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Driver Behavior during All Red Interval at Signalized Intersections in Erbil City

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ABSTRACT

This case study investigated red light violations at urban signalized intersections in Erbil city-Iraqi Kurdistan Region. The results obtained in the study are important to improve traffic safety at signalized intersections. Field observations were conducted at six at-grade and grade separated signalized intersections which were selected in different locations in the city. Drivers' behavior at these signalized intersections based on direct field data collection and video recording technique for the whole observed time is examined. The video recording technique is used to abstract the driver behavior traffic data during the onset of all red light. Also, some camera pictures are taken to assist studying the driver behavior while crossing the stop line after the onset of a red light. The analysis is conducted to identify the driver behavior during red light gathered from the data collected of a total of 328 violation records which are lower than the red light violation rates recorded by other studies.

The calculated red light violation rates for the 6 studied intersections ranged from 0.58 violation per 10,000 vehicles-cycle to 1.52 violation per 10,000 vehicles-cycle. The results show that average aged male and female drivers are more probable to run red lights. In addition, the male drivers have much higher tendency to run the red light than female drivers. Most red light violating drivers in Zanko and Mashtal signalized intersections are young because they are near the college town. Most of red light violations occurred during the peak hours between 8:00 a.m. to 9:00 a.m when most urban driving is done. About 95.34 % of the red light violation records are passenger cars (private and taxi). Approximately 17.38% of drivers tended to stop after onset of the red light. The drivers crossed the stop line after the onset of red light and not stopped are 76.22% within the all red interval and only 6.4% after the end of all red interval. About 51.0 % of the violators ran the red light within 2.0 seconds of its onset, while over 95.0 percent of the violators ran the red light within 4.0 seconds of its onset. The average speed of the red light violator vehicles is 34.95 kph. The most frequent vehicle speed at the time of violation is 32.14 kph. For all studied signalized intersections, 8.0 – 26 % of violating vehicles ran the red light at speeds ≤ PSL, while 74.0 – 92.0 % of violating vehicles ran the red light at speeds > posted speed limit (PSL). The number of red light violations (RLVs) are high at low and high traffic volumes but they are low for medium traffic volumes. The red light violation increases as the signalized intersection control delay value increases and it decreases as the control delay decreases. 56.3% of red light violators are straight ahead, while (43.7%) are left turn vehicles. Simple regression analysis is carried out using IBM SPSS to model the effect of elapsed time since red light onset, violating vehicle speed, traffic volume, signalized intersection control delay, and average approach speed on red light violation (RLV).

The most suitable relationship between the RLVs and elapsed time since red light onset is the fourth-degree polynomial model with a coefficient of determination R^2 = 0.9931, the third-degree polynomial model for vehicle speed since red light onset with a coefficient of determination R^2 = 0.9519, second-degree polynomial for the signalized intersection traffic volume counts, positive second-degree polynomial for signalized intersection control delay with a coefficient of determination R^2 = 0.8493, the third-degree polynomial model for the observed mean approach speed with a coefficient of determination R^2 = 0.773.

1.Introduction

According to the manual of uniform traffic control devices (MUTCD) for the green, yellow, and red traffic light indications, when drivers receive the yellow light, they should be prepared to come to complete stop when the light turned to red. The light display, sequence and duration of a light phase changing from green to red light is referred to as intersection phase-switching mode. Therefore, during such period, traffic flows near a signalized intersection may dynamically change, causing traffic conflicts to generate and reducing the safety and efficiency of the whole signalized intersection. (David Yang et al, 2006).

Intersections are the most dangerous parts of the roadways with frequent traffic accidents, especially during phase-switching periods. Twenty percent of nationally crashes are at signalized intersections. At every signalized intersection, drivers from any approach and for any movement might decide whether to proceed and cross the stop line (used clearance time (UCT)based on their own judgments to cross the intersection during the change interval (yellow and all red). (Fatemeh Baratian-Ghorghi, et al, 2016).

The HCM, considers the used clearance time (UCT) as a part of the green light. UCT is defined as “The time, in seconds, between light phases during which an intersection is still used by vehicles”. While a driver approaches a signalized intersection he should take care of the yellow light, which means that the right-of-way is about to end for his phase. Fatemeh Baratian - Ghorghi , et al, 2016.

Driver red light violation is a major traffic safety challenge to traffic engineers at signalized intersections. According to statistics, 85% of intersection accidents occurred during phase-switching period. Therefore, setting up an appropriate phase-switching mode is an important issue to improve traffic safety and efficiency. C. Y. David Yang, et al, 2006.

Also, the red light violation (RLV) is considered to be one of the major causes of crashes at signalized intersections, because they are contributing in 50% of fatal accidents at these intersections. Andrzej P. Tarko, et al, 2003.

According to MUTCD, the red light violation (RLV) is: “… when a driver fails to stop at the presence of a steady red light indication.”. A red light violation is an individual driver behavior and may be deliberate or unintentional. Also, affected by traffic and geometric characteristic of the signalized intersection. Drivers from all categories run the red lights therefore, it is difficult to determine an effective way to prevent the drivers from violating the red light. Red light violators include drivers of all ages, economic classes, and gender. Reginald R. Souleyrette, et al, 2004.

Variations in violation rates are result of some factors such as when the vehicle is considered to be a red light violator, method of data collection and the locations of studies. The red light violation is occurred frequently in many countries. C. Y. David Yang, et al, 2006.

The engineering, education, and enforcement (3E’s) measures may contribute in the solution of RLV problem. Increasing the safety at signalized intersections requires a comprehensive study of the drivers’ behavior at signalized intersections. This requires collecting data about the timing of the traffic light, geometric characteristics, operational conditions, and human factors. C. Y. David Yang, et al, 2006.

In a study conducted in 2004 by Reginald R., et al, showed that 48 % of the red running drivers are those who are in hurry, not because of other factors. The advantage of an all-red interval reduces due to the fact that nearly 50% of red light violations are deliberate. Therefore, alternative approaches are necessary to be considered, such as red camera and traffic police enforcement.

Red light violators are those drivers who are younger, less using seatbelts, have poorer driving records, drive smaller vehicles, and have multiple speed convictions. Also, the familiar drivers with certain signalized intersection are more likely to run the red light. Reginald R. Souleyrette , et al, 2004.

Police enforcement or a red light camera (RLC) are used to identify drivers who cross the stop line and proceed through the signalized intersection after the onset of the red light. Some drivers drive more cautiously and stop abruptly in order to avoid committing violation in the presence of RLCs, they may stop for the next green light leading to the reduction in the signalized intersection capacity. Fatemeh Baratian-Ghorghi , et al, 2016.

The California vehicle code allows a vehicle which entered the intersection during a yellow light indication to clear the intersection during the all red light indication. C. Y. David Yang, et al, 2006. Not stopping at the onset of red light meaning poor driving experience. High cognitive demand situations, are associated with dementia type reported crashes. Sheila K. West, et al, 2009.

According to past researches in this field, the use of all-red interval in the cycle time at signalized intersections resulted in reducing the number of red light violation crashes. Many researches have studied the effects of implementing the all-red clearance interval by using before and after studies for a year before and a year after. Familiar drivers are using the all-red interval and trying to make it a part of the clearance time. This reduces the signalized intersection safety level over a long time period and it may be as for the traffic lights without all red interval. Reginald R. Souleyrette , et al, 2004.

In 2003 Tarko, et al, in their study in Indiana they studied evaluation of the red light violation rate and the identification of the factors that are caused by red light violation. During the red light-violation data collection at the studied signalized intersection, the traffic was monitored continuously by traffic police. Four months of traffic surveillance was conducted, after that photo monitoring guiding signs for drivers about red light violations were installed at approaches to the intersections. Fourth months later, they investigated the reduction in red light violation. Also, they studied the effect of the adult student population to show that young drivers running the red light more than the older drivers. The RLV rates was increased for the studied signalized intersections during the normal school days (presence of students) in comparison to the vacation days (absence of students) with a significance level ranging between 1% and 8%.

