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Red Light Running Violations of Four Intersections in Colombo Suburban

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Abstract: Four signalized intersections were selected which located in Colombo suburban, Battaramulla, Pelawatte, Thalawthugoda and Denzil kobbekaduwa. The observational survey was conducted for both peak and off-peak hours. Totally, 118,837 vehicles were observed and categorized them into three types; motor vehicles, motorcycles, and three wheelers. The Red Light Running (RLR) violation rate was 0.94% for motor vehicles, 2.44% for motorcycles, and 1.33% for three wheelers. The rate for motorcyclists was high in off-peak hours than peak hours. The RLR violation rate of motor vehicle drivers is lower than those for motorcyclists. The observed drivers were classified into two age groups: young and adult and more RLR violation rate was observed by young drivers than adults. Young drivers were found to be more likely to have risk-taking and adult drivers were found to be more likely to have opportunistic behaviors.

Keywords: Red Light Running; Traffic Rule Violations; Traffic Safety; Signalized intersection

1. INTRODUCTION

Road traffic violation is a serious safety problem at all signalized intersections across the world (Yan, et al, 2016). These careless and thoughtless behaviors are the responsible for a notable number of intersection crashes and have resulted in considerable numbers of serious injuries and significant property damages (Yan, et al, 2016). At authors' knowledge there are not published studies about RLR violation in Sri Lanka through RLR violation rates are reported many other countries. The RLR violation rates between the countries may be different due to variances in motorization, safety culture, and road traffic management.

According to the traffic safety law of the Sri Lanka the motor vehicles, non-motor vehicles, and pedestrians should stop the driving or walking in front of red traffic lights (DMT, 2009). Thus, all vehicles were crossed the intersection against the red light called as RLR violations. If a vehicle enters an intersection any time after the signal light has turned red, the driver has committed a RLR violation. Violations also include people turning left on red at intersections where doing so is prohibited. The RLR violations by type of road users have also not been reported in Sri Lanka so far. Traffic violations are one of main risk factors of road traffic deaths. However, RLR violation is a common traffic violation in Sri Lanka.

2. LITERATURE REVIEW

Yan et al. (2016) studied on RLR violations at five intersections by road user category in Changsha, China. The objective of this research was to estimate the RLR violation rate by

type of road users and to investigate the reporting of the violation rate in Changsha. An observational study was conducted to estimate the RLR of different road users and to examine differences in rates from type of day and time period by road users. RLR was calculated as number of violations divided by total number of vehicles/pedestrians multiplied by 100. Portable digital cameras and smart phones with high definition camera were used to record a traffic flow at given dates and time period. The reported RLR violations rate for motor vehicle drivers was 0.14%, far lowering than those for motorcyclists (18.64%), bicyclists (18.74%) and pedestrians (18.54%). The rate on holiday was 1.89 times that on weekday for drivers. The rate for motorcyclists was high in off-peak hours, but low on weekend and on holiday. The rate for bicyclists was 32% lower on weekend than on weekday. For pedestrians, the rates were high on weekend and holiday and in off-peak hours. The rates of RLR violations were much higher for motorcyclists, bicyclists, and pedestrians than for motor vehicle drivers in Changsha, China. The effects of type of day and time period on RLR violations were varying with the type of road users.

Zhang et al. (2016) introduced the concept of critical distance combining with the start and end of red light for RLR violation study. Unintentional RLR violations at red onset and RLR violations at red end were identified the critical distances were calculated based on the observation data. They were analyzed the characteristics of every type by classifying the type of RLR violations. They were extracted moment of turning to yellow light, distance between target car to stop line on the yellow onset, distance between rear wheel of target car to upstream recent reference line on yellow, vehicle type, time headway, moment of braking lights turning on, and the number of RLR violations at red end. Video observation and statistics found that, majority of red light runners at red start are deliberate (63.3%), while the unintentional red light violators also share some proportion (36.7%). The video surveillance also showed that drivers would run a red light at red end but considerably less than the number of running a red light at red onset. It was found that Countdown timer reduces RLR violations at red onset, but the green flash device produces the opposite effect. Red light camera increases unintentional RLR violations at red onset but has no significant effect on deliberate behavior. Raising speed limit has no significant effect both on deliberate and unintentional RLR violations at red light. Running a red light at the red end will be decreased considerably under red light camera and green flash device conditions. But the higher speed limit and countdown timer will produce the opposite effect.

