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Red light running motorcyclists at signalized intersection in Malaysia: An empirical study

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Abstract. This study investigates factors associated with red light running motorcycle (RLR-MC) behavior during their approach and crossing of signalized 3-leg and 4-leg intersections along majors in Malaysia. Twenty-seven (27) intersections with Pre-timed traffic light (PTTL) and Actuated traffic light (ATL) were selected and observed during peak and off peak hour period. In general, the average rate of RLR-MC was 3.61%, with the highest rate of RLR-MC recorded was 22%, while the lowest rate was 0.6%. Observations have shown three-ways of RLR-MC approached the signalized intersection, i.e. (1) approaching the SI with Weaving/Lane Splitting, (2) approaching the SI from center of the lane, and (3) approaching the SI from the left side/the shoulder. There are three ways RLR-MC crossing the signalized intersection, i.e. (1) by Illegal maneuver (i.e. Illegal U-turn, contra-flow, prohibited left-turn), (2) by stopping first at or before the stop line, and (3) without stopping before the stop line. 'Crossing the SI without stopping at the stop line' is the majority with 51.15% from total observation. It is recommended that SI with high RLR-MC be equipped with adequate traffic island, replace SI signal type to actuated traffic signal and installing traffic light pole instead of gantry.

1. Introduction

According to the World Health Organization, close to a quarter (24.1%) of the world's road traffic deaths occur among motorcyclists or powered-two-wheelers (PTW) [1]. Of these motorcycle fatalities, the South-East Asia region (i.e. mostly low- to middle-income countries) has the highest rate with 49.9%, compared to only up to 10.9% motorcyclist fatalities in high-income countries in the European region. Sixty five percent of the world's motorcycles are in Asia, whereas Europe and North America account for only 16% [2]. The 4 countries with the highest numbers of motorcycles per 1,000 of population are Malaysia, Thailand, Cambodia and Japan [2, 3]. In developing and low to middle-income countries, such as those in the Asian region, motorcycles are used and exposed frequently as they are relatively affordable to buy and run [1, 2]. Hence, the high number of motorcycles on Asian roads is reflected in their high proportion of fatality crashes.

Malaysia may be the best example to study motorcycle crashes, as it typifies the countries with safety problems for motorcyclists and its data is close to the average, i.e. 47% of registered vehicles are motorcycles and 59% of the victims of reported accident fatalities are motorcyclists [1, 4]. In 2013, Malaysia ranked number 5 in the world among countries with a high percentage of motorcyclist fatalities, i.e. more than 50% of the total road fatalities are associated with motorcycles [1]. In addition

to this, Malaysian motorcycles represent about 20% to 35% of motorized vehicle fleet, which are over-represented in road traffic crashes (as similar to Singapore [5] and Indonesia [6]); accounting for about 47% of total road traffic crashes and 59% of road fatalities [7]. On average, more than 70 motorcyclists are killed in road traffic crashes every week, and more than ten motorcycle riders are killed every day [1, 7].

1.1 Motorcycle Safety at Intersection in Malaysia

Although the great majority of motorcycle fatal crashes in Malaysia are reported on straight road sections (66%), motorcycle fatal crashes reported on major signalized intersections (i.e. 3-leg and 4-leg signalized intersection) is the next most common (18.5%) [7]. Table 1 shows the percentage of motorcycle fatal crashes at intersections based on the total reported crash cases from 2010 – 2011. Based on it, all type of signalized intersections have a higher motorcycle fatal crash rate (23.9%: 4-leg, 19.8%: 3-leg) compare to the un-signalized intersections (p<0.01), despite both un-signalized 4-leg and 3-leg intersection have a higher number of reported crash cases. Moreover, if we narrow down these motorcycle fatal crash rates based on various road jurisdiction classifications (Table 2) and various area type (Table 3), **signalized intersection**s are shown to have a statistically significantly higher fatality risk (i.e. fatality rate) than un-signalized intersection (p<0.05).