In 2003 Moon, et al, showed that about 30% of red light violation crashes are due to deliberate disobeying of red lights, and more than 50% of red light violation crashes are due to driver unawareness of the red light. Therefore, only the remaining 20% of signalized intersection crashes may be reduced by providing an adequate all-red clearance interval. In addition, they concluded that the red light violation rates is higher during off-peak hours due to low traffic volumes, high mean approach speeds, and the random pattern of traffic arrival.

In 2004, Reginald R. Souleyrette, et al, in a long term study in Minneapolis, Minnesota signalized intersections studied the safety effect and effectiveness of the all-red clearance interval at low speed urban signalized intersections. They examined the implementation of the all-red clearance interval for 2 years before and 2 to 4 years after the implementation. Also a comparison group and a number of regression models were used.

In 2009, Sheila K. West et. al., in their study in Salisbury, Maryland they studied the rate of red lights violations among older drivers. The relationship between failure to stop and measures of vision and cognition were also studied. Data was collected for 1,425 drivers aged between 67 to 87 years. A real-time driving performance data was collected for each driver for 5 days and again at 1 year. They showed that, about 3.8% of older drivers failed to stop at the onset of red lights, with 15% of those who ran the red light (3.8%) having failed and 10% or more of the red lights were encountered. Drivers with smaller vertical attentional visual field (AVF) were more probable to fail to stop during the onset of red light. The demographic and vision variables were not related to failure to stop. Failure to stop at the onset of red lights is uncommon event in older drivers and associated with reduced visual ability. Sheila K. West, et al, 2009.

Zhizhou WU, et. al, 2015 used video data to analyze driving behaviors near intersections under the two different phase-switching modes, considering drivers' psychology changes, red-light violation maneuvers and speed characteristics. They studied the two most common light switching modes implemented in urban intersections in China green countdown mode and green flashing mode. In their results they showed that the green flashing mode leads to lower rates of red-light running, a higher rate of stopping during onset of red light, a lower speed/acceleration dispersion rate, lower average operating speed, and smaller speed fluctuation.

Table (1-1) lists the strategies suggested by some researchers to reduce the red light violations instead of traffic police and photo camera enforcements through improving the traffic control system and the geometric layout of the intersections. Using “non-enforcement” strategy may be sufficient in some cases to reduce the red light violations at signalized intersections.

Andrzej P. Tarko , et al, 2003, addressed three methods of measuring the extent of the RLVs:

1. Red light violation crashes Frequency,
2. Red light violation Frequency, and
3. Public perception of the red light violation problem.

There are a number of studies focusing on driving behaviors under different traffic treatments, but since driving behaviors, geometrics, and build environment are quite different, research results from other countries cannot be directly transferred in Erbil City-Iraqi Kurdistan region.

Thus, the aim of this study is to examine the characteristics of Erbil city’s drivers’ behaviors during all red period, in order to improve signalized intersection safety and traffic efficiency and to establish a foundation for understanding red light violation and the effects of driver, intersection, and environment.

2. METHODOLOGY

A methodology is used for the collection and analysis of the necessary data. The most important elements of the methodology are site selection, time of day for observation, period of observation and type of data.

2.1 Selection and Description of Intersections

In this study, six signalized intersections in urban area of Erbil city with similar traffic and geometric characteristics are selected as shown in Figure (2-1). Traffic police surveillance at the time of data collection is not continuously present at these signalized intersections where the survey took place.

There are many combinations for light switching modes from a phase to the next phase, they are classified in accordance with the light display status at the end of a green light, during the switching period and at the early stage of a red light. In Erbil city signalized intersections, the most typical red phase-switching mode is steady yellow, there are few signalized intersections with yellow countdown mode. Therefore, all the six selected signalized intersections are using steady yellow mode.

Table (1-1). Suggested Red Light Violation Countermeasures C. Y. David Yang, et al, 2006

Countermeasure Reference	
Use automated red light photo enforcement cameras.	Rudy and Hobeika, 2003; Retting and Kyrychenko, 2002; BMI, 2001; Retting and Kyrychenko, 2001; Retting et al., 1999; Retting et al., 1998; Retting and Williams, 1996
Adjust the timing of traffic signals with adequate yellow clearance interval time/in accordance with recommendations made by ITE.	Brewer et al., 2002; Milazzo et al., 2002; Schattler et al., 2002; BMI, December 2001; Milazzo et al., June 2001; Retting et al., 2000; Retting et al., 1999; Retting et al., 1998; Retting and Greene, 1997; Retting and Williams, 1996; Retting et al., 1995; Zador et al., 1985
Increase signal and sign visibility.	Brewer et al., 2002; BMI, 2001; Retting et al., 1995
Improve signal coordination among intersection groups.	Brewer et al., 2002
Use protected left-turn phases.	BMI, 2001
Provide all-red intervals at intersections.	Retting et al., 1995
Increase sight distance.	Retting et al., 1995