The cyclists' RLR violation behaviors in the United States (US) were studied by Pai and Jou (2014). The objective of this study was to observe the bicyclists RLR violations by considering the crossing behaviors into three distinct comportment: risk-taking, opportunistic, and law-obeying. This mixed logit model of bicyclists' three different crossing behaviors were developed. Several factors were found to considerably increase the possibility of bicyclists' risky behaviors, most notably: intersections with short red-light duration, T/Y intersections, when riders were pupils in uniform, when riders were riding electric bicycles, and when riders were without helmet. The risk-taking bicyclists were those who would ignore the red light and travel through the junction without stopping (but may slow down). The opportunistic ones those who would formerly wait at red lights but would be too eager to wait for red lights to become green and afterward cross the junction by looking for gaps among crossing traffic and the law-obeying bicyclists are those who would stop by obeying the red light. Off-peak hours were related with an increase in the possibility of risk-taking behaviors. It was found that when pupils in uniform crossed the streets during peak hours, they were almost to commit risk-taking and opportunistic behaviors. The result could be logical by a pupil having to get to the school on time during peak hours. Electric bicycles were more likely than those of usual bikes to have risky behaviors. Pupils were in uniform and two risky behaviors. The results

indicated that about half the population of pupils in uniform, the probability of two risky behaviors was higher than for the other age groups, and for the other half the probability was lower. Bicyclists' affinity to commit risk taking and opportunistic behaviors was higher at T/Y junctions; and when they were riding unhelmeted.

Ren et al. (2016) were in a study to find the prominent factors of RLR in China. The objective of this research was to study the influential factors of RLR violations at signalized intersections and prediction using a rare events logistic regression model. For this a large amount of high-resolution traffic and signal data were collected from loop detectors to extract 9-month's RLR events from three signalized intersections, and then identified the effective factors that considerably influence RLR behaviors. Loop detector data were simply and mechanically collected in real time with low cost for the purpose of signal operations, using loop detector data to help analysis and prevent RLR becomes very eye-catching. The proposed deterioration models were based on the association between drivers' behaviors and impact factors including velocity, time gaps. This research was addressed the rare events issue of RLR by developing a rare events binary logistic deterioration model. The results showed that rare events logistic regression model performs significantly better than standard logistic regression model.

The key factors that affect RLR was studied in the US by Wang et al. (2016). The key factors that affect RLR and the contributing factors were compared between US and China. Data were collected through field observations and video recordings. Four intersections in Shanghai were selected as the study sites. Data of RLR drivers and comparison drivers who did not run the red lights were collected at four intersections in the urban area of Shanghai. Driver's genders, safety belt use, hand-held cell phone use, and presence of passengers were manually recorded by observers at each intersection. Driver's vehicle operations as they approached and traveled through the intersections were recorded by video cameras. Preliminary analyses were firstly conducted to identify the features of the RLR and comparison groups. It was determined that around 57 percentage of RLR crossed the stop line during the 0–0.4 second time interval after red-light onset and the numbers of red light violators decreased as the time increased among the RLR vehicles, 38 percentage turned left and 62 percentage went straight and at the onset of red about percentage of RLR vehicles were in the middle of a vehicle platoon. Modeling results concurred with the preliminary analysis in-states drivers, male drivers and passenger vehicles were more likely to run red lights. Modeling results also showed that an increase in traffic volume increased the likelihood of RLR. A comparison of these results with similar studies in the US shows consistency, which indicated that the influencing factors of RLR were similar, despite the different jurisdictions and driving behaviors. This study found that the random effects logistic regression model was capable of analyzing RLR behavior while considering the heterogeneity between intersections.

To determine a fine structure in RLR violations, a research was conducted in Malaysia (Baratian-Ghorghi et al, 2016). The objective of this study was to develop a novel fine structure for RLR traffic violations based upon the estimated economic impact of potential crashes by RLR violations and estimated delays caused by providing all-red intervals to prevent potential conflicts. A physical model was developed to determine the crash probability at a discrete time after the traffic signal turns red. According to their graph, no cost was assigned to the time between onsets of all red to 2.9 seconds after because the probability of a crash at this interval is zero. A $196 fine was computed as the greatest amount for drivers who intentionally ran the red signal after 7.5 seconds. Traffic simulation models were used to predict the presence of vehicles at the intersection and a physical model was developed to determine a crash probability for a violator entering an intersection at a discrete time after the

traffic signal changes to red. The results indicated that the intersection remains safe during the all-red time and up to 1.4 seconds after the termination of this interval. In the next step, The Highway Capacity Manual (HCM) was also employed to estimate the delay incurred by road users. The study then suggested the methods to enable decision-makers to consider total costs to devise an appropriate fine structure including crash costs and road user delay costs associated with providing all-red time.

Bhosale et al. (2017) done a research on RLR violations at saturated intersections in the city of Mumbai, India, where the traffic is highly heterogeneous. When considered all vehicles, almost one in seventeen drivers were seen to be jumping red signals. Unlike the RLR behaviour that had been reported from intersections elsewhere, a peculiarity observed here is RLR were within a single red phase. Two distinguishable segments of RLR behavior were studied. They were classified into two regimes: Regime 1, just after the onset of red and Regime 2, just before the onset of next green. Around one-third of RLR events occur in Regime 1, and the rest in Regime 2. Different distributions on the time distribution of RLR events were fitted. The Kolmogorov-Smirnov (K-S) test suggested that exponential distribution fits best for RLR behaviours in Regime 1, and extreme value distribution fits best for Regime 2. In addition to these two regimes, a lower rate of RLR was observed in the time period between these regimes, and normal distribution was the best for this duration. Causal factors were analyzed of RLR behaviour in the two regimes, model were developed at a microscopic level, specific to vehicle-class and regime. While 'red to green ratio' and 'presence of policing' proved to be affecting RLR in both the regimes, 'relative time for conflict area is free' affected RLR in Regime 2, but not in Regime 1.

