Driver Behavior Characteristics at Urban Signalized Intersections

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This paper was submitted for presentation and publication at the 83rd Annual Meeting of the Transportation Research Board, January 2004, Washington, D.C.

Word Count = 4,586 + (5 x 250) = **5,836**

Submission Date: November 15, 2003

ABSTRACT

Red light running and the associated risk of severe crashes at signalized intersections have been an ongoing concern to many safety professionals. The proportions of crashes that occur due to such driver behavior represent a substantial number of crashes at urban and suburban signalized intersections in Michigan. In the year 2001, red light running related crashes in Michigan represented approximately 28 percent of the crashes of all severities, and 40 percent of fatal and serious injury crashes (KA crashes) occurring within signalized intersections. Many initiatives to discourage red light running have been used with various degrees of success. Such programs include public awareness campaigns, automated enforcement programs and some engineering countermeasures. These initiatives have resulted in some reductions in the overall crash statistics in the communities where such programs have been implemented. A series of evaluation studies were performed in Michigan to test the effectiveness of change and clearance intervals calculated according to ITE guidelines on late exits (LE) and red light violations (RLV) at nine signalized intersections in Detroit, Michigan. This study used four approaches at four test intersections where engineering treatments have been applied (16 total test sites) and four approaches at five control intersections. Driver behavior was examined at test and control intersections by observing and quantifying the number of vehicles that have not cleared the intersection when the cross-street signal light turns green (late exit), and red light violations. The 'red light running' data at the test and control sites did not exhibit a significant difference. However, the test sites showed significantly lower 'late exit' rates as compared to the control sites.

INTRODUCTION

Red light running and the associated risk of severe crashes at signalized intersections have been an ongoing concern to many safety professionals. The proportions of crashes that occur due to such driver behavior represent a substantial number of crashes at urban and suburban signalized intersections in Michigan. In the year 2001, red light running related crashes in Michigan represented approximately 13 percent of all crashes occurring within intersections of all types. Within signalized intersections, red light running crashes represent 28 percent of crashes and 40 percent of fatal and serious injury crashes (KA crashes) in the year 2001 *(1)*. The red light running crash trends in Michigan are similar to that in the nation. It has been estimated that in the United States (US), over 1.8 million crashes occur at intersections of all types each year. In the year 2001, there were 218,000 traffic crashes involving red light running in the US which included 181,000 injuries and 880 fatalities *(2)*.

Many initiatives to discourage red light running have been used with various degrees of success. Such programs include public awareness campaigns, automated enforcement programs and some engineering countermeasures. These efforts have affected the overall crash experience in the communities where such programs have been implemented.

Low cost safety treatments at signalized intersections are often effective in mitigating traffic crashes and injuries, some of which may be a result of red light running. Many safety projects in Michigan involving low cost safety treatments have achieved significant crash reductions. Some of the engineering improvements include redesigning the signal change (yellow) and clearance (all-red) intervals, upgrading the signal lenses to 12 inches (30.5 cm) in diameter, installing left-turn lanes and/or phases where needed, re-striping the intersection approaches, aligning the signal heads over the travel lanes and others *(3,4)*. Past research has indicated that providing longer signal change and clearance intervals at intersections are often effective in reducing the number of red light violations at signalized intersections *(5,6,7,8,9)*.

A potential high-risk situation is created by drivers who enter the intersection late in the yellow change interval, or even after the onset of the red signal and are traveling through the intersection when the cross-street signal turns green. This is referred to as a late exit *(7)*. The provision of an all-red interval of adequate length protects late exiting vehicles from being exposed to oncoming cross-street traffic. Therefore, if a vehicle enters the intersection late in the yellow change interval, or just after the onset of the red signal, the provision of the all-red clearance interval minimizes the probability of the exposed vehicle being involved in a right-angle collision, since the release of the cross-street traffic is delayed. Therefore, engineering countermeasures such as the provision of an adequate all-red clearance interval may improve intersection safety and help reduce right-angle crashes, even if drivers run the red light within a fraction of a second after the onset of the red signal.

A study was conducted in Michigan to examine red light violations, late exits and traffic crashes at urban signalized intersections. The purpose of this study was to identify the impact the signal timing change and clearance interval (mainly the all-red interval) on the stated driver behavior characteristics.