*ITE ≡ Institute of Transportation Engineers

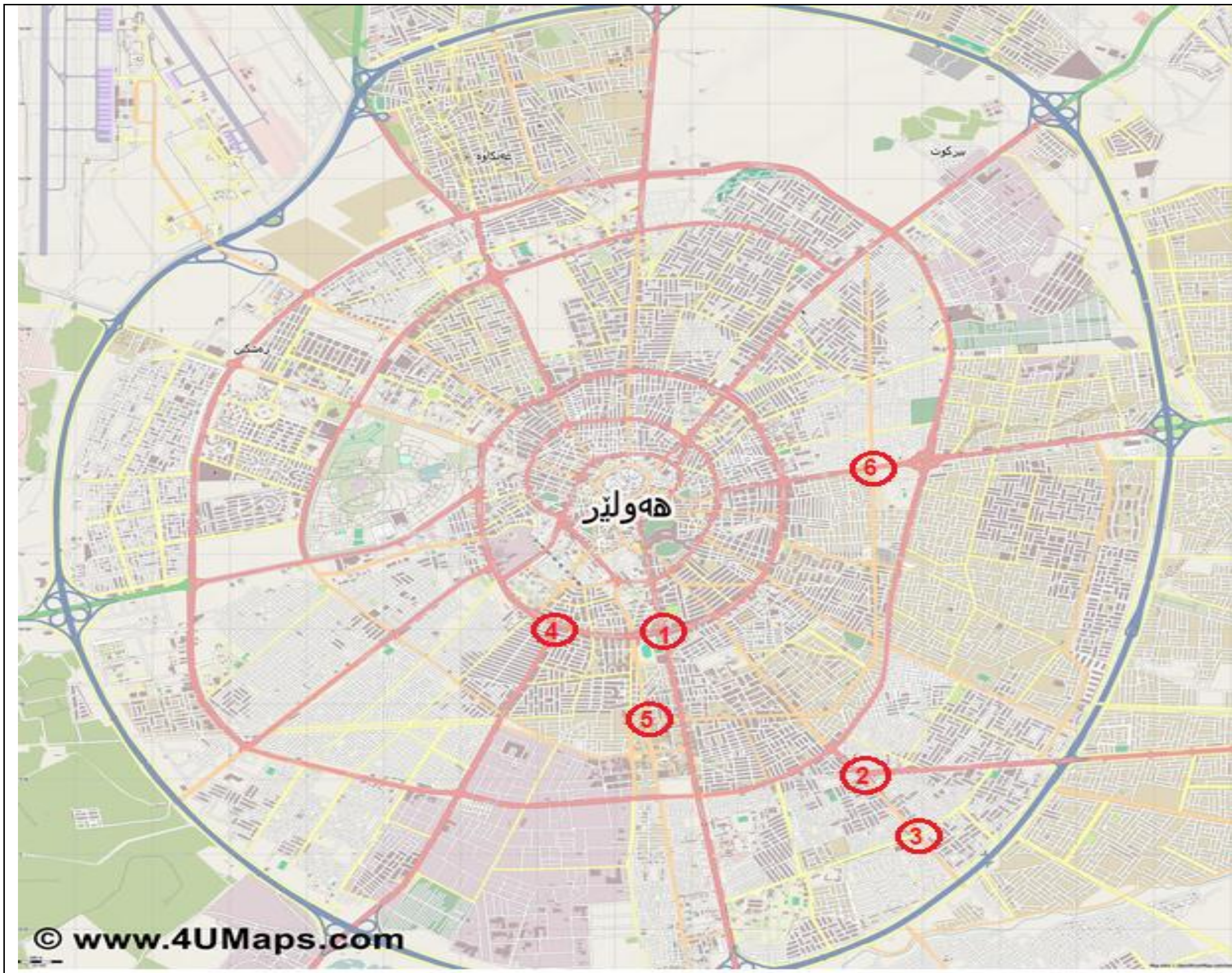

Figure (2-1): Erbil Satellite map showing the Selected intersections.

2.2 Data Collection

The field survey, and Google Street View, are used to determine the geometric data of the intersections (number and width of lanes, approach grades, existence and condition of pavement marking and the approaches posted speed limits) and the traffic data (signal timing details, mean approach speed, traffic volume, and the intersection control delay). Information summary related to infrastructure and traffic data of the 6 studied intersections are shown in Table (2-1).

The video recording technique was used for collecting the driver behavior data during all red in the maximum intersection traffic volume period (which occurs at morning) in working days for three continuous hours from 7:30 a.m. to 10:30 a.m. This is because the maximum possible higher number of red light violators was expected to occur during this period of time.

The collected data about the driver behavior during all red interval includes:

1. Gender and age group of the violator
2. Day Time (in hours) of the violation occurrence
3. Type of the vehicle driven by the red light violator
4. Distribution of driver responses during all red interval (violating during all red and stopping- passing the stop line and then stopping, violating during all red and not stopping, violating after all red and not stopping)
5. Vehicle elapsed time and operating speed
6. Traffic volume
7. Intersection control delay
8. Type of vehicle maneuver

After that, by replaying the video film for many times with the aid of a computer program named EVENT (Al-Neami, 2000), the required data is abstracted from a total of about 383 traffic signal cycles (containing about 1480 traffic light phases) at the six signalized intersections. Then, drivers who cross the stop line and not stopping after the onset of the red light were identified. In addition, several pictures were taken to collect more accurate data about the vehicles crossing the stop line after the onset of the red light.

Table (2-1): Geometric and Traffic Data of the Six Studied Intersections

Signalized Intersection Name	Signalized Intersection Code	Approach	Yellow Time (sec)	All red Time (sec)	Green Time (sec)	Cycle Time (sec)	Total Cycles for 3 hours	Total Phases for 3 hours	Posted Speed (kph)	Mean Approach Speed (kph)	STD (kph)	Hourly Traffic Volume (vph)	3 Hour Traffic Volume (vp3h)	% Stop Vehicles	Intersection Control Delay (Sec/veh)	No. of Lanes (3.5 m)
Yariga	1	EB	3	2	30	150	72	288	30	56.2	20.2	820	2460	23	16.4	3
		SB	3	2	20				30	45.4	10.4	900	2700	27	10.8	2
		WB	3	2	50				30	41.4	16.8	820	2460	23	9.6	3
		NB	3	2	30				30	24.2	16.1	1440	4320	48	14.2	2
		Intersection								**39.13**	**15.80**	**3980**	**11940**	**33.1**	**12.9**	
Mashtal	2	EB	3	2	30	180	60	240	30	16.9	10.9	780	2340	24	10.7	2
		SB	3	2	50				30	18.7	3.3	610	1830	53	13.4	3
		WB	3	2	30				30	20.5	6.8	140	420	57	9.3	2
		NB	3	2	50				30	36.1	13.1	150	450	63	18.4	3
		Intersection								**19.57**	**8.00**	**1680**	**5040**	**40.6**	**12.3**	
Zanko	3	EB	3	2	40	150	72	288	30	35.8	25.1	780	2340	44	17.9	2
		SB	3	2	40				30	29.4	13	1200	3600	32	15.1	3
		WB	3	2	20				30	26.6	14	960	2880	40	27.5	2
		NB	3	2	30				30	28.2	17.8	1500	4500	47	13.3	3
		Intersection								**29.51**	**16.96**	**4440**	**13320**	**40.8**	**17.7**	
Kooran	4	EB	3	4	90	210	51	154	30	36.6	17.8	578	1734	64	13.2	4
		SB	-	-	-				-	-	-	-	-	-	-	-
		WB	3	11	40				30	24.3	8.8	300	900	42	9.6	4
		NB	3	11	45				30	18.9	4.9	516	1548	29	15.1	5
		Intersection								**27.40**	**11.09**	**1394**	**4182**	**45.9**	**13.1**	
Azadi	5	EB	3	2	30	160	68	270	30	34	13.3	900	2700	40	18.7	3
		SB	3	2	50				30	29.8	12.8	1200	3600	32	15.1	3
		WB	3	2	35				30	33.9	12.2	600	1800	53	17.5	3
		NB	3	2	25				30	32.2	14.8	840	2520	41	12	3
		Intersection								**32.13**	**13.30**	**3540**	**10620**	**39.5**	**15.7**	
Rizgary	6	EB	3	4	40	228	60	240	30	17.9	7.5	750	2250	55	16.4	3
		SB	3	4	60				30	22.8	7.8	960	2880	39	10.8	3
		WB	3	4	40				30	23.7	6.5	705	2115	32	9.6	3
		NB	3	4	60				30	25.3	7	900	2700	33	14.2	3
		Intersection								**22.56**	**7.24**	**3315**	**9945**	**39.6**	**12.7**	
All Intersections							**383**	**1480**				**18349**	**55047**			

3. DATA ANALYSIS AND RESULTS

3.1 Total observations of the RLVs

Table (3-1) summarizes the total observations of the RLVs for each signalized intersection approach and the total number of vehicles that passed at the approach for the observation time.

These estimates of red light violation rates are low with respect to those reported in other studies. This may be due to the fact that the red light violation data used in the calculation of these rates are for relatively short time period of the day (only the peak period).

Table (3-1): RLV Counts for Studied Signalized Intersections

Signalized Intersection Name	Signalized Intersection Code	Approach	Hourly Traffic Volume vph	3 Hour Traffic Volume (vp3h)	RLV	Cycle Time (sec)	Total Cycles for 3 hours	No. of Phases	RLV/10000 veh-Cycle
Yariga	1	EB	820	2460	9	150	72	4	66*10000 /11940*72= **0.77**
		SB	900	2700	18				
		WB	820	2460	12				
		NB	1440	4320	27				
		Intersection	3980	**11940**	**66**				
Mashtal	2	EB	780	2340	4	180	60	4	**1.52**
		SB	610	1830	15				
		WB	140	420	10				
		NB	150	450	17				
		Intersection	1680	**5040**	**46**				
Zanko	3	EB	780	2340	13	150	72	4	**0.81**
		SB	1200	3600	18				
		WB	960	2880	32				
		NB	1500	4500	15				
		Intersection	4440	**13320**	**78**				
Kooran	4	EB	578	1734	8	210	51	3	**2.37**
		SB							
		WB	300	900	21				
		NB	516	1548	22				
		Intersection	1394	**4182**	**51**				
Azadi	5	EB	900	2700	6	160	68	4	**0.58**
		SB	1200	3600	12				
		WB	600	1800	9				
		NB	840	2520	10				
		Intersection	3540	**10620**	**37**				
Rizgary	6	EB	750	2250	2	228	47	4	**1.06**
		SB	960	2880	19				
		WB	705	2115	23				
		NB	900	2700	6				
		Intersection	**3315**	**9945**	**50**				
	All Intersections		**18349**	**55047**	**328**				**0.93**

3.2 Description of Red Light Violations

The effect of the factors abstracted from the traffic data about the driver behavior during all red interval on the red light violation is analyzed and discussed in this section.