3. DATA AND METHODOLOGY

An observational study was done to record the RLR violation rate of different road users at signalized intersections at Colombo suburban. With a view to achieve the aim of this study, four signalized intersections with approximately similar traffic volume were selected. Figure 1 shows Battaramulla intersection, Denzil kobbekaduwa intersection, Pelawatte intersection and Thalawathukoda intersection along the B47 roadway which were the selected intersections for this study.

Figure 1. The selected intersection at B47 roadway

Characteristics of four selected intersection are summarized in Table 1. Battaramulla intersection is a T-intersection where as others are cross intersections.

Table 1. Characteristics of intersections

Characteristics	Battaramulla	Denzil Kobbekaduwa	Pelawatte	Thalawathugoda
Countdown timer	Yes	No	Yes	Yes
Type of Intersection	T-Intersection	Cross Intersection	Cross Intersection	Cross Intersection

Battaramulla intersection is a three-arm signalized intersection formed by meeting Pannipitiya road (B047) and Cotte road (B240). Figure 2 shows the arm distribution of Battaramulla intersection. Pannipitiya (B047) roadway has two approaching lanes whereas Cotte road (B240) has three approaching lanes in both directions. All the legs in the intersection are separated by center-medians. The right turns from Koswatta direction and Palawatthe direction are always flashing yellow allowing vehicles to move by yielding pedestrians. Table 2 explains characteristics of Battaramulla intersection.

Figure 2. Arm Distribution of the Battaramulla intersection

Table 1. Characteristics of Battaramulla intersection

Characteristics of road		Koswatta leg (B240)			Rajagiriya leg (B240)			Pelawatte leg (B047)		
Number of approaching lanes		3 (Including left turn lane)			3 (Including right turn lane)			2 (Including right and left turn lane)		
Width of lanes (mm)		Straight	Straight	Left turn	Straight	Straight	Right turn	Right turn	Left turn	
		3,200	3,600	5,600	2,950	3,050	2,700	3,980	6100	
		12,400			8,700			10,080		
Hourly number of vehicles		Motor Vehicles	Motor cycles	Three wheelers	Motor Vehicles	Motor cycles	Three wheelers	Motor Vehicles	Motor cycles	Three wheelers
		559	255	267	550	181	207	428	113	181
Pedestrian cross width (mm)		2,500			2,500			2,450		
Green light time(s)		Straight			Straight		Right turn	Right turn		
	Morning (off-peak)	75			77		27	20		
	Evening (peak)	33			88		50	20		

Denzil Kobbekaduwa intersection is a four arms signalized intersection formed by meeting Denzil Kobbekaduwa road (The Parliament to Koswatte) and Pannipitiya road (B047). Figure 3 shows the arm distribution of Denzil Kobbekaduwa intersections. Denzil Kobbekaduwa road has three approaching lanes including dedicated left-turn lane and right-turn lane. Pannipitiya road at Denizil Kobbekaduwa intersections have four approaching lanes including dedicated left-turn lane and right-turn lane. The left-turning movements in all the legs at intersections have the flashing yellow indicating vehicles to move by yielding pedestrians. Table 3 gives characteristics of Denzil Kobbekaduwa intersection. The signal times in all the intersection are fixed but varying with the time of the day. The data collection was done in morning off-peak hours and evening peak hours and the green times during the data collection are given in the Table. During the data collection the cycle time did not change.

Figure 3. Arm distribution of Denzil Kobbekaduwa intersection

Table 3. Characteristics of Denzil Kobbekaduwa Intersection

Characteristics of road		Batharamulla leg (B47)				Parliment leg			Pelawatte leg (B47)				Koswatta leg		
Number of approaching lanes		4 (Including right and left turn lane)				3(Including right and left turn lane)			4(Including right and left turn lane)				3(Including right and left turn lane)		
Width of lanes (mm)		Left turn	Straight	Straight	Right turn	Left turn	Straight	Right turn	Left turn	Straight	Straight	Right turn	Left turn	Straight	Right turn
		6,600	3,100	3,200	3,200	6,200	3,100	3,200	6,100	3,400	3,200	2,950	6,000	2,750	3,200
		16,100				12,500			15,650				11,950		
Hourly number of vehicles		Motor Vehicles	Motor cycles	Three wheelers		Motor vehicles	Motor cycles	Three wheelers	Motor Vehicles	Motor cycles	Three wheelers		Motor Vehicles	Motor cycles	Three wheelers
		375	203	217		581	225	212	379	198	229		501	244	253
Pedestrian cross width (mm)		2,500				2,500			2,600				2,450		
Green light time (s)		Straight		Right turn		Straight		Right turn	Straight		Right turn		Straight		Right turn
	Morning (off-peak)	30		30		60		15	45		30		70		40
	Evening (peak)	41		21		67		13	51		30		72		25