Table 1. The percentage of motorcycle fatal crashes at intersections

Intersection type	Signalized	Un-signalized
4-leg	23.9% * (n = 522)	17.4% * (n = 1,404)
3-leg	19.8% * (n = 334)	15.9% * (n = 5,326)

n: Total number of reported crash cases involving motorcycle since 2010 – 2011.
* Statistically significant difference according to Chi-sq. test (p < 0.05)
Source: PDRM (2011), analyzed by MIROS

Table 2. The percentage of motorcycle fatal crashes at intersections based on various category of road jurisdiction

Intersection at various road jurisdiction	Signalized	Un-signalized
Federal	20.0% * (n = 436)	15.8% * (n = 2,247)
State	26.8% * (n = 164)	15.2% * (n = 1,866)
Municipal	23.7% * (n = 249)	17.0% * (n = 2,004)
Others	19.4% * (n = 36)	16.4% * (n = 671)

n: Total number of reported crash cases involving motorcycle since 2010 – 2011. Others: Private roads or local roads,
* Statistically significant difference according to Chi-sq. test (p < 0.05)
Source: PDRM (2011), analyzed by MIROS

Table 3. The percentage of motorcycle fatal crashes at intersections based on various area type

Intersection within the vicinity of various area type	Signalized	Un-signalized
Residential	25.0% * (n = 164)	16.5% * (n = 1,664)
Commercial	22.0% * (n = 205)	18.1% * (n = 930)
Industrial	33.3% * (n = 33)	30.4% * (n = 191)
School	17.4% * (n = 23)	12.1% * (n = 248)
No development	20.5% * (n = 448)	14.9% * (n = 3,819)

n: Total number of reported crash cases involving motorcycle since 2010 – 2011.
No development signifies an area with very few populations, e.g. plantation, forest, etc.
* Statistically significant difference according to Chi-sq. test (p < 0.05)
Source: PDRM (2011), analysed by MIROS

2. Literature Review

One of the factors that influence fatal crashes among motorcyclists may be due to the red light running (RLR). Local studies such as [8] and [9] have found out that, red light running among Malaysian motorcyclists MCRLR is high compared to other road users and the reasons for this problem are varied and complex. A cross-sectional study was conducted in Selangor, Malaysia to identify road traffic-light violations and the findings shows that motorcycle recorded higher violation of traffic lights with 13.5% motorcycles compared to four-wheeled vehicles with 11.1%, and the odds ratio analysis shows that the violation increased by 1.24 times for motorcycles compared with four-wheeled vehicles [8]. Factors influencing MCRLR in Malaysia are found to be more on during the weekends [8], on intersection without enforcements (e.g. Red light running cameras, police, etc.) [8, 10], longer cycle time (>160s), four-phase signal timing, four-leg signalized intersections and high motorcycle volume [9].

The known behaviors associated with motorcycle risky behavior observed at intersection studies such as in Abdul Manan and Várhelyi [11], Haque, et al. [12] , Haque, et al. [13], Hawa, et al. [10], Clarke, et al. [14], de Rome, et al. [15] and Radin Umar [16], are: weaving between motorist, running red lights, speeding, splitting while speeding, not stopping at the stop line, not wearing helmet, wearing dark clothing and not using headlights. However, among all the risky behavior discussed previously, red-light running among road users stood out as the most extreme or highly risky behavior, which leads to a crash. This is because road crashes occur when there are conflicting vehicle movements [17-19]. Many research in developed countries, e.g. U.S., UK, European countries, etc., has put more focus on discovering the driver (including motorcyclists) characteristics and road traffic environment factors associated with red light runners behavior. The driver's characteristics which are associated with red light runners behavior are found to be: young drivers/riders [20, 21], male [22, 23], less likely to wear safety belts [23], poor driving records [24, 25], under the influence of alcohol [26, 27] and drive smaller or older vehicle [28, 29]. Red light runners are also more likely to be younger than 30- years old, have a record of moving violations, are driving without a valid license and/or have consumed alcohol [19, 28]. As for road traffic environment factors, Porter and England [23] and Martinez and Porter [22] concluded that higher traffic volumes at intersection can be associated with increase in red light violations among car drivers. Furthermore, an intersections with higher traffic volumes, drivers would have more chances to be in a following position in the traffic flow at the onset of yellow, thus the red light running rate and crash risk would increase [30]. Moreover, speeding car drivers were more likely to run red lights compared to non-speeding drivers and 90% of them were mostly located between the distances of 61.3m to 128.0m from the intersection [30].