3.2.1 Driver Gender and Age Group

Distribution of red light violators, by driver gender and three age groups, is plotted in Figure (3-1). The results shows that average age male and female drivers are more likely to be red light violators compared to other age group drivers except for Zanko and Mashtal signalized intersections, the younger driver violators are higher because these two intersections are near the college town and the proportion of younger drivers are higher. Also, it can be seen that the male drivers have much higher tendency to run the red light than female drivers.

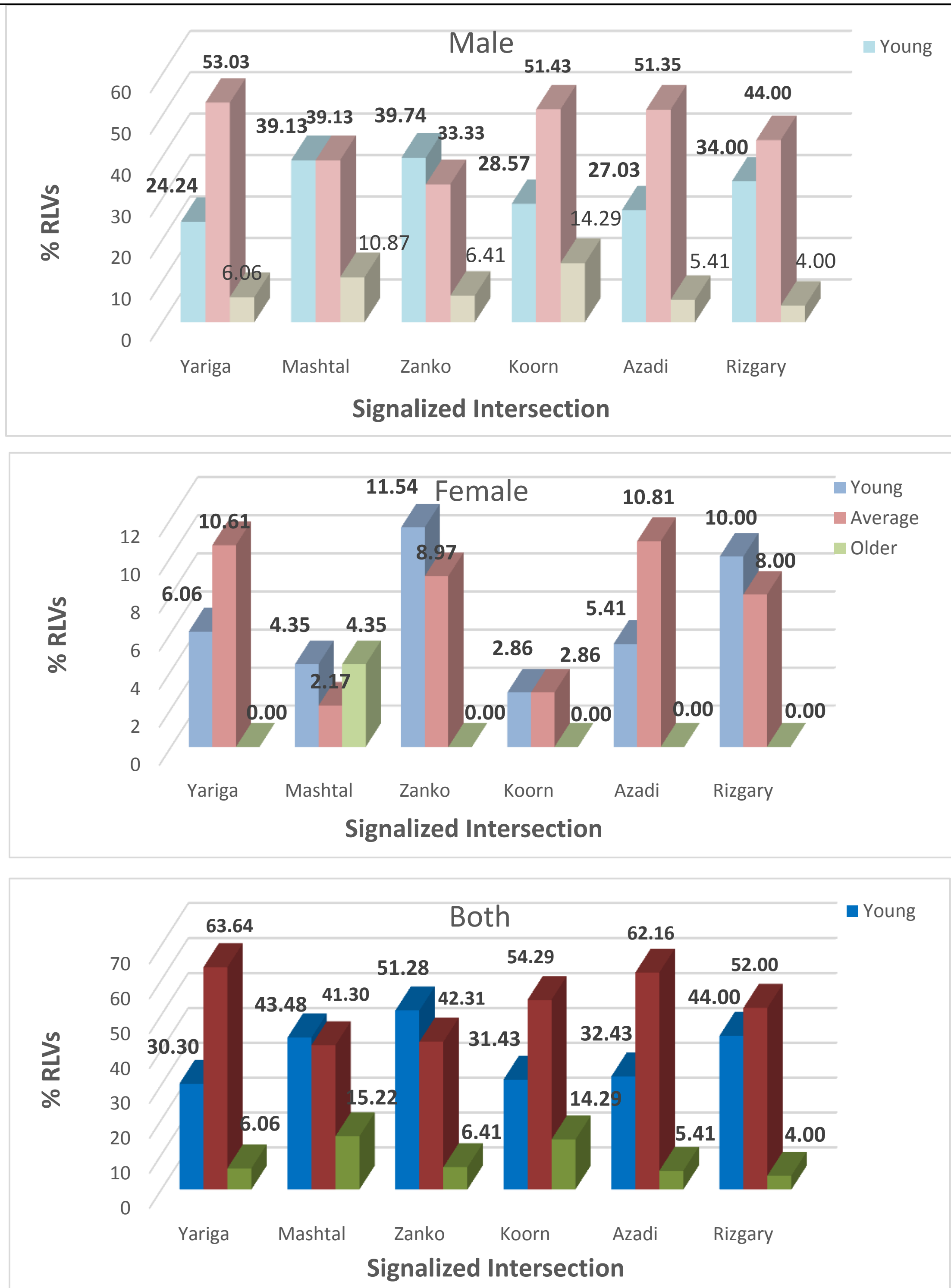

Figure (3-1): Normalized RLVs by Driver Gender and Age Group: Top- Male Middle- Female Bottom-Both

3.2.2 Day Time of the Violation Occurrence

Figure (3-2) illustrates the distribution of RLVs by violating day time (in hours). The trend is expected, because the red light violations occurred during the morning peak hour for each intersection when most urban driving is occurred (i.e., 8:00 a.m. to 9:00 a.m.) because the drivers are in hurry to go to working places.

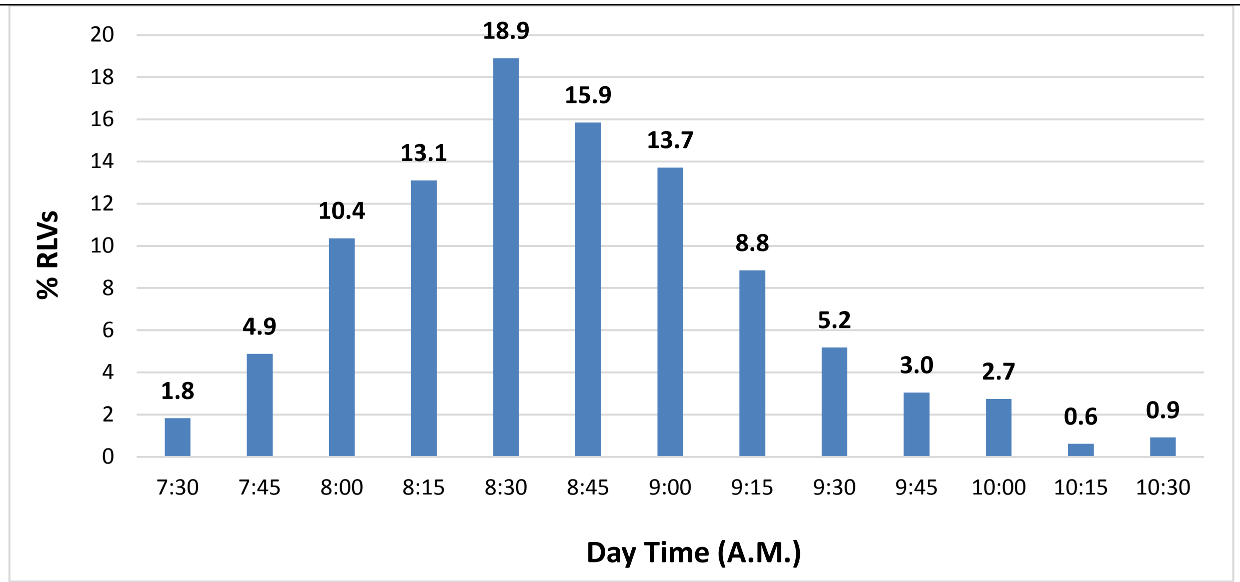

Figure (3-2): Distribution of Red Light Violations by Day Time.

3.2.3 Type of the Vehicle Driven by the Red Light Violator

About 95.43 percent of the total of 328 recorded red light violations are passenger cars (private and taxi). The percentage of red light violations per vehicle type are shown in Figure (3-3).