BACKGROUND

The design of the Change and Clearance Intervals (CCI) has been a contentious issue among the traffic engineering and safety professionals for the past two decades. The Institute of

Transportation Engineers (ITE) *(10)* published guidelines for the design of the change and clearance interval that was adopted by many transportation officials. However, there are still many agencies that do not use the ITE equation, or use it with modified interpretations. Some public officials *(11)* claim that the length of the yellow interval, as recommended by ITE, is too short and forces drivers to violate the red light.

ITE provides two sets of equations for calculating the yellow change interval, based on the inclusion or exclusion of an all-red clearance interval (ARI). The current national Manual of Uniform Traffic Control Devices (MUTCD) *(12)* does not require all-red clearance intervals to be implemented in the signal timing design; they are considered an option.

Past research *(7,9)* has indicated that yellow intervals set either at, or longer than that recommended by ITE are effective in reducing RLV and late exits. Research *(5,7,9)* suggests that all-red intervals set closer to the values recommended by ITE may help reduce the probability of vehicles being exposed to oncoming cross-street traffic and subsequent right angle conflicts and crashes.

In a recent ITE informational report *(2)*, a toolbox of countermeasures to reduce red light running was provided. This toolbox was developed by establishing a panel of experts from federal, state and local governments, academia, and the private sector, and by administering a survey to the practicing engineers to obtain knowledge in addressing red light running through engineering countermeasures. The use of ARIs was mentioned in this toolbox since they have been “shown to increase the safety of an intersection” *(2)*. Even though ARIs do not directly affect a motorists decision to run a red light, they do provide an additional margin of safety for motorists that intentionally or inadvertently run a red light.

The results of a nationwide survey on the use of ARIs were published in The Urban Transportation Monitor *(13)*. Out of a total of 400 surveys disseminated to city traffic engineers throughout the nation, 76 responses were received (response rate of 19 percent). The geographic locations of the responding cities were not revealed. Responses of this survey indicated that 79 percent of the cities implement ARIs at all of their signal locations and 21 percent implement them only at some signal locations. Thirty-five (35) percent of the responding cities use a standard interval length for the ARIs: of which 73 percent use standard lengths of 1.0 second or less. Past research has shown that ARIs greater than 1.0 second are more effective in reducing crashes and injuries (*14*).

Another independent survey was conducted as a part of this study to identify design policies for ARIs used by state transportation departments throughout the USA. The survey was administered to all 50 state transportation departments via email and 21 responses were received (response rate of 42 percent). Eighteen (18) of the 21 state agencies that had documented policies on CCIs stated that their policy follows the ITE guidelines and use all-red intervals in the signal timing. Some agencies however, use modified interpretations of the ITE guidelines by using different values of the parameters than suggested, such as driver perception-reaction time, deceleration rates and others

STUDY OBJECTIVES

A study was performed in Michigan to test the effectiveness of change and clearance intervals calculated according to ITE guidelines on late exits (LE) and red light violations (RLV) at nine signalized intersections in Detroit, Michigan. This study used four approaches of four test intersections where engineering treatments have been applied (16 total test sites) and four approaches of five control intersections (20 total control sites). The driver behavior associated with vehicles that have not cleared the intersection when the cross-street light turns green (late exit), and red light violations were compared between the test and the control sites. This study seeks to assess the relationship between CCI design and specifically, the use or nonuse of adequate all-red intervals in the signal timing design and red light running, late exits and traffic crashes.

SITE DESCRIPTION

A total of nine signalized intersections were used in this study; four intersections were used as test sites and five intersections were used as control sites. The test and control intersection characteristics are summarized in Table 1.

All four approaches of four signalized intersections with ARIs were used as the test sites (test sites) and all four approaches of five similar intersections were used as the control sites; for a total of 16 test sites and 20 control sites. The traffic volumes and roadway geometries of the five control sites were similar to the test sites, except they did not have adequate ARIs in their signal timing. The four test intersections are: Seven Mile Road and Ryan Road, Seven Mile Road and John R Road, Hubbell Road and Puritan Road, and Evergreen Road and Plymouth Road.

