly named intersections. Also, five control sites were eliminated prior to examining the data based on post-randomization determination of inappropriate intersection configuration.

Based on the ITE proposed recommended practice for determining change intervals, the duration of the yellow signal is computed as follows:

$$y = t + v/(2a + 2Gg),$$

where y is the length of the yellow interval, to the nearest 0.1 s; t is the driver perception/reaction time, recommended as 1.0 s; v is the velocity of approaching vehicle, in ft./s; a is the deceleration rate, recommended as 10 ft./s^2; G is the acceleration due to gravity, 32 ft./s^2; and g is the grade of approach, in percent divided by 100 (downhill is negative).

The duration of the all-red clearance interval is determined by one of the following formulas:

$$r = (w + L)/v, \tag{1}$$

$$r = P/v, \tag{2}$$

or

$$r = (P + L)/v, \tag{3}$$

where r is the length of the red clearance interval, to the nearest 0.1 s; w is the width of the intersection measured from the near-side stop line to the far edge of the conflicting traffic lane; P is the width of the intersection measured from the near-side stop line to the far side of the farthest conflicting pedestrian crosswalk; L is the length of vehicle, recommended as 20 ft.; and v is the velocity of approaching vehicle, in ft./s

The recommended application of the red interval formulas is to use Eq. (1) where there is no pedestrian traffic, the longer of Eq. (1) or Eq. (2) where there is ‘the probability’ of pedestrian crossings, and Eq. (3) where there is significant pedestrian traffic or the crosswalk is protected by pedestrian signals. At the request of NYSDOT, Eq. (3) was applied to all experimental intersections. Application of the ITE formulas indicated that 40 of the 51 experimental sites required increases in the duration of change interval timing (Appendix A). The final data set consisted of these 40 experimental sites and 56 control sites.

Baseline and change interval timings based on ITE proposed recommended practice for experimental sites are provided in the appendix. During the baseline period, for the experimental sites yellow signal timings ranged from 3 to 4 s, with most set at 4 s, and all-red timings ranged from 2 to 3 s, with most set at 2 s. Computed yellow timings ranged from 2.6 to 5.4 s, and computed all-red timings ranged from 1.1 to 6.5 s. NYSDOT implemented the recommended tim12 ing intervals during October 1994. At some intersections, small deviations from recommended timings were made (i.e. where computations yielded values below the minimum allowed by NYSDOT). Independent field inspections were conducted to verify the timing changes.

Computerized crash data files were obtained from NYSDOT for experimental and control intersections for the period October 1991 through October 1997. Crash analyses were limited to 'reportable crashes,' defined by NYSDOT as those that involved injuries or a minimum of $1000 property damage. Although the data files include some, typically minor, crashes not required by New York law to be reported, detailed information concerning these 'nonreportable' crashes was not available, and the crashes were excluded. Approximately 60% of the crashes were reportable. The FREQ procedure of the SAS computer software (SAS Institute, 1990) was used to compute odds ratios (OR) and P-values. The odds ratios provide a comparison between experimental and control sites for postintervention crashes adjusted for the number of preintervention crashes.

3. Results

The total numbers of reportable crashes for the study period (including before and after timing changes) were 1985 for the experimental sites and 2621 for the control sites. Overall, 5% fewer reportable crashes were recorded during the 36-month postintervention study period compared with the 36-month preintervention period (Table 1). Though not statistically significant, an 8% reduction ($OR = 0.92$, $P = 0.08$) in all reportable crashes at experimental sites was found relative to those occurring at control sites. Table 1 also shows results for multiple-vehicle crashes combined, rear-end crashes, right-angle crashes, and crashes involving pedestrians and bicyclists. Experimental sites were 5% less likely than control sites to report multiple-vehicle crashes postintervention, although this change was not significant ($P = 0.20$). No significant changes were observed postintervention at experimental sites relative to control sites for right-angle or rear-end collisions. However, the 37% reduction in crashes involving pedestrians and bicyclists at experimental sites relative to control sites was significant ($P = 0.03$). As a quality control measure, pedestrian/bicyclist crash data for the control sites were examined to ensure that increases in the numbers of crashes were not confined to a small number of sites and were not the result of a data entry error. Analysis indicated that increases in pedestrian/bicyclist crashes at the control sites were widespread across the sample.

Table 2 lists results for analyses of injury crashes. Seventy-six percent of reportable crashes involved injuries. Overall, there was a significant 12% reduction ($P = 0.03$) in all reportable crashes involving injuries at experimental sites relative to those occurring at control sites. Experimental sites were 9% less likely than control sites to report multiple-vehicle injury crashes postintervention ($P = 0.10$). Again, a 37% reduction in crashes involving pedestrians and bicyclists at

Table 1
Number of crashes and odds ratios[a]

Crash type	Control		Experimental		OR	P
	Preintervention	Postintervention	Preintervention	Postintervention		
All reportable	1323	1298	1044	941	0.92	0.08
All multiple-vehicle	1241	1182	968	875	0.95	0.20
Rear-end	292	262	221	223	1.12	0.18
Right-angle	141	122	142	118	0.96	0.41
Pedestrian/bicyclist	62	94	59	56	0.63	0.03

[a] Preintervention and postintervention study periods were both 36 months, P-values are one-tailed.