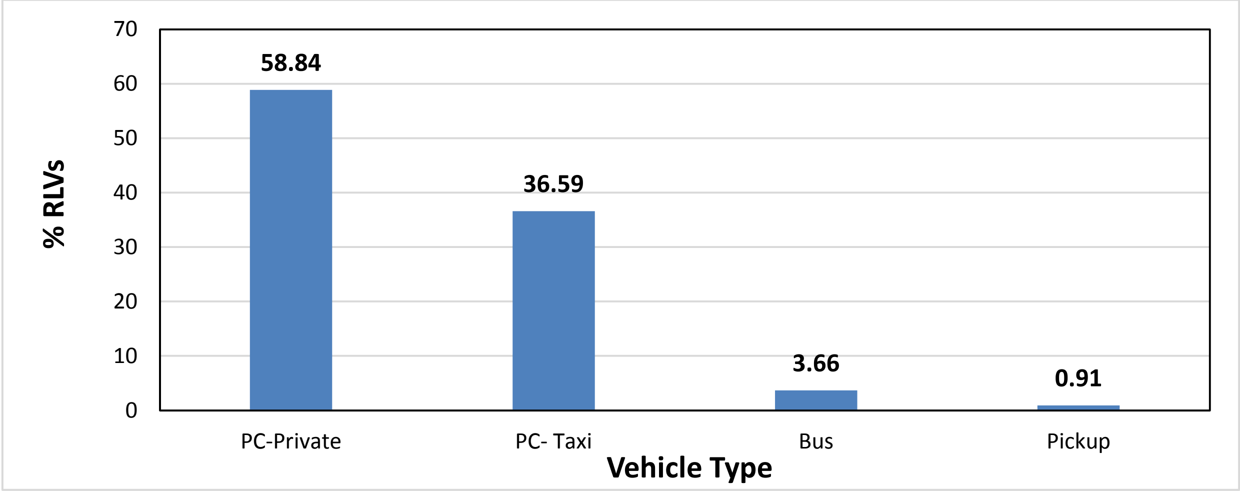

Figure (3-3): Distribution of RLV Records by Vehicle Type

3.2.4 Distribution of Driver Responses during All Red Interval

Red light violators are separated into the following three groups:

1- Violating during all red and stopping
2- Violating during all red and not stopping
3- Violating after all red and not stopping.

Using these categories, Figure (3-4) shows the percentages of violation records from collected data for the studied intersections in Erbil city.

Fewer violating drivers tended to stop (approximately 17.38%) after onset of the red signal as compared to the non stopping drivers. Most of the RLVs (76.22%) crossed the stop line during the all red intervals and not stopped. 6.4% of drivers entered the intersection after the end of all red light interval and not stopped.

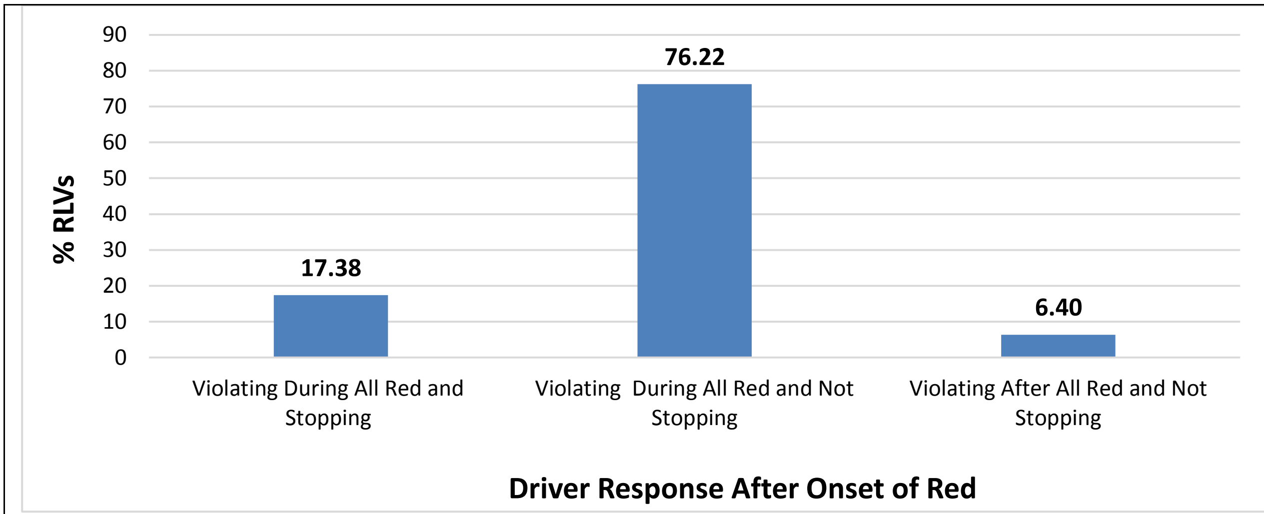

Figure (3-4): Distribution of Driver Responses After the Onset of All Red Light.

3.2.5 Violating Vehicle Elapsed Time and Operating Speed

The percentage of RLVs by time elapsed from the start of red light are provided in Figure (3-5). The average value is 2.1 seconds with a standard deviation of 1.0 seconds. About 51.0 % of the violations occurred during 2.0 seconds of the start of red light, while over 95.0 % of the violations occurred during 4.0 seconds.

Also, the operating speed of the violating vehicle is measured at each intersection at start of red phase (termination of yellow phase) for violating vehicles. The percentage of red violating vehicle speeds at the time of red light violation is shown in Figure (3-6).

The average speed or the red light violator is 34.95 kph. The most occurring vehicle speed at the time of violation is 32.14 kph (the modal speed). While, 50% of the violating drivers ran the red light at speeds of 34.07 kph or less (the median speed). This difference may be due to the fact that the data is not normally distributed.

The speeding of violating vehicles is examined by comparing their speeds to the corresponding posted speed limits (PSLs) at each signalized intersection approach. Figure (3-6) present the distribution of red light violation records for non speeding vehicles (violation speed ≤ PSL) and speeding vehicles (violation speed > PSL) for the six studied intersections.

By examining the results presented in Figure (3-7), it can be noted that for all studied signalized intersections, between 8.0 – 26 % of violating vehicles ran the red light at speeds ≤ PSL, while between 74.0 – 92.0 % of violating vehicles ran the red light at speeds > PSL. The high traffic volumes at these intersections as shown in Table (2-2), is the probable cause.

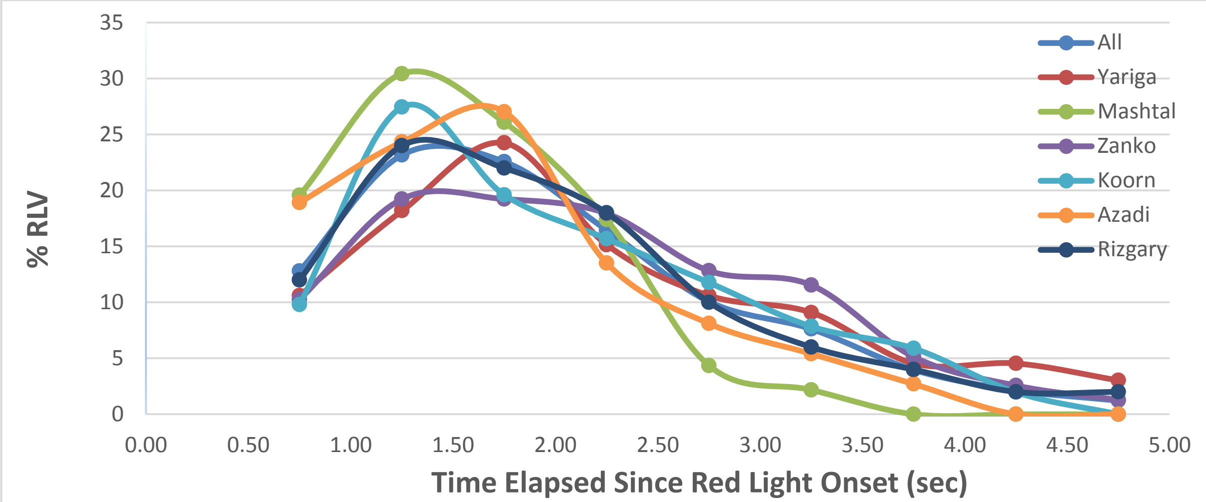

Figure (3-5): Distribution of Violation Records by Elapsed Time Since Red Light Onset