The test intersections were selected for inclusion in this study due to the existence of adequate ARIs in the signal timing. The lengths of the ARI at the test intersections ranged from 1.4 seconds to 2.0 seconds, which are essentially equal to the lengths calculated as per the ITE equation [ARI = (W+L)/V, where W is the intersection width in feet, L is the length of the clearing vehicle in feet and V is the approach speed in feet per second]. The yellow intervals at the test sites were 4.0 seconds long, which are slightly longer than the values calculated using the ITE formula. The signals at the test sites operate on 60 and 70-second cycle lengths.

It is important to note that three of the four test intersections (excluding the intersection of Evergreen Road and Plymouth Road) were also a part of a road improvement program in Detroit, where other low cost improvements were installed in addition to implementing all-red intervals designed per the ITE recommended equation. These other improvements included replacing the traffic signals with 12-inch (30.5 cm) diameter signal lenses, which formerly had 8-inch (20.3 cm) diameter signal lenses, installing left turn lanes and left turn phases where needed, and removing on-street parking in close proximity to the intersection.

The approaches of five unimproved intersections were selected as the control sites, and they are: Seven Mile Road and Dequindre Road, Meyers Road and Puritan Road, Ryan Road and Nevada Road, Plymouth Road and Hubbell Road, and Gratiot Avenue and Conner Road.

These sites were selected since they do not have ARIs installed, or have ARIs less than or equal to 1.0 seconds, which is substantially lower than the value calculated as per the ITE equation. Three of the five control intersections had ARIs of 0.0 seconds and the other two control intersections had ARIs of 1.0 and 0.5 seconds that can be considered inadequate for the roadway geometry and approach speed. The yellow change intervals at the control sites range from 3.6 seconds to 5.0 seconds. The yellow interval lengths at the control sites are slightly longer than the values calculated by the ITE recommended practice, with one exception at Hubbell Road and Plymouth Road where the length of the yellow interval is approximately equal to the calculated ITE value. These signals operate on 50, 60 and 70-second cycle lengths. These control intersections also provide a range of intersection geometries, traffic volumes and operating speeds similar to the test sites. The control intersections are in the same general vicinity as the test sites, which was done intentionally in order to maintain similar driver behavior characteristics at the test sites under study.

DATA COLLECTION

As a part of this study, data was collected at each of the test and control intersection approaches, including: traffic volume counts, speed studies, red light violations and late exits for each of the intersection approaches.

Traffic Volume and Speed Data

Traffic volume data was collected for days and times in which RLV and LE data was taken. Volume data was counted for the through vehicles only. Data was collected at each of the intersection approaches for the test and control sites as shown in Table 2. All the test intersections carry relatively low to moderate through traffic volumes during the study periods. The control intersections also carry similar range of traffic volumes, with the exception of Gratiot Avenue, which carries much higher through traffic volumes even during the off peak periods.

Spot speed studies were conducted at each approach of the test and control intersections during the off peak periods at locations of approximately 150 to 200 feet before the intersection using a radar gun. Speed data for a sample of 100 vehicles per approach were collected. The results of the speed study, as shown in Table 2 indicated that the observed 85^{th} percentile speeds exceeded the posted speed limits at almost all of the test and control intersection approaches. The posted speed limit for most of the roads that comprise the test and control intersections is 30 miles per hour (mph) (48 kph), with three exceptions: Plymouth Road at Evergreen Road and Conner Road have posted speed limits of 35 mph (56 kph), and Gratiot Avenue has a 45 mph (72 kph) speed limit. Thus, the appropriateness of the posted speed limits is questionable, since a majority violated the posted speed limits.

Red Light Violations and Late Exits

Red light violation and late exit data was collected at the approaches of the test and control intersections using video cameras. In this study, a RLV is defined as a vehicle that crosses the stop bar and continues through an intersection, after the onset of the red light. A late exit is defined as a vehicle that proceeds through the intersection, and is still in the intersection when the cross street light turns green. For a late exit, drivers may have either entered the intersection at the end of the yellow change interval or during the red signal.