Pelawatte intersection is also a four arms signalized intersection formed by meeting Pannipitiya road (B047) and the Parliament road. Figure 4 shows the arm distribution of Pelawatte junction. The Parliament road from Parliament direction has three approaching

lanes including dedicated left-turn lane and right-turn lane. From DB Wijesingha leg has two lanes. Pannipitiya road at Palawatte intersections have four approaching lanes including dedicated left-turn lane and right-turn lane. The left-turning movements in all the legs at intersections have the flashing yellow indicating vehicles to move yielding pedestrians. Table 4 explains characteristics of Pelawatte intersection.

Figure 4 Arm distribution of Pelawatte intersection

Table 4 characteristics of Pelawatte intersection

Characteristics of road		batharamulla leg (B47)				parliment leg (B533)			Thalawathugoda leg (B47)				DB wijayasingha leg	
Number of approaching lanes		4(Including right and left turn lane)				3(Including right and left turn lane)			4 (Including right and left turn lane)				2(Including right and left turn lane)	
Width of lanes (mm)		Left turn	Straight	Straight	Right turn	Left turn	Straight	Right turn	Left turn	Straight	Straight	Right turn	Left turn	Right turn
		6,100	2,800	3,000	2,800	3,100	3,100	2,800	5,800	2,900	3,000	3,000	3,600	3,200
		14,700				9,000			14,700				6,800	
Hourly number of vehicles		Motor vehicles	Motor cycles	Three wheelers		Motor vehicles	Motor cycles	Three wheelers	Motor vehicles	Motor cycles	Three wheelers		Motor vehicles	Motor cycles	Three wheelers
		686	234	267		529	218	244	670	187	238		427	193	220
Pedestrian cross width(mm)		2,900				3,000			2,900				3,000		
Green light time		Straight		Right turn		Straight		Right turn	Straight		Right turn		Straight	Right turn
	Morning (off-peak)	25		15		23		23	30		12		20	20
	Evening (peak)	45		12		30		30	47		12		30	30

Thalawathugoda intersection is also a four arms signalized intersection formed by meeting Pannipitiya road (B047) and Hokandara road (B368). Figure 5 shows the arm distribution of Thalawathugoda junction.

Figure 5 The Arm distribution of Thalawathugoda intersection

Hokandara (B368) road has three approaching lanes including dedicated left-turn lane and right-turn lane in both directions. Pannipitiya road at Thalawathugoda intersections have four approaching lanes including dedicated left-turn lane and right-turn lane. The left-turning movements in all the legs at intersections have the flashing yellow indicating vehicles to move yielding pedestrians. Table 5 further gives the characteristics of Thalawathugoda intersection.

Table 5. Characteristics of Thalawathugoda intersection

Characteristics of road		Batharamulla leg (B47)				Athulkotte leg (B368)			Pannipitiya leg (B47)				Hokandara leg (B368)		
Number of approaching lanes		4(Including right and left turn lane)				3(Including right and left turn lane)			4(Including right and left turn lane)				3(Including right and left turn lane)		
Width of lanes (mm)		Left turn	Straight	Straight	Right turn	Left turn	Straight	Right turn	Left turn	Straight	Straight	Right turn	Left turn	Straight	Right turn
		6,150	3,000	3,150	2,800	6,050	2,900	3,100	7,300	3,150	3,050	3,350	5,000	3,050	3,600
		15,100				12,050			16,850				11,650		
Hourly number of vehicles		Motor Vehicles	Motor cycles	Three wheelers		Motor Vehicles	Motor cycles	Three wheelers	Motor vehicles	Motor cycles	Three wheelers		Motor vehicles	Motor cycles	Three wheelers
		762	313	303		627	226	229	552	211	241		461	238	248
Pedestrian cross width(mm)		2,550				2,500			2,550				2,600		
Green light time		Straight		Right turn		Straight		Right turn	Straight		Right turn		Straight		Right turn
	Morning (off-peak)	75		40		52		46	58		20		45		40
	Evening (peak)	93		40		90		90	69		18		55		40

This study collected vehicle counts, RLV counts at selected intersections for three vehicle types; motor-cycle, three-wheeler, and car. These data were collected both in peak hours and off-peak hours of weekends during month of August in 2017. For each selected day, observations were conducted in two time periods morning off-peak hours and evening peak hours in each with 2 hours. The data collection was done in two days resulting the traffic flows of 8 hours at each intersections. The other geometric and traffic related information of four intersections were also collected, including length of green light time, width of the road and pedestrian cross width. The field observations were performed with help of eight undergraduate students.

Violation rate of motor vehicle driver, motorcyclist and three wheelers were estimated dividing the number of violation by number of total vehicles of each type as taking as a

percentage. For example, total number of motorcycle RLR violations were divided by total number of motorcycles passes the intersection during the same period and express as a percentage as motorcycle RLR rates.