Many factors, such as rider characteristics influencing or associated with red light running among motorcyclists are yet to be uncovered, especially in Malaysia. Research on traffic and environment factors that are influencing red light runners among car passenger are widely being reported but limited on motorcycle riders. As for Malaysia, research on motorcycle rider behavior and characteristics associated with red light running is still limited, and much focus was put on finding the associated factors from the traffic and road environment perspective, as seen in Law, et al. [9], Kulanthayan, et al. [8], Che Puan and Ismail [31] and Hawa, et al. [10].

2.1 Aims of current study

The current study investigates motorcycle rider behavior and characteristics factors associated with motorcyclist red light running behavior at signalized intersection and suggest countermeasures in order to curb the risky behavior. Given this focus, it was of particular interest to identify motorcyclists' risky behavior prior and during their red light running behavior and factors associated with red light running motorcycle.

3. Methodology

This study was conducted in early 2016 and ends in mid 2017, with 3 main phases: (1) Site selection criteria and identification, (2) Site verification and data collection, (3) Statistical Analysis. This study only focused on red light running motorcycle (RLR – MC) on selected signalized intersections on 3 and 4-legged intersections along major roads in Malaysia.

3.1 Site selection criteria and identification

There are two types of traffic light signal time in Malaysia based on Kulanthayan, et al. [8] observation. The most common is the pre-timed traffic light (PTTL) with the signal timing cycle length usually falling between 45 and 120 seconds. The timing for each signal is determined based on traffic volume and traffic patterns in each particular area. The second type is a traffic light with a sensor, i.e. actuated (ATL). This system maximizes the efficiency at a traffic junction by allocating green time for each approach to a traffic junction according to traffic demand. This means that if the sensor detects that the demand of a particular approach is higher, it will redistribute the green time accordingly to optimize the usage of the traffic junction. Another type of traffic light has a countdown timer (CTTL). It is a two-digit time indicator, placed on the pole above the traffic signal. Its purpose is to reduce congestion at traffic junctions, help motorists to have a better understanding of the traffic flow and helps motorists to be aware of the remaining time left on the green phase. This study however, do not take into account the CTTL type due to is rarity and uncommon along main roads in Malaysia.

This study considered only two types of traffic light signal time, i.e. Pre-timed traffic light (PTTL) and Actuated traffic light (ATL), on each 3-leg and 4-leg signalized intersection. As for the location, we prioritized the signalized intersections that connect a major road with a minor road, for example a Primary road with a Secondary road, or Collector with a Local roads, etc. The location of these signalized intersections were also narrowed down into nearby an industrial, a residential or commercial area. This is based on the fact that the fatality rate involving motorcycles at signalized intersection are higher compared to their respective category. Additional selection criteria for each signalized intersection (SI) are as follow:

1. The SI is on a straight geometry road section and on a flat terrain. This is to ensure the site has no sight distance limitation and the crossing road users are not affected or influence by it.
2. The major road on the SI has a minimum of 10% of motorcycles from the traffic volume. This is to ensure that the site has sufficient number of observation of motorcycles.
3. The SI shall have a vantage point for the researches to conduct the observations and to collect speed data obscurely from other road users.
4. The SI has some history of traffic crash involving motorcycle or the SI is observed to have RLR behaviour among motorcyclists passing through. This criterion is to justify the site's current risky condition.

This study is a nationwide study, thus to reflect and represent Malaysia, the SI was sampled from major towns in Malaysia respective to the region, i.e. Kuala Lumpur or Shah Alam (Central region), Penang (Nothern region), Johor Bahru (Southern region), and Kuantan (Eastern region).