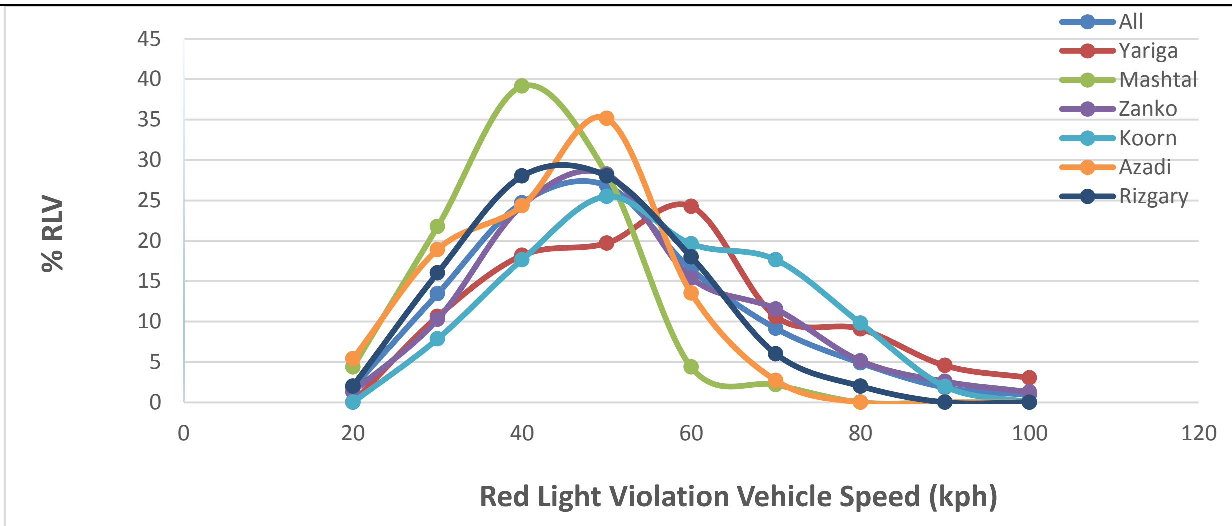

Figure (3-6): Distribution of Red Light Violation Records by Vehicle Speed Since Red Light Onset

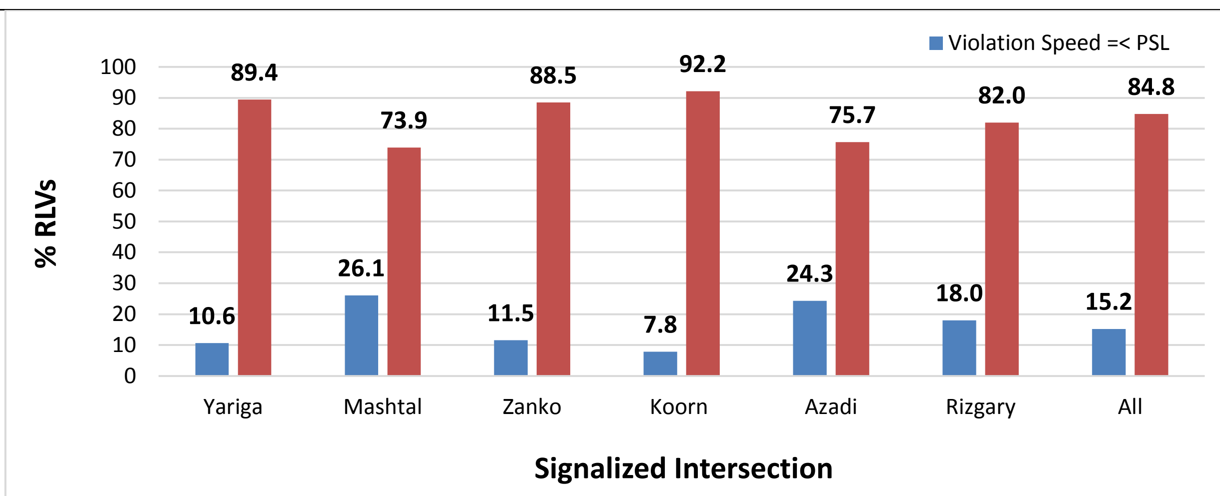

Figure (3-7): % RLV by Violating Vehicle Speed in Comparison to the Posted Speed limit.

Table (3-2): Number of RLV by Traffic Volume.					
Signalized Intersection Name	Signalized Intersection Code	Bound	Hourly volume vph	Total Observations per 3 Hours	
				Vehicles	RLV
Yariga	1	EB	820	2460	9
		SB	900	2700	18
		WB	820	2460	12
		NB	1440	4320	27
		Intersection	**3980**	**11940**	**66**
Mashtal	2	EB	780	2340	4
		SB	610	1830	15
		WB	140	420	10
		NB	150	450	17
		Intersection	**1680**	**5040**	**46**
Zanko	3	EB	780	2340	-13
		SB	1200	3600	18
		WB	960	2880	32
		2NB	1500	4500	15
		3Intersection	**4440**	**13320**	**78**
Kooran	4	EB	578	1734	8
		WB	300	900	21
		NB	516	1548	22
		Intersection	**1394**	**4182**	**51**
Azadi	5	EB	900	2700	6
		SB	1200	3600	12
		WB	600	1800	9
		NB	840	2520	10
		Intersection	**3540**	**10620**	**37**
Rizgary	6	EB	750	2250	2
		SB	960	2880	19
		WB	705	2115	23
		NB	900	2700	6
		Intersection	**3315**	**9945**	**50**
	All		**18349**	**55047**	**328**

3.2.6 Traffic Volume

During the data collection period, traffic volume is monitored and determined with the red light violators data as shown in Table (3-2). As it appears from Table (3-2), the number of RLVs are high at low and high traffic volumes but they are low for medium traffic volumes. The possible reason may be that the drivers are running the red at low volumes due to the presence of low numbers of vehicles and there is low number of conflicts. While, at high volumes the reason may be due to the high delay values which encourage the drivers to ran the red light.

3.2.7 Intersection Control Delay

During the data collection period, the required data for intersection control delay (following the HCM method) is collected and then its value is estimated, as shown in Table (3-3). It appears that there is a clear relationship between the number of RLVs and the intersection control delay value. The drivers red light violation increases as the control delay value increases and it decreases as the control delay decreases.

3.2.8 Type of Vehicle Maneuver

The majority of observed RLVs (56.3%), are straight ahead (through), followed by left turn violating vehicles (43.7%). The right turn on red (RTOR) are allowed in all studied signalized intersections. Generally, left turn traffic maneuver RLVs are higher than straight through at Yariga, Kooran, Azadi and Rizgary signalized intersections. While, at Mashtal and Zanko signalized intersections straight going drivers have a higher tendency to be red light violator than left turns because these two signalized intersections are at grade and the straight through maneuver is not grade separated. But at Kooran t-signalized intersection the higher left turn maneuver RLVs may be due to that this intersection is an at-grade t-signalized intersection with heavy left turn traffic volume. The heavy left turn traffic volume may be also the reason for the higher left turn maneuver RLVs at Azadi signalized intersection. The results are displayed in Table (3-4).