4. RESULTS AND DISCUSSION

The total approaching vehicles of the selected signalized intersections are presented in Table 6. The traffic count covered motorcycles, three-wheelers, motor vehicles. The motor vehicles include all motorized vehicles such as cars, vans, buses, goods transport, and trucks. In total, 118,837 vehicles, including 64,597 motor vehicles, 24,447 motorcycles and 28,386 three wheelers passed through the all four intersection during the time duration of data collection. The RLR violation rates of each intersection were calculated dividing the number of violations by the observed total number of vehicles of each type for each intersection during the data collection period.

Table 6 Approaching Traffic of the Each

Intersection	Types of vehicles	Number of vehicles (All four direction)				Total Traffic (8hr)
		Day-01 Morning 10.00-12.00 Off-peak	Day -02 Morning 10.00-12.00 Off-peak	Day-01 Evening 15.30-17.30 Peak	Day-02 Evening 15.30-17.30 Peak	
Thalawathugoda junction	Motor vehicles	5,357	4,903	4,352	4,561	
	Motorcycles	2,104	2,353	1,644	1,787	
	Three wheelers	2,063	2,280	1,800	1,996	35,200
Denzil Kobbekaduwa junction	Motor vehicles	4,582	3,302	3,486	3,298	
	Motorcycles	2,262	1,443	1,563	1,682	
	Three wheelers	2,500	1,571	1,509	1,697	28,895
Battaramulla junction	Motor vehicles	3,802	3,756	2,516	2,197	
	Motorcycles	1,434	1,154	961	828	
	Three wheelers	1,638	1,650	1,048	896	21,880
Pelawatte junction	Motor vehicles	5,301	5,535	3,813	3,836	
	Motorcycles	2,183	1,711	1,364	1,381	
	Three wheelers	2,438	2,258	1,523	1,519	32,862

4.1 Battaramulla Intersection

The RLV rates as a percentage in Battaramulla intersection by each vehicle type are presented in Table 7.

Table 7 RLR violation rates in Battaramulla intersection by different road users

Road user	Time period	Number of vehicles	Number of violations	Violation rate (%)
Motor vehicle	Total	12,207	106	0.86
	Morning (off-peak)	4,649	45	0.968
	Koswatta leg	1,736	8	0.461
	Rajagiriya leg	1,523	25	1.642
	Pelawatte leg	1,390	12	0.863
	Evening (peak)	7,558	61	0.807
	Koswatta leg	2,732	13	0.476
	Rajagiriya leg	2,860	33	1.154
	Pelawatte leg	1,966	15	0.763
Motorcycle	Total	4,350	85	1.954

	Morning (off-peak)	1,762	42	2.384
	Koswatta leg	780	4	0.513
	Rajagiriya leg	507	29	5.720
	Pelawatte leg	475	9	1.894
	Evening (peak)	2,588	43	1.662
	Koswatta leg	1256	5	0.398
	Rajagiriya leg	931	32	3.437
	Pelawatte leg	401	6	1.496
Three Wheelers	Total	5,196	61	1.174
	Morning (off-peak)	1,908	33	1.730
	Koswatta leg	825	7	0.850
	Rajagiriya leg	568	19	3.345
	Pelawatte leg	515	7	1.360
	Evening (Peak)	3,288	28	0.852
	Koswatta leg	1,313	7	0.533
	Rajagiriya leg	1,075	13	1.209
	Pelawatte leg	900	8	0.889

In Battaramulla intersection total of 12,207 motor vehicles were observed and among them 4,649 were observed during off-peak hours and the rest of 7,558 motor vehicles were observed during peak hours. Out of these total of 106 RLR violations were found and the total RLR violation rate was 0.86 percent. In off-peak hours, there were only 45 RLR violations and violation rate was 0.968 percent. During peak hours the RLR violation rate was 0.807 percent. The number of motor vehicles passed by the intersection was higher than motorcycles or three wheelers. When considering motorcycles, the RLR rate was the highest although they are the least number of vehicles passed the intersection. RLR violation rate of motorcycles in off-peak hours was 2.384 percent were higher than peak hours which was 1.662 percent. Overall RLR violation rates for three wheelers were higher than motor vehicles but lower than motorcycles. And in three wheelers most RLR violations occurred during off-peak hours compared to peak hours.

4.2 Denzil Kobbekaduwa Intersection

The RLV rates of each vehicle type in each leg in Denzil Kobbekaduwa intersection are presented in Table 8.