Table 2
Number of injury crashes and odds ratios[a]

Crash type	Control		Experimental		OR	P
	Preintervention	Postintervention	Preintervention	Postintervention		
All reportable	1007	989	803	695	0.88	0.03
All multiple-vehicle	932	878	733	630	0.91	0.10
Rear-end	243	210	181	169	1.08	0.29
Right-angle	112	92	116	101	1.06	0.38
Pedestrian/bicyclist	62	94	59	56	0.63	0.03

[a] Preintervention and postintervention study periods were both 36 months; P-values are one-tailed.

experimental sites relative to control sites was significant ($P = 0.03$). Significant changes in crash risk were not observed for right-angle or rear-end injury crashes.

4. Discussion

Results from this study suggest that modifying traffic signal change intervals to values associated with the ITE proposed recommended practice reduces the risk of crashes involving pedestrians and bicyclists and may reduce the overall risk of multiple-vehicle crashes, particularly those resulting in injuries. The finding that 40 out of 51 experimental sites needed signal timing changes to conform with the ITE proposed recommended practice suggests the overall number of intersections that can benefit from signal timing changes is very large.

Although right-angle collisions generally are a specific target of signal change interval improvements, such crashes did not decline significantly at the experimental sites relative to the control sites postintervention. One reason may be that most timing changes in this study were relatively modest and, therefore, may not have been large enough to prevent right-angle crashes, which may occur several seconds after onset of the red signal. And unintentional running of red lights caused by inattention or other driver failures may occur long after the light has turned red, and, therefore, resulting crashes would not be reduced by this countermeasure. Also, crash type information provided by the NYSDOT computerized crash data files is rather vague and often does not provide adequate details for documenting more specific crash circumstances. Pedestrian crashes may be more affected by relatively small changes in the duration of signal change interval timing because of the tendency of many pedestrians to enter into the intersection immediately after onset of a green light or walk signal, thus potentially placing themselves in the path of drivers who are late clearing the intersection. For example, a study of real-world pedestrian behavior at signalized intersections reported that pedestrians began crossing, on average, within 1 s of the walk light illumination (Fugger et al., 2000). In discussing this finding, the authors state that it may be necessary to provide a clearance interval to protect pedestrians from drivers who enter on yellow or red signals, but they do not address the amount of clearance time needed.

Given the overall injury results, the large proportion of intersections in need of re-timing to conform with the ITE proposed recommended practice, and the relatively low cost of re-timing traffic signals, modifying the duration of traffic signal change intervals to conform with values associated with the ITE proposed recommended practice should be strongly considered by transportation agencies to reduce the frequency of urban motor vehicle injury crashes.

This study has limitations. The crash analysis did not account for numerous intersection-specific variables such as geometry, traffic volume, number of signal phases, and total cycle length, which could be factors in the relationship between the duration of the change interval and crash risk. Also, even though sites were randomly assigned to be experimental or control, they were not stratified or matched to control for influential factors such as geographic location, intersection design, and operational characteristics, and some experimental and control sites had to be dropped. Finally, long-term effects on crash risk are not known and may differ from those observed in the 3-year experimental period.

In addition to providing adequate signal change interval timing, the risk of crashes at traffic signals can be reduced through changes in signals, enhancing enforcement against red light running, and replacing signals with alternative forms of traffic control. For example, signal visibility can be improved by increasing the size of the signal display (typically from 8 to 12 in. lenses), installing brighter signals, installing additional signal heads, and repositioning the location of signal heads. Such efforts have been shown to reduce crashes and automobile insurance claims (Polanis, 1992; Feber et al., 2000). Red light cameras have been shown to substantially reduce red light violations, and this type of enforcement is supported by the majority of urban motorists (Retting et al., 1999b,c).

Two alternatives to traffic signal control that can reduce crash risk are roundabouts and multiway stop control. Persaud et al. (2002) reported that conversion of 24 US intersections from stop signs and signal control to roundabouts reduced total motor vehicle crashes by 39% and injury crashes by 76%. Following conversion of 199 urban intersections from traffic signal to multiway stop sign control, Persaud et al. (1997) reported a reduction in crashes of approximately 24%, with larger reductions found for injury crashes.

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Appendix A

See Table A1 (overleaf).