RLV and LE data was randomly collected on various days of the week and times of the day during good weather conditions during the off peak periods. In order to accurately collect RLV and LE data, video cameras were carefully positioned at the intersection approaches to record the actions of the approaching vehicles, the location of the stop bars and the disposition of the traffic signal lights. The video cameras were positioned unobtrusively, so that most drivers were not aware that their driving behavior was being monitored. Thus, the location of the video camera did not influence driver behavior in terms of red light running and late exits. Data was recorded for a minimum of one-half hour per approach, for all the intersection approaches for each day of data collection. RLV and LE data were only counted for through vehicles and **not** for the turning vehicles. Red light violations were counted when a vehicle was observed crossing

the stop bar after the onset of the red signal. Late exits were counted when a vehicle was observed to be traversing through the intersection when the light for the cross street approach was green.
The actual observations for RLV and LE, taken at all the intersection approaches were used to calculate three different rates, including RLV/LE per hour, RLV/LE per 1,000 through vehicles and RLV/LE per 10,000 vehicle-cycles. It is important to note that the rate 'RLV per 10,000 vehicle-cycles' was recently introduced in the literature *(15)*. Bonneson, et.al. *(15)* stated that this rate is the most appropriate statistic for quantifying red light running, since it considers the critical exposure factors of flow rate and cycle length which are the basic elements that explain red light running.

At the 16 test sites (intersection approaches) with all-red intervals of 1.4 to 2.0 seconds in length, average rates of 0.20 LE per hour, 1.4 LE per 1,000 through vehicles and 0.23 LE per 10,000 vehicle cycles were observed. Half of the test sites did not experience any late exits during the observation period. At the control sites, average rates of 0.74 LE per hour, 3.4 LE per 1,000 through vehicles and 0.47 LE per 10,000 vehicle cycles were observed.

In terms of the RLV rates, the average experience at all approaches of the test sites was 1.16 RLV per hour, 5.94 RLV per 1,000 through vehicles and 0.67 RLV per 10,000 vehicle-cycles. At the control sites, average rates of 1.20 RLV per hour, 4.27 RLV per 1,000 through vehicles and 0.59 RLV per 10,000 vehicle-cycles were observed.

ANALYSIS AND RESULTS OF RLV AND LE

Statistical analyses were performed in order to determine if the groups of intersections with ARIs of adequate lengths experience less late exit and red light violations than a group of intersections with inadequate or no ARIs as determined by the ITE equation. The Student's t-test was used for testing the difference between RLV and LE data at the test and control group. In this analysis, adjustments were made to account for the unequal variances and unequal sample sizes. The purpose of this analysis was to determine if the LE and RLV rates at the test intersections (with ARIs of adequate length) are less than the LE/RLV rates at the control sites (with no or inadequate ARIs) at a 95 percent level of confidence. The data from the individual observation (data points) were used in this analysis for all approaches of the four test intersections combined, as well as for all approaches of the five control intersection combined. The distributions of the observations converted to three rates (RLV/LE per hour, RLV/LE per 1,000 through vehicles and RLV/LE per 10,000 vehicle-cycles) were compared for the test and control groups. Tables 3 and 4 show the characteristics of the distribution of LE and RLV, respectively, for the test and control groups on a per hour basis, per 1,000 through vehicles and per 10,000 vehicle-cycles.

The mean late exit rates, on a per hour, per 1,000 through vehicles, and per 10,000 vehicle-cycle basis at the test group are lower than the means observed at control group. The difference in the LE rates at the test and control sites may be attributed to the presence or absence of ARIs of adequate length. The test group consisted of a total of 80 data points of observations and the control group consisted of 88 data points. The results of the statistical analyses using the Student's t-test are summarized in Tables 3 and 4. The results of this analysis indicate that the mean late exit rates (per hour, per 1,000 through vehicles and per 10,000 vehicle-cycles) experienced at the test sites (with adequate ARIs) were significantly lower than the late exit rates at the control sites (with no or inadequate ARIs). The results of the analysis were significant at a

95 percent level of confidence. No significant differences of the mean red light violation rates at the test and control sites were observed for either of the RLV rates (per hour, per 1,000 thru vehicles and per 10,000 vehicle-cycles).