Table 8. RLR violation rates in Denzil Kobbekaduwa intersection by different road users

Road user	Time period	Number of vehicles	Number of violations	Violation rate (%)
Motor vehicle	Total	14,668	97	0.661
	Morning (off-peak)	7,884	47	0.596
	Batharamulla leg	1,143	13	1.137
	Parliment leg	2,867	20	0.698
	Pelawatte leg	1,361	7	0.514
	Koswatta leg	2,513	7	0.279
	Evening (peak)	6,784	50	0.737
	Batharamulla leg	1,856	14	.754
	Parliment leg	1,774	9	.507
	Pelawatte leg	1,665	16	.961
	Koswatta leg	1,489	11	.739
Motor cycle	Total	6,950	126	1.813
	Morning (off-peak)	3,705	58	1.565
	Batharamulla leg	511	8	1.566
	Parliment leg	1,348	27	2.003
	Pelawatte leg	656	7	1.067
	Koswatta leg	1,190	16	1.345

	Evening (peak)	3,245	68	2.096
	Batharamulla leg	1,111	13	1.17
	Parliment leg	447	14	3.132
	Pelawatte leg	928	20	2.155
	Koswatta leg	759	21	2.767
Three Wheelers	Total	7,277	89	1.223
	Morning (off-peak)	4,071	39	0.958
	Batharamulla leg	754	6	0.796
	Parliment leg	1,156	11	0.952
	Pelawatte leg	838	7	0.835
	Koswatta leg	1,323	15	1.134
	Evening (peak)	3,206	50	1.560
	Batharamulla leg	980	10	1.02
	Parliment leg	533	9	1.689
	Pelawatte leg	993	10	1.007
	Koswatta leg	700	21	3.000

Motorcycles have the highest RLR violation rates even though they were the least of vehicles passing the intersection. The lowest RLR violation rate remain with motor vehicle but it was the most available vehicle in the intersection. The violation rates of motor vehicles in peak hours and in off-peak hours were close. When considering the violations of motorcycles and three wheelers, violation were high in peak hours than in off-peak hours.

4.3. Pelawatte Intersection

Table 9 depicts the RLR violation rates in Pelawatte intersection each type of vehicle category during both peak hours and off-peak hours. Motor vehicle was most predominant vehicle type in the intersection but its' violation rate was relatively lower than motorcycles and three wheelers. The RLR violation rates were higher during the off-peak hours than peak hours in all vehicles types.

Table 9. RLR violation rates in Pelawatte intersection by different road users

Road user	Time period	Number of vehicles	Number of violations	Violation rate (%)
Motor vehicle	Total	18,474	161	0.872
	Morning (off-peak)	7,638	79	1.033
	Batharamulla leg	2,179	22	1.010
	Parliment leg	2,305	20	0.868
	Thalawathugoda leg	2,052	21	1.023
	DB wijayasingha leg	1,102	16	1.451
	Evening (peak)	10,836	82	0.757
	Batharamulla leg	2,659	29	1.091
	Parliment leg	2,831	15	.530
	Thalawathugoda leg	3,308	20	.605
	DB wijayasingha leg	2,038	18	.883
Motorcycle	Total	6,639	161	2.426
	Morning (off-peak)	2,742	90	3.282
	Batharamulla leg	963	19	1.973
	Parliment leg	679	12	1.767
	Thalawathugoda leg	614	44	7.166
	DB wijayasingha leg	486	15	3.084
	Evening (peak)	3,894	71	1.823

	Batharamulla leg	852	27	3.169
	Parliment leg	932	9	.966
	Thalawathugoda leg	881	22	2.497
	DB wijayasingha leg	1,229	13	1.058
Three Wheelers	Total	7,735	114	1.474
	Morning (off-peak)	3,039	73	2.402
	Batharamulla leg	948	13	1.371
	Parliment leg	862	12	1.392
	Thalawathugoda leg	713	35	4.909
	DB wijayasingha leg	516	13	2.519
	Evening (peak)	4,696	41	0.873
	Batharamulla leg	1,105	14	1.267
	Parliment leg	1,292	6	.464
	Thalawathugoda leg	1,184	12	1.014
	DB wijayasingha leg	1,115	9	.807

4.4. Thalawathugoda Intersection

In Thalawathugoda intersection, RLR violation rate of motor vehicles was the lowest compared to motorcycles and three wheelers. The highest RLR violation rate of motorcycle was recorded as 3.055 percent in Thalawathugoda compared to other intersections. The RLR violation rates for each vehicle category was higher in off-peak hours compared to peak hours.

Table 10. RLR violation rates in Thalawathugoda intersection by different road users

Road user	Time periode	Number of vehicles	Number of violations	Violation rate (%)
Motor vehicle	Total	19,173	250	1.304
	Morning	10,260	170	1.657
	Batharamulla leg	3,618	51	1.500
	Athulkotta leg	2,209	39	1.766
	Pannipitiya leg	2,172	38	1.750
	Hokandara leg	2,261	42	1.858
	Evening	8,913	80	0.898
	Batharamulla leg	2,477	27	1.090
	Athulkotta leg	2,775	18	0.649
	Pannipitiya leg	2,238	18	0.804
	Hokandara leg	1,423	17	1.194
Motorcycle	Total	7,888	241	3.055
	Morning	4,457	166	3.725
	Batharamulla leg	1,001	35	3.500
	Athulkotta leg	1,098	28	2.550
	Pannipitiya leg	1,122	77	6.862
	Hokandara leg	1,236	26	2.104
	Evening	3,431	75	2.186
	Batharamulla leg	1,500	18	1.200
	Athulkotta leg	703	19	2.703
	Pannipitiya leg	564	21	3.723
	Hokandara leg	664	17	2.560
Three Wheeleers	Total	8,139	135	1.659