Table (3-3): % RLVs by Intersection Control Delay and the Red-Violator

Signalized Intersection Name	Signalized Intersection Code	Bound	Hourly volume vph	Total Observations per 3 Hours		Total Cycles per 3 Hours	RLV/10000 veh-Cycle	Delay sec/veh
				Vehicles	RLV			
Yariga	1	EB	820	2460	9	40	0.91	16.4
		SB	900	2700	18	40	1.67	10.8
		WB	820	2460	12	40	1.22	9.6
		NB	1440	4320	27	40	1.56	14.2
		Intersection	**3980**	**11940**	**66**	**160**	**0.35**	**12.94**
Mashtal	2	EB	780	2340	4	50	0.34	10.7
		SB	610	1830	15	50	1.64	13.4
		WB	140	420	10	50	4.76	9.3
		NB	150	450	17	50	7.56	18.4
		Intersection	**1680**	**5040**	**46**	**200**	**0.46**	**12.25**
Zanko	3	EB	780	2340	13	50	1.11	17.9
		SB	1200	3600	18	50	1.00	15.1
		WB	960	2880	32	50	2.22	27.5
		NB	1500	4500	15	50	0.67	13.3
		Intersection	**4440**	**13320**	**78**	**200**	**0.29**	**17.66**
Kooran	4	EB	578	1734	8	50	0.92	13.2
		SB						
		WB	300	900	21	50	4.67	9.6
		NB	516	1548	22	50	2.84	15.1
		Intersection	**1394**	**4182**	**51**	**150**	**0.81**	**13.13**
Azadi	5	EB	900	2700	6	50	0.44	18.7
		SB	1200	3600	12	50	0.67	15.1
		WB	600	1800	9	50	1.00	17.5
		NB	840	2520	10	50	0.79	12.0
		Intersection	**3540**	**10620**	**37**	**200**	**0.17**	**15.69**
Rizgary	6	EB	750	2250	2	50	0.18	16.4
		SB	960	2880	19	50	1.32	10.8
		WB	705	2115	23	50	2.17	9.6
		NB	900	2700	6	50	0.44	14.2
		Intersection	**3315**	**9945**	**50**	**200**	**0.25**	**12.73**
All			**18349**	**55047**	**328**	**1110**	**2.33**	

Table (3-4): % RLV by Type of Vehicle Maneuver				
Signalized Intersection Name	Signalized Intersection Code	Total Violation Count	Left Turn %	Straight %
Yariga	1	66	62.6	37.4
Mashtal	2	46	32.1	67.9
Zanko	3	78	47.2	52.8
Koorn	4	51	75.0	25.0
Azadi	5	37	53.4	46.6
Rizgary	6	50	67.7	32.3
All		**328**	**56.3**	**43.7**

3.3 Statistical Modeling of Red Light Violation Data

3.3.1 Simple regression analysis

The fourth-degree polynomial model is an acceptable relationship between the percentage RLVs and elapsed time since red light onset. The maximum percentage of RLVs are at 1.5 sec elapsed time with a coefficient of determination R^2 = 0.9931 as shown in Figure (3-8).

While, the third-degree polynomial model is the most suitable relationship between the RLVs and violating vehicle speed since red light onset with maximum percentage of RLVs value at 48 kph and a coefficient of determination R^2 = 0.9519 as shown in Figure (3-9).

The relationship between observed RLVs and signalized intersection traffic volume counts are shown in Figure (3-10). It appears that there is a second-degree polynomial relationship, where the number of RLVs are high at low volumes then decreases (negative relationship) till the medium volumes, then increases (positive relationship) at high volumes. As mentioned earlier, this trend may be due to that the drivers are running the red at low volumes due to the presence of low numbers of vehicles. While, at high volumes they ran the red due to the high delay values as mentioned before.

The relationship between observed RLVs and signalized intersection control delay also investigated as shown in Figure (3-11). It appears that there is a positive second-degree polynomial relationship between them. The number of RLVs are increases at high delays.

Finally, the relationship between the observed approach speed and RLVs is modeled as shown in Figure (3-12). The third-degree polynomial model is the suitable relationship between these two variables with maximum RLVs value at 35 kph and a coefficient of determination R^2 = 0.773.