TRAFFIC CRASH ANALYSIS AND RESULTS

A traffic crash analysis was also performed for all the test and control sites. Traffic crash data was collected for each of the study intersections for a period of three years. It is important to note that the yellow and all-red intervals were not changed during the three-year study period. The traffic crashes were analyzed by crash type such as, angle and rear end, as well as for the total and injury crashes. The angle crashes were carefully analyzed from police reports to determine the cause of the angle crash. The angle crashes included in this study only considered those resulting from red light running or clearance interval issues (referred to as RLR angle crashes). Other angle crashes which may have resulted from traffic signal malfunctions, inclement weather conditions or other reasons were excluded from the analyses.

The purpose of selecting the noted crash types and severities is that these types of crashes are only expected to be impacted due to the treatment effect. The annual average of three years of crash data for the test and control sites (crash frequencies and crash rates) are presented in Table 5. The crash rates were calculated using the average daily entering intersection volumes. In addition, the expected crash frequency at the test site was adjusted for volume differences between the test sites and control sites. It should be noted that the average daily traffic (ADT) of the test group is slightly higher than the ADT of the control group.

The average crash frequency and crash rates of the test group of intersections combined have lower RLR angle crashes than the average of the control group. The average RLR angle crashes observed at the test group is 4.1 crashes per year and for the control group is 10.9 crashes per year. The average RLR angle crash rate observed at the test group is 0.32 crashes per million entering vehicles and for the control group is 1.15 crashes per million entering vehicles.

The Poisson test of significance *(16)* was used to identify if the differences in the angle crash frequencies at the test group and the control group were statistically significant. Based on this test, the difference in the RLR angle crashes at the test and control group (approximately 65 percent lower at the test group) is statistically significant at a 95 percent level of confidence. This result holds true when comparing the crash frequencies at the test and control groups directly, or when comparing the crashes that were adjusted to account for volume differences in the test and control sites. On average the test intersections also experienced slightly lower total, rear end and injury crashes than the control intersections, however not at a significant level.

SUMMARY AND CONCLUSIONS

This study included the evaluation of the all-red interval on red light violations and late exits at nine intersections in Detroit, Michigan. Four approaches of four test intersections (total of 16 approaches) were used as the test sites, which had all-red intervals with lengths determined by the ITE equation. Four approaches of five intersections (total of 20 approaches) were used as control sites, which had no all-red intervals, or all-red intervals with lengths less than that determined by the ITE equation. Specifically, 12 of the 20 control sites had **no** all-red intervals present in the signal timing, four sites had all-red intervals of 0.5 seconds and four sites had 1.0-second all-red intervals. The results of this study indicated the following:

- The safety consequences of drivers who violate the red signal within a fraction of a second after it turns red, is dependent on the proper use of the all-red interval. If an all-red interval of adequate length is used, drivers will have a lower probability of being involved in a right angle crash. If an all-red interval is not present or does not have an adequate length, these drivers have a higher probability of being involved in an angle crash.
- A comparison of the test and control groups in Detroit indicated that the late exit rates (LE per hour, LE per 1,000 through vehicles, and LE per 10,000 vehicle-cycles) at the test sites with all-red intervals of adequate length were **significantly** lower as compared to the control sites, which had no or inadequate lengths of all-red intervals. However, the statistical test on RLV rates (RLV per hour, RLV per 1,000 through vehicles, and RLV per 10,000 vehicle-cycles) indicated that there were **no** significant differences in the red light violation experience at the test and control sites in Detroit.
- A comparison of the angle crashes involving red light running indicated that on average, these crashes were significantly lower at the test group, than at the control group of intersections.

Providing adequate all-red clearance intervals can significantly impact intersection safety by reducing the probability of occurrence of right angle crashes, even if drivers run the red light (within a fraction of a second after the onset of the red signal). Thus, even though the presence or absence of an all-red interval does not influence drivers' decisions to violate the red signal, the provision of all-red intervals of adequate length provide significant safety benefits. The impacts of implementing all-red intervals of adequate length (as per the ITE equation) will allow the intersection to operate safely.