	Morning	4,343	80	1.842
	Batharamulla leg	883	21	2.378
	Athulkotta leg	1,018	17	1.700
	Pannipitiya leg	1,184	23	1.943
	Hokandara leg	1,258	19	1.510
	Evening	3,796	55	1.449
	Batharamulla leg	1,537	13	0.846
	Athulkotta leg	797	14	1.757
	Pannipitiya leg	742	18	2.426
	Hokandara leg	720	10	2.560

4.5 Comparison of RLR violation rates

RLR violation rates in each intersection by different road users are shown in Figure 6. Overall, the RLR violation rates were higher in Thalawathugoda intersection compared to other intersections studied. And the lowest RLR violation rates were recorded for Denzil Kobbekaduwa intersection among the intersections studied. The highest RLR violation rates were recorded for motorcycles followed by three wheelers, and motor vehicles in each and every intersection. Although predominant vehicle type for these intersection was motor vehicle, it had the lowest RLR violation rate. The RLR violation rates of motor vehicles in Pelawatte intersection was almost similar the RLR violation rates of motor vehicles in Battaramulla intersection, but RLR violation rate of motorcycles at Pelawatte intersection was much higher than that of Battaramulla intersection. The violation rates of three wheelers at Pelawatte, Denzil Kobbekaduwa, and Battaramulla intersections were similar.

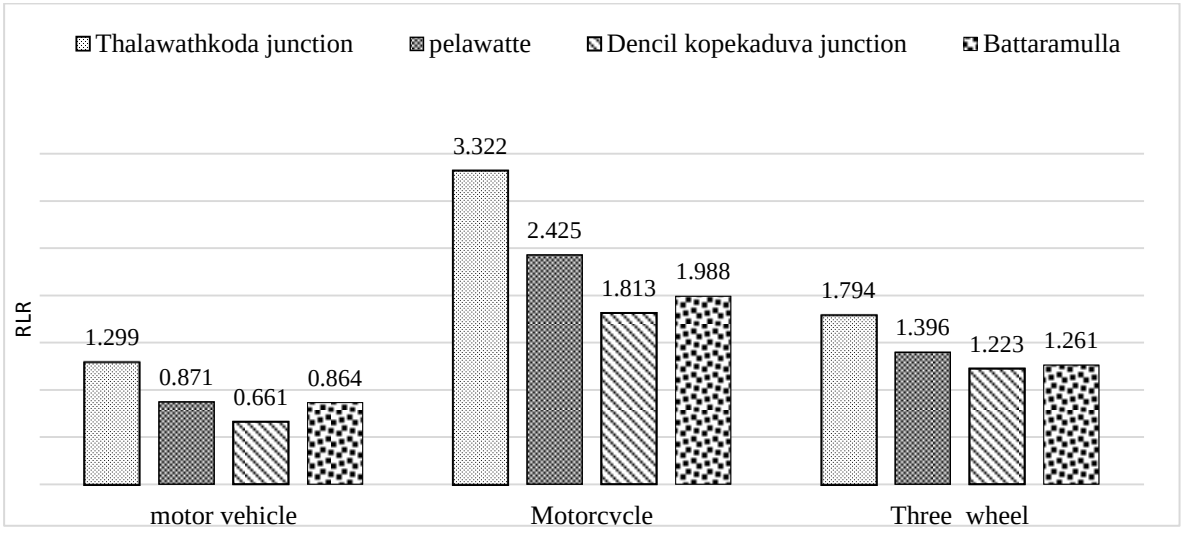

Figure 6 Comparison of violation rate by the type of road user

When investigating the time of the day, it was noted that the highest RLR violation rates were recorded each type of vehicles in off-peak hours compared to peak hours, as shown in Figure 7.