In order to effectively and efficiently perform the data collection, each city, e.g. Kuala Lumpur and Shah Alam, was screened (via Google maps and Google Street view) in terms of SI availability and SI geometry type, while being cross checked with the crash history from the police data base. The plan was to select at least four SI with each type of SI signal time (PTTL and ATL) and each for 3-leg and 4-leg intersection on every major town in their respected region. For example, the central region has three major cities (Kuala Lumpur, Petaling Jaya, Shah Alam), thus the screened number of intersection would be 48 (3 cities x 2 SI signal time type x 2 of SI type x 4 SI) for each region. Thus the total number of SI planned for screening was 192 (4 region x 48 SI).

3.2 Site verification and data collection
After the rigorous screening process, we had to verify each of the selected sites in order to conform to the site selection criteria by conducting a preliminary observation on each sites. Once the site fulfils the selection criteria, it undergoes the data collection process.

3.2.1 *Method of data collection.* To capture the observation of each motorcyclists passing from Scenario 1 and up through Scenario 2, two synchronized camera position on a strategic location in the vicinity of the SI. These cameras was mounted on a customized retractable (i.e. telescoping pole), which can lifted as high as 4 to **7** meters depending on the site condition and restriction. The reason to have a 7 meters observation view point is to capture all activity within the intersection, which also covers all intersection legs. The time of recording was conducted during peak (7.00am – 8.00am, 5.00pm – 6.00pm) and off peak hour (10.00am – 11.00am, 4.00pm – 5.00pm) with duration of 1-hour each.

3.3 Types of variables for acquisition. Once all the sites have been identified, each signalized intersection's characteristics, infrastructure measurements, signal timings, traffic volume and motorcycle characteristics were captured and categorized accordingly (see Table 4).

Table 4. Variables on signalized intersection characteristics

No.	Factors	Variables (continuous / categorical)
1.	SI type	3-leg, 4-leg
2.	SI signal type	Actuated, Pre-timed
3.	Red / Green time category [a]	Actuated, 40s-80s, 80s–120s, 120s–160s, 160s–200s
4.	Amber time category	Actuated, 1s, 2s, 3s
5.	Major / Minor road signal infrastructure	Signal on Pole, Signal on Gantry
6.	Total num. of lanes on Major / Minor road	2 lanes, 4 lanes, 5 lanes, 6 lanes
7.	Speed limit on Major / Minor road	50km/h, 60km/h, 70km/h, 90km/h
8.	Number of traffic island	0, 1, 2, 3, 4, 5
12.	Major road crossing length [ab]	0m – 10m, 10m – 15m, 15m – 20m, 20m – 25m
15.	% of MC passing on Major / Minor leg	< 15%, 15% - 25%, 25% - 50%, > 50%
16.	Num. of vehicles on Major leg 1 & 2	- Count -
17.	Motorcycle type based on c.c.	<250cc, >250cc
18.	Motorcycle number of occupancy [a]	1, 2, > 2
19.	Location of RLR-MC	From Major road, From Minor road
20.	Destination of RLR-MC	To Major road, To Minor road
21.	Gender	Male, Female
22.	Helmet wearing	With helmet, no helmet

Notes:
a – indicates that the factors were measures on site and later categorized into few categories.
b – Crossing distance is measured from the stop line to stop line for each leg.
Traffic volume: Number of vehicles passing the intersection during 1hour of observation
Num. of vehicles on Major leg 1 and leg 2: Count of vehicles on each leg during each RLR-MC occurrence

For every red-light running motorcycle, all of its characteristics, movement and motorcyclists' riding behavior was identified and recorded (see the variables in Table 4). As part of the data collection and analysis process, the research team developed state-of-the-art prototype software called MECHRED (Motorcycle Characteristics and Motorcyclists' Red light running Behavior Data Management Software), dedicated for data collection and management of motorcycle characteristics and motorcyclists' red light running behavior at signalized intersection. MECHRED consists of two video interfaces and a data logger interface (see Figure 1). For every passing motorcycle in the video, the observer goes through each factor (see Table 4) and chooses the suitable option for the motorcycle and