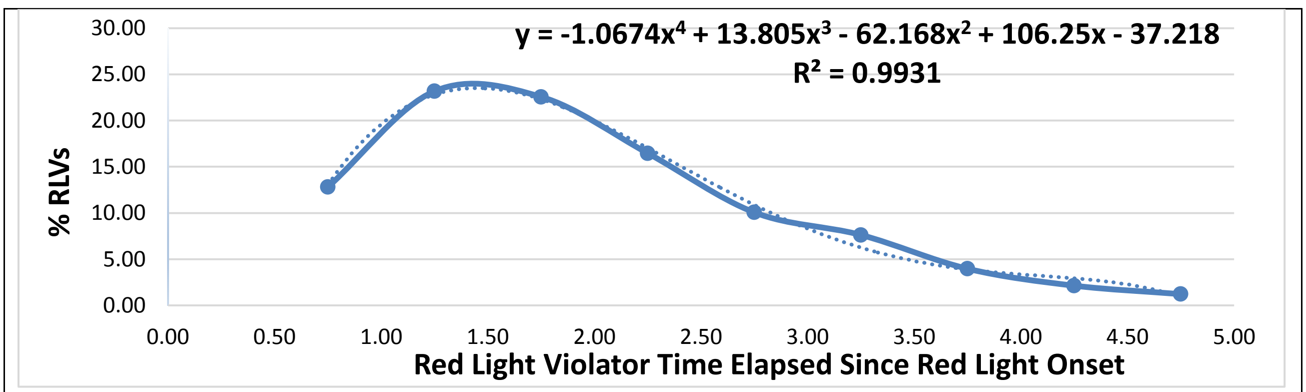

Figure (3-8): % RLVs by Elapsed Time Since Red Light Onset for All Intersections

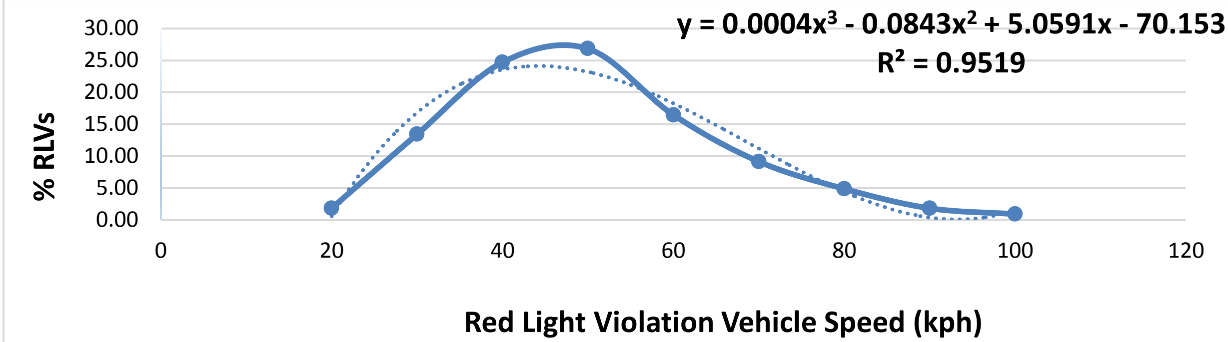

Figure (3-9): % RLVs by Violating Vehicle Speed Since Red Light Onset

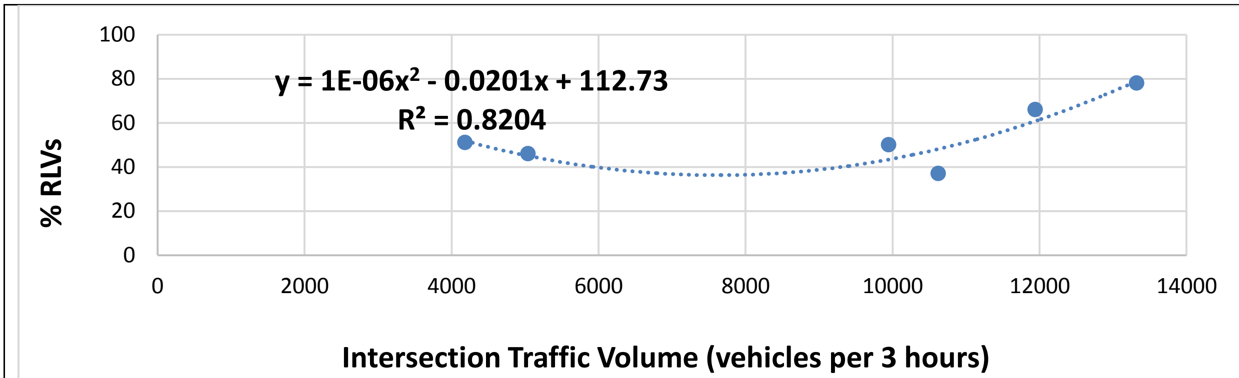

Figure (3-10): Number of RLV by Intersection Traffic Volume.

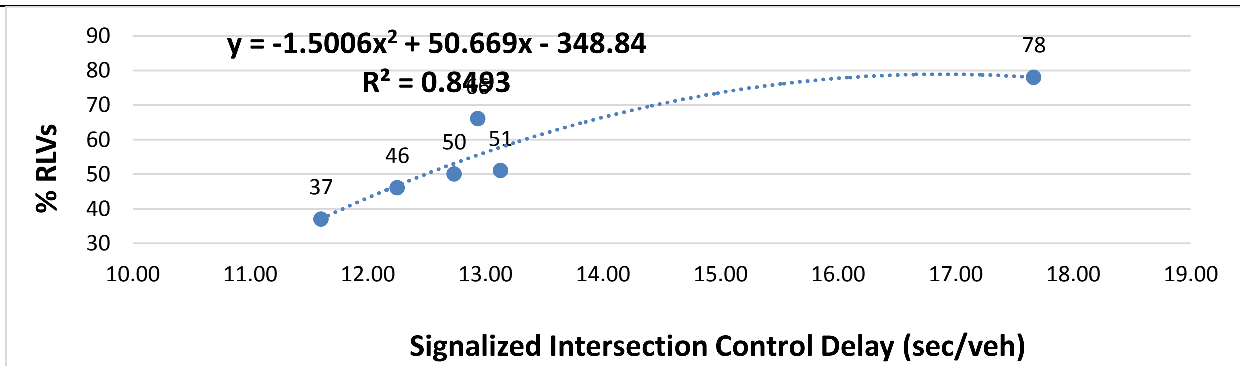

Figure (3-11): % RLVs by Signalized Intersection Control Delay

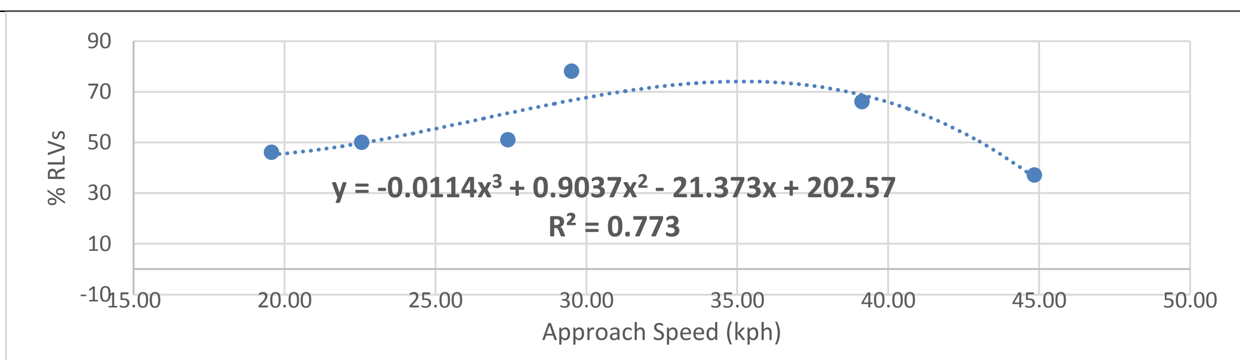

Figure (3-12): RLVs and the Approach Speed

4. CONCLUSIONS

The results of this study can be used in understanding and solving the red light violation problem within the studied area. The results obtained in this study are highlighted below:

1- The RLV rates obtained are low with respect to those reported in other studies. These rates for the 6 studied intersections ranged from 0.58 to 1.52 per 10,000 vehicles-cycle.
2- The average aged male and female drivers are more probable to be RLV. In addition, the male drivers have higher tendency to be RLV than female drivers.
3- Most violating drivers at Zanko and Mashtal intersections are young because they are near the college town. Therefore, driver type is important for studying driver behavior during light change.
4- Most of the red light violations occurred during the peak hour (8:00 a.m. to 9:00 a.m.) when the traffic volume is high.
5- About 95.43 % of the red light violation records are passenger cars (private and taxi).
6- Approximately 17.38% of violating drivers stopped after the onset of red light. While, 76.22% of RLVs crossed the stop line during the all red intervals and not stopped, and only 6.4% of RLVs entered the intersection after the onset of all red light and not stopped.
7- The average value of violations by time elapsed from the start of red light is 2.1 seconds with a standard deviation of 1.0 seconds. About 51.0 % of the violations occurred within 2.0 seconds of its onset, while more than 95.0 % of violations occurred during 4.0 seconds. Violating drivers at Mashtal signalized intersection entered within the first second of the red interval meaning less risk.
8- The mean speed of the RLV vehicle is 34.95 kph. While, the most occurring vehicle speed at the time of violation is 32.14 kph. 50% of the drivers ran the red light at speeds of 34.07 kph or less.
9- For all studied signalized intersections, 8.0 – 26 % of violating vehicles ran the red light at speeds ≤ PSL, while 74.0 – 92.0 % of violating vehicles ran the red light at speeds > PSL.
10- The number of RLVs are high at low and high traffic volumes but they are low for medium traffic volumes.
11- The red light violation increases as the signalized intersection control delay value increases and it decreases as the control delay decreases.
12- Nearly, 56.3% of red light violators are straight ahead, followed by left turn vehicles (43.7%).
13- The most significant relationship between the RLVs and elapsed time since red light onset is the fourth-degree polynomial model with a coefficient of determination R2 = 0.9931, with vehicle speed since red light onset is the third-degree polynomial model with a coefficient of determination R2 = 0.9519, with the signalized intersection traffic volume counts is the second-degree polynomial, with the signalized intersection control delay is the positive second-degree polynomial with a coefficient of determination R2 = 0.8493 and with the observed mean approach speed is the third-degree polynomial model with a coefficient of determination R2 = 0.773.

5. RECOMMENDATIONS

According to the results of this study, the following recommendations may be followed:

1- Investigating the possible effect of different signalized intersection traffic and geometric characteristics on RLVs is highly recommended.
2- Studding the effect of countdown green and yellow on RLV rates. The continuous green mode could induce more conservative maneuvers, while countdown yellow and green mode could cause more aggressive driving behaviors.
3- The results of this study may be used by Erbil traffic engineers and legislators to design the cycle times with more appropriate all-red and yellow intervals and upgrade the traffic light face itself to be more visible.
4- Lowering the signalized intersection delay is recommended by using intelligent transportation system (ITS) applications.

5- Installing red light cameras and increasing the police surveillance at signalized intersections would be effective in reducing RLvs. In addition, public awareness and law enforcement measurements are two main factors.

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