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Table A1
Baseline and computed change interval timings for 40 experimental intersections

Site no.	Direction[a]	Baseline signal timing			Institute of Transportation Engineers signal timing			Site no.	Direction[a]	Baseline signal timing			Institute of Transportation Engineers signal timing		
		Yellow	Red	Total	Yellow	Red	Total			Yellow	Red	Total	Yellow	Red	Total
62	NB/SB	4	2	6	3.9	3.1	7.0	85	NB/SB	4	2	6	3.4	3.5	6.9
62	EB/WB	4	2	6	4.8	1.9	6.6	85	EB/WB	4	2	6	4.8	1.5	6.3
64	NB/SB	3	2	5	3.8	4.6	8.4	86	NB/SB	4	2	6	3.3	4.6	7.9
64	EB/WB	4	2	6	4.7	1.9	6.6	86	EB/WB	4	2	6	4.9	1.3	6.2
66	NB/SB	4	2	6	3.5	3.3	6.8	87	NB/SB	4	2	6	3.2	4.6	7.8
66	EB/WB	4	2	6	4.9	1.4	6.3	87	EB/WB	4	2	6	4.8	1.6	6.4
67	NB/SB	4	2	6	4.7	1.9	6.5	88	NB/SB	4	3	7	3.0	5.7	8.7
67	EB/WB	4	3	7	4.7	1.9	6.6	88	EB/WB	4	2	6	4.8	1.4	6.2
68	NB/SB	4	3	7	4.5	2.3	6.8	89	NB/SB	4	2	6	3.4	4.2	7.6
68	EB/WB	4	3	7	5.0	3.2	8.2	89	EB/WB	4	2	6	4.8	1.7	6.5
69	NB/SB	4	3	7	3.1	4.7	7.8	90	NB	4	2	6	2.6	5.6	8.2
69	EB/WB	4	3	7	5.4	1.1	6.5	90	EB/WB	4	2	6	4.9	1.3	6.2
70	NB	4	2	6	2.9	3.1	6.0	91	NB/SB	4	2	6	3.8	2.3	6.1
70	EB/WB	4	2	6	3.8	1.5	5.3	91	EB/WB	4	2	6	4.7	1.7	6.4
71	SB	4	2	6	3.0	3.0	5.9	92	NB/SB	3.5	2	5.5	3.9	2.7	6.7
71	EB/WB	4	2	6	3.1	2.3	5.4	92	EB/WB	4	2	6	4.7	2.0	6.7
72	NB/SB	4	2	6	2.9	3.4	6.3	97	NB/SB	4	2	6	3.3	4.4	7.7
72	EB/WB	4	2	6	3.1	2.4	5.5	97	EB/WB	4	2	6	4.7	1.6	6.3
74	NB/SB	4	2	6	2.9	3.4	6.3	98	NB/SB	4	3	7	4.0	1.9	5.9
74	EB/WB	4	2	6	4.2	1.7	5.9	98	EB/WB	4	2	6	3.8	4.6	8.4
75	NB/SB	4	3	7	3.8	3.5	7.3	100	NB/SB	4	2	6	4.4	2.4	6.8
75	EB/WB	4	2	6	4.9	1.9	6.8	100	EB/WB	4	2	6	3.4	3.8	7.3
76	NB/SB	4	2	6	3.9	3.6	7.6	101	NB/SB	4	2	6	4.5	1.6	6.1
76	EB/WB	4	2	6	4.2	2.4	6.7	101	EB/WB	4	2	6	3.6	3.8	7.4
77	NB/SB	4	2	6	2.8	5.0	7.7	102	NB/SB	4	3	7	4.8	2.8	7.6
77	EB/WB	4	3	7	4.4	2.3	6.7	102	EB/WB	4	2	6	3.1	2.9	6.0
78	NB/SB	4	2	6	3.2	3.3	6.5	104	NB/SB	4	2	6	5.3	1.5	6.9
78	EB/WB	4	2	6	4.3	1.7	6.0	104	EB/WB	4	2	6	2.8	6.2	9.0
79	NB/SB	4	2	6	2.8	5.9	8.7	105	NB/SB	4	2	6	5.4	1.6	7.0
79	EB/WB	4	2	6	4.4	1.6	6.0	105	EB/WB	3	2	5	3.8	3.9	7.7
80	NB/SB	4	2	6	3.7	4.6	8.3	109	NB/SB	4	2	6	3.7	2.9	6.6
80	EB/WB	4	2	6	5.1	1.5	6.6	109	EB/WB	4	2	6	4.5	1.9	6.3
81	NB/SB	4	2	6	2.7	6.5	9.1	110	NB/SB	4	2	6	4.4	1.8	6.2
81	EB/WB	4	2	6	4.2	2.4	6.6	110	EB/WB	3.5	2	5.5	3.0	4.0	7.0
82	NB/SB	4	2	6	3.6	3.4	6.9	111	NB/SB	4	2	6	4.3	1.7	6.1
82	EB/WB	4	2	6	4.5	1.6	6.1	111	EB/WB	3.5	2	5.5	3.5	2.8	6.3
83	NB/SB	3	2	5	3.1	4.5	7.7	112	NB/SB	4	2	6	4.2	1.8	6.1
83	EB/WB	4	2	6	4.5	1.4	5.8	112	EB/WB	3.5	2	5.5	2.8	4.5	7.3
84	NB/SB	4	2	6	3.3	4.9	8.2	113	NB/SB	4	2	6	4.5	1.8	6.3
84	EB/WB	4	2	6	4.7	1.8	6.5	113	EB/WB	3.5	2	5.5	3.5	3.5	7.0

[a] Direction of travel: EB, eastbound; NB, northbound; SB, southbound; WB, westbound.