motorcyclist. The observers (MECHRED users) are the main author, co-authors and six highly trained research assistants who conducted the data collection. The MECHRED's user enters the observed information, e.g. motorcycle type, motorcyclists' gender, motorcycle movement, etc., from the video interface.
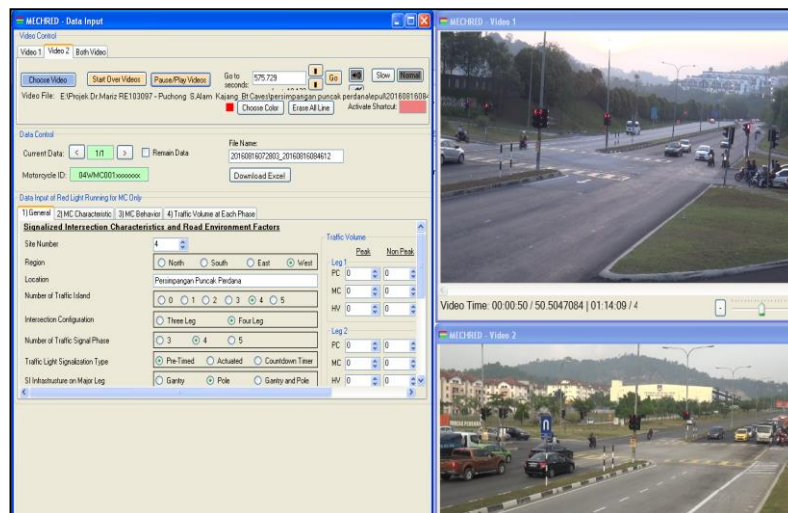

Figure 1. Screenshot of the MECHRED software

3.4 Statistical Analysis

The main objective of this research intends to find the factors associated with red light running motorcycle (RLR-MC) at signalized intersections. The analysis for this study catered multivariate categorical data which looked into the associated SI factor variables in **Scenario 1**, i.e. red light running motorcyclist behavior when approaching the SI and the associated SI factor variables in **Scenario 2**, i.e. red light running motorcyclist when crossing the SI (see Figure 1). In analyzing these variables, a Multiple correspondence analysis (MCA) was used in order to clustered or find a pattern relating RLR-MC behavior to the SI characteristics, infrastructure, dimension, signal timing, traffic volume and motorcycle characteristics.

Multiple correspondence analysis (MCA) are methods for analyzing observations on categorical variables. MCA is usually viewed as an extension of simple correspondence analysis (CA) to more than two variables. CA analyses a two-way contingency table; MCA and JCA analyze a multi-way table. Multiple Correspondence Analysis (MCA) is also a part of a family of multidimensional descriptive methods (e.g., clustering, factor analysis, and principal component analysis) revealing patterning in complex datasets when we dispose more qualitative variables (ordinal, or nominal) in [32]. As mention in Kalayci and Basaran [33], MCA is used to represent datasets as "clouds" of points in a multidimensional Euclidean space; this means that it is distinctive in describing the patterns geometrically by locating each category of analysis as a point in a low-dimensional space. The results are interpreted on the basis of the relative positions of the categories and their distribution along the dimensions; as categories become more similar in distribution, the closer (distance between points) they are represented in space [33]. MCA can be a particularly powerful one as it "uncovers" groupings of categories in the dimensional spaces, providing key insights on relationships between categories, without needing to meet assumptions requirements such as those required in other techniques widely used to analyse categorical data (e.g., Chi-square analysis, Fischer's exact test, -statistics, and ratio test) [33].

According to [34] and [33], for the proximity between categories we need to distinguish two cases. First, the proximity between levels of different nominal variables means that these levels tend to appear together in the observations. Second, the proximity between levels means that the groups of observations associated with these two levels are themselves similar.

4. Results

This section discusses the results and findings of the study. This section is divided into four subsections: Site selection, Analysis on Scenario 1, Analysis on Scenario 2 and Overall Analysis.