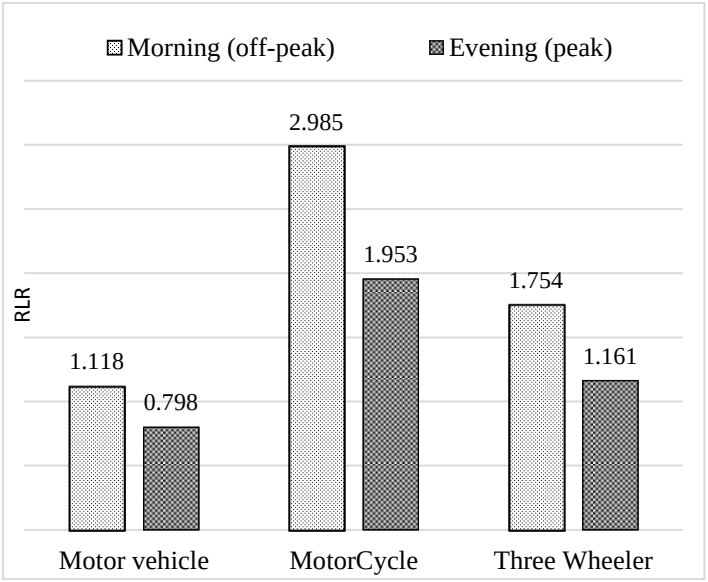

Figure 7 Comparison of violation rate by time period

In addition to time period, the age group and gender of the violators were recorded. It was indeed a challenging task to accurately judge violator's age, although identifying a young vehicle drivers to be much easier. The observed drivers were thus classified into two age groups: young and adult. Table 11 gives the observed data on those variables together with driver behaviour. The observed drivers' behaviours were classified into two groups: risk-taking and opportunistic. The risk-taking drivers are those who would ignore the red light and travel through the intersection without stopping but may be slow down. The opportunistic drivers were those who would originally wait at red lights but would be too impatient to wait for red lights to become green and subsequently cross the intersection by seeking gaps among crossing traffic. According to Table 11, male drivers were associated with an increased probability of risk-taking behaviors. Young age drivers were found to be more likely to have risk-taking and adult age drivers were found to be more likely to have opportunistic behaviors.

Table 11. Violators' behavior in all four intersections

Road user	Variable	Description	Risk taking drivers	Opportunistic drivers
Motor vehicles	Gender	Male	231	357
		Female	14	8
	Age	Young	145	181
		Adult	100	184
	Time of the day	Morning	150	192
		Evening	95	173
	Intersection type	4 arms	200	304
		T/Y junction	45	61
Motorcycles	Gender	Male	258	365
		Female	11	2
	Age	Young	143	211
		Adult	126	156
	Time of the day	Morning	162	217
		Evening	107	150

	Intersection type	4 arms T/Y junction	230 39	319 48
Three Wheeler	Gender	Male Female	197 1	206 0
	Age	Young Adult	107 91	96 110
	Time of the day	Morning Evening	109 89	121 85
	Intersection type	4 arms T/Y junction	168 30	175 31

The rate of RLR violations (0.94%) was low for motor vehicle drivers in Sri Lanka compared with the rates in the US, which was found to be approximate 20% (Porter and Berry, 2001), and Greater Manchester, the United Kingdom, (11.3%) (Yousif et al., 2014). But rate of RLR motor vehicles in Sri Lanka was higher for motor vehicle drivers in Changsha, China which was found to be 0.14% by Yan et al. in 2016. The violation rates changes with time of observation and the road user. Overall, the RLR violation rate found in Colombo suburban was lower than India (5.22%), the United Kingdom (11.3%), Jordan (12.4%), and Changsha (China).

5. CONCLUSIONS AND RECOMMENDATIONS

RLR violations in Colombo suburban was studied categorizing vehicles into three groups; motor vehicles, motorcycles, and three wheelers. Four signalized intersections with approximately similar traffic volume were selected. Those were Battaramulla intersection, Denzil kobbekaduwa intersection, Pelawatte intersection, and Thalawathugoda Intersection. By observation, the violation rates were estimated dividing the number of violation by total number of vehicles and expressed as a percentage. Number of violations and number vehicles were collected both peak hours and off-peak hours. When considered all vehicles, the average RLR violation rate was 1.39 percent. The RLR violation rate found in Colombo suburban was lower than India (5.22%), the United Kingdom (11.3%), Jordan (12.4%), and Changsha (China). The highest RLR violation rate in Colombo suburban was recorded for motorcycle drivers followed by three wheelers, and other motor vehicles. When considered the observed three intersections, the highest RLR violation rate was recorded for Thalawathugoda intersection followed by Pelawatte intersection, Bateramulla intersection, and Denzil kobbekaduwa intersection. The RLR violation rate was higher in off-peak hours than in peak hours.

The limitation on this study was the absence of collecting the RLR violation data for pedestrians. The study can be further improved extending the observations in all the intersections. However, the findings of this study give important information, when developing and implementing interventions and education programs to reduce RLR of different road users.

The RLR violation rates at signalized intersections can be reduced by implementation of suitable remedial measures depending on the situation. Some of the remedial measures which can be suggested to reduce RLR violations are listed below.

- Red-light ticket cameras: - Red light cameras automatically photograph vehicles that go through red lights. The cameras are connected to the traffic signal and to sensors that monitor traffic flow just before the crosswalk or stop line. The system

continuously monitors the traffic signal, and the camera captures any vehicle that does not stop during the red phase.

- Improve intersections for motorists**:** - anything about an intersection that confuses or frustrates motorist increases red-light violations. Therefore, communities can improve signage. Signs should clearly indicate that a signal is ahead and which lane(s), if any, are for turns only.
- It is important to build new turning lanes, on roads where development has added a significant amount of new traffic volume.

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