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LIST OF TABLES

TABLE 1 Test and Control Intersection Characteristics

Site	Intersection	Approach	Change and Clearance Interval (Seconds) After Improvement		Off-Peak Period Cycle Length (Seconds)	Signal Phasing
			Yellow	All Red		
Test Sites	Seven Mile Road and Ryan Road	NB & SB Ryan	4.0	2.0	70	3-phase with E-W Left Turn Phase
		EB & WB Seven Mile	4.0	2.0		
	Seven Mile Road and John R Road	NB & SB John R	4.0	2.0	70	3-phase with E-W Left Turn Phase
		EB & WB Seven Mile	4.0	2.0		
	Hubbell Road and Puritan Road	NB & SB Hubbell	4.0	1.5	60	2-phase
		EB & WB Puritan	4.0	1.5		
	Evergreen Road and Plymouth Road	NB & SB Evergreen	4.0	1.4	70	2-phase
		EB & WB Plymouth	4.0	1.4		
Control Sites	Dequindre Road and Seven Mile Road	NB & SB Dequindre	4.0	0.0	50	2-phase
		EB & WB Seven Mile	4.0	0.0		
	Meyers Road and Puritan Road	NB & SB Meyers	4.0	1.0	50	2-phase
		EB & WB Puritan	4.2	0.5		
	Ryan Road and Nevada Road	NB & SB Ryan	4.8	0.0	60	2-phase
		EB & WB Seven Mile	4.8	0.0		
	Hubbell Road and Plymouth Road	NB & SB Hubbell	3.6	0.0	60	2-phase
		EB & WB Plymouth	3.6	0.0		
	Gratiot Avenue and Conner Road	NB & SB Gratiot	4.5	0.5	70	3-phase with N-S Left Turn Phase
		EB & WB Conner	5.0	1.0		

TABLE 2 Traffic Volume and Speed Data

Intersection Name	Type of Site	Approach	Average Through Traffic Volume at the Approach (vph)	Posted Speed Limit (MPH)	Approach Speed (MPH) 85th Percentile Speed
Seven Mile Road and Ryan Road	Test	EB	341	30	33.5
		WB	360	30	31.1
		NB	182	30	39.5
		SB	184	30	38.8
Seven Mile Road and John R Road	Test	EB	315	30	36.2
		WB	301	30	35.8
		NB	93	30	37.9
		SB	116	30	38.5
Hubbell Road and Puritan Road	Test	EB	240	30	39.1
		WB	262	30	38.7
		NB	113	30	37.5
		SB	129	30	37.0
Evergreen Road and Plymouth Road	Test	EB	219	35	37.3
		WB	263	35	34.7
		NB	249	30	38.0
		SB	242	30	37.4
Seven Mile Road and Dequindre Road	Control	EB	291	30	33.6
		WB	362	30	32.4
		NB	155	30	38.8
		SB	158	30	38.9
Meyers Road and Puritan Road	Control	EB	192	30	35.9
		WB	232	30	35.1
		NB	209	30	35.1
		SB	180	30	33.7
Ryan Road and Nevada Road	Control	EB	194	30	37.1
		WB	189	30	37.5
		NB	277	30	24.1
		SB	239	30	27.3
Plymouth Road and Hubbell Road	Control	EB	367	30	32.6
		WB	318	30	34.8
		NB	179	30	37.6
		SB	189	30	36.0
Gratiot Avenue and Conner Road	Control	EB	328	35	43.2
		WB	320	35	44.2
		NB	1003	45	51.2
		SB	1014	45	50.4

TABLE 3 Characteristics of LE Rates at the Test and Control Sites and Results of the Students t-Test

Characteristics of Late Exit Rates						
Description	**Late Exits Per Hour**		**Late Exits Per 1,000 Through Vehicles**		**Late Exits Per 10,000 Vehicle-Cycles**	
	Test Group	**Control Group**	**Test Group**	**Control Group**	**Test Group**	**Control Group**
Mean ($\bar{X}$)	0.20	0.74	1.35	3.35	0.23	0.47
Standard Deviation	0.53	1.15	3.77	5.61	0.69	0.79
Variance (σ^2)	0.28	1.33	14.20	31.51	0.48	0.57
Unbiased Estimates of σ^2 ($\hat{\sigma}^2$)	0.28	1.34	14.38	31.87	0.49	0.58
Sample Size (Number of Observations)	80	88	80	88	80	88