Figure 2. Photos of RLR-MC at selected sites

Table 5. Selected location of signalized intersection

Region	State	N	Location	SI type 4L	3L	Crash history
i	Johor Bharu (Southern)	1	Persimpangan Jalan Padi Mahsuri (Bandar Baru Uda)	√		6
		2	Persimpangan Jalan Pendidikan (Taman Universiti		√	81
		3	Persimpangan Kampung Ungku Mohsin (Jalan	√		10
		4	Persimpangan Kampung Melayu (Jalan Tampoi)		√	0
ii	Perlis (Northern)	5	Persimpangan Jln Tuanku Syed Sirahjuddin		√	0
		6	Persimpangan Jln Tuanku Syed Alwi	√		5
		7	Persimpangan Jln Tuanku Syed Putra		√	0
		8	Persimpangan Masjid Batu 2	√		2
	Kedah	9	Persimpangan Jln Kubang Rotan (Jalan Alor Star –	√		0
		10	Persimpangan Jln Tun Razak (Alor Star)		√	18
	Penang	11	Persimpangan Jalan Sri Tanjung Pinang		√	6
		12	Persimpangan Jalan Sungai Dua		√	9
		13	Persimpangan Jalan Jelutong	√		167
iii	Kuala Terengganu (Eastern)	14	Persimpangan Medan Selera Batu Burok (FR3)	√		2
		15	Persimpangan Jalan Batu Burok (FR3) - Jalan Tok	√		0
		16	Persimpangan Kamarudding (FR3) - Jalan Pusara		√	0
	Kuantan	17	Persimpangan Jalan Beserah - Jalan Air Putih (FR2)	√		0
iv	Selangor (Central)	18	Persimpangan Tesco Bukit Puchong		√	0
		19	Persimpangan Puncak Perdana	√		0
		20	Persimpangan Jln UPM Sri Serdang		√	68
		21	Persimpangan Jln Wan Siew Sg Chua	√		51
		22	Persimpangan Padang Jawa	√		47
		23	Persimpangan Persiaran Kewajipan, Subang Jaya		√	350
		24	Persimpangan Persiaran Sukan S.Alam		√	60
		25	Persimpangan Uitm (Pintu 2) Shah Alam	√		0
		26	Persimpangan Jln Batu Caves	√		102
		27	Persimpangan Sunway Suria	√		0

Crash history = Total number of crash from 2012 – 2014, N: Site number
SI: Signalized intersection, 4L: four leg signalized intersection, 3L: three leg signalized intersection

4.1 Site selection

The total number of SI planned for screening was 192 (4 region x 48 SI). However, the number of SI after the screening was decreased down to 50 due to site selected criteria, e.g. most of them do not have a significant reported crash history and unsuitable road geometry. Results from the preliminary observation, we have narrowed down to **27** sites, as seen in

Table 5. Forty-eight per cent (40%) from the screened 50 sites was rejected due to insufficient number of red-light running motorcycle and unsuitable vantage point for observation. Figure 2 shows photos of RLR-MC occurrences at selected sites.

4.2 Analysis of red light runner among motorcycle

As mention previously, data collection was being conducted during peak and off-peak hours, thus, the number of data sets for this study increased up to 54. Based on Table 6, the average rate of RLR-MC is 3.61%, by which the highest rate of RLR-MC recorded was 22% at Site 24, while the lowest rate was 0.6% at Site 8 during off peak hours. We also record RLR among other vehicle, which is 1.2%. Moreover, average rate of number of red light running motorcycles during peak hours is higher (4.66%) than the off peak (3.6%).