Results of Students t-Test

Description	**Late Exits per Hour**	**Late Exits per 1,000 Through Vehicles**	**Late Exits per 10,000 Vehicle-Cycles**
$t_{calculated}$	3.929	2.717	2.071
Degrees of Freedom k'	126	155	168
t Critical (one-tail test) at α = 0.05 and k'	1.65	1.65	1.65
Significant Reduction?	Yes; since $t_{calculated} > t_{critical}$	Yes; since $t_{calculated} > t_{critical}$	Yes; since $t_{calculated} > t_{critical}$

TABLE 4 Characteristics of RLV Rates at the Test and Control Sites and Results of the Students t-Test

Characteristics of Red Light Violation Rates						
Description	**Red Light Violations Per Hour**		**Red Light Violations Per 1,000 Through Vehicles**		**Red Light Violations Per 10,000 Vehicle-Cycles**	
	Test Group	**Control Group**	**Test Group**	**Control Group**	**Test Group**	**Control Group**
Mean ($\bar{X}$)	1.16	1.20	5.94	4.27	0.67	0.59
Standard Deviation	1.86	1.81	13.47	6.75	1.16	0.92
Variance (σ^2)	3.47	3.27	181.44	45.50	1.34	0.84
Unbiased Estimates of σ^2 ($\hat{\sigma}^2$)	3.52	3.30	183.74	46.02	1.36	0.85
Sample Size (Number of Observations)	80	88	80	88	80	88

Results of Student t-Test			
Description	**RLV per Hour**	**RLV per 1,000 Through Vehicles**	**RLV per 10,000 Vehicle-Cycles**
$t_{calculated}$	0.052	-1.00	-0.518
Degrees of Freedom k'	165	115	152
t Critical (one-tail test) at $\alpha = 0.05$ and k'	1.65	1.65	1.65
Significant Reduction?	No, Not Significant	No, Not Significant	No, Not Significant

TABLE 5 Traffic Crash Comparison of the Test and Control Intersections

Intersection	Type of Site	Annual Average Crash Frequencies of Three Years of Data (Crashes per year)				Intersection ADTs (vpd) Approximate Average of 3 Years of Data	Annual Average Crash Rates of Three Years of Data (Crashes per million Entering Vehicles)			
		Total Crashes	Angle Crashes* Related to RLR and CI	Rear End Crashes	Injury Crashes		Total Crashes	Angle Crashes* Related to RLR and CI	Rear End Crashes	Injury Crashes
Seven Mile Road and Ryan Road	Test	34.7	2.3	10.3	7.3	28240	3.37	0.22	1.00	0.71
Seven Mile Road and John R Road	Test	30.3	4.3	9.3	5.7	28500	2.91	0.41	0.89	0.55
Hubbell Road and Puritan Road	Test	13.3	2.7	1.7	5	22500	1.62	0.33	0.21	0.61
Evergreen Road and Plymouth Road	Test	51.3	7	10.7	17.7	57600	2.44	0.33	0.51	0.84
AVERAGE OF TEST GROUP (Tf)		**32.4**	**4.1**	**8**	**8.9**	**34210**	**2.58**	**0.32**	**0.65**	**0.68**
Seven Mile Road and Dequindre Road	Control	37	8.3	8.3	8.7	24800	4.09	0.92	0.92	0.96
Meyers Road and Puritan Road	Control	23.6	9	3.3	8.7	30710	2.11	0.80	0.29	0.78
Ryan Road and Nevada Road	Control	16.7	16	2.6	3.7	18850	2.43	2.33	0.38	0.54
Hubbell Road and Plymouth Road	Control	34.3	9.7	7.3	12	26140	3.59	1.02	0.77	1.26
Gratiot Road and Conner Road	Control	64.3	11.3	23	16	45800	3.85	0.68	1.38	0.96
AVERAGE OF CONTROL GROUP (Cf)		**35.2**	**10.9**	**8.9**	**9.8**	**29260**	**3.21**	**1.15**	**0.75**	**0.90**
Expected Crash Frequency- Test Sites: Ef =Cf *(Test ADT/Control ADT)		**41.2**	**12.7**	**10.4**	**11.5**					

*Does not include angle crashes related to signal malfunction or inclement weather conditions, such as snow, ice, etc.

ADT = Average Daily Traffic, vpd = vehicles per day