Table 6. Number of RLR MC at the selected sites based on peak and non-peak hour

Site	Traffic vol. - Major leg		Num. of RLR-MC		Site	Traffic vol - Major leg		Num. of RLR-MC	
	Off peak	Peak	Off peak	Peak		Off peak	Peak	Off peak	Peak
1	1,055	1,249	20 (1.90%)	18 (1.44%)	15	2,771	2,844	45 (1.62%)	37 (1.30%)
2	1,583	2,063	49 (3.10%)	94 (4.56%)	16	2,195	2,950	107 (4.87%)	145 (4.92%)
3	2,226	2,635	111 (4.99%)	161 (6.11%)	17	2,940	3,047	109 (3.71%)	136 (4.46%)
4	2,751	3,006	27 (0.98%)	38 (1.26%)	18	3,818	4,058	55 (1.44%)	139 (3.43%)
5	2,250	2,010	33 (1.47%)	46 (2.29%)	19	2,194	3,528	106 (4.83%)	370 (10.49%)
6	963	1,292	26 (2.70%)	6 (0.46%)	20	2,644	3,327	92 (3.48%)	79 (2.37%)
7	1,624	1,979	16 (0.99%)	36 (1.82%)	21	1,358	1,326	37 (2.72%)	27 (2.04%)
8	840	1,188	5 (0.60%)	21 (1.77%)	22	878	1,159	30 (3.42%)	22 (1.90%)
9	1,894	2,209	106 (5.60%)	154 (6.97%)	23	2,449	3,084	27 (1.10%)	116 (3.76%)
10	1,434	1,930	33 (2.30%)	44 (2.28%)	24	2,007	3,008	443 (22.07%)	677 (22.51%)
11	2,964	3,116	54 (1.82%)	50 (1.60%)	25	2,571	2,630	38 (1.48%)	62 (2.36%)
12	1,918	2,490	79 (4.12%)	94 (3.78%)	26	1,489	2,141	53 (3.56%)	55 (2.57%)
13	2,549	2,163	227 (8.91%)	276 (12.76%)	27	3,449	3,404	112 (3.25%)	188 (5.52%)
14	2,110	2,840	15 (0.71%)	21 (0.74%)	Ave	2,108	2,469	76 (3.61%)	115 (4.66%)

Note: (%):
The rate of red light running motorcycle from the total volume count in percentage.
Ave. : Average, Traffic volume: Vehicle count for one hour period

Figure 3 shows the distribution plot of RLR-MC based on the major road traffic volume. Based on the regression line, the slope for the rate of RLR-MC during the peak hour is steeper than the off-peak hour. In other words, the rate of RLR-MC occurrence increases as the traffic volume along the major road increases, especially during peak hour.
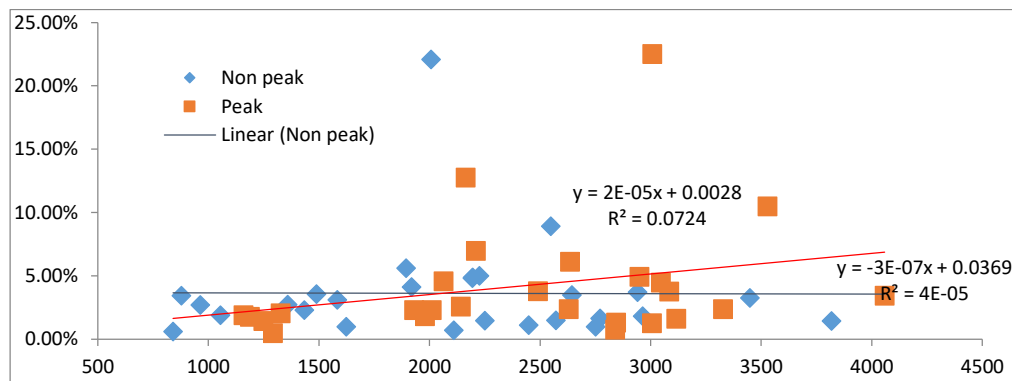
Figure 3. Distribution of RLR-MC rate based on the major road traffic volume

Table 7 shows that 3-leg SI has the highest RLR-MC rate (60.8%) compared to 4-leg SI, especially during peak hour period. However, non-peak hour period has the highest RLR-MC rate (66.9%) compared to peak hour period, especially at 4-leg. This analysis however, is not statistically significantly different ($p > 0.05$), or in other term, RLR-MC on 3-leg SI occurrences are not much difference on 4-leg SI, regardless the period.

Table 7. Number of RLR-MC based on period category and type of SI

Period category	Four Leg	Three Leg	Grand Total
Non-peak	1,375 (*40.1%*), (66.9%)	680 (*39.2%*), (33.1%)	2,055
Peak	2,057 (*59.9%*), (66.1%)	1,056 (*60.8%*), (33.9%)	3,113
Grand Total	3,432	1,736	5,168

(%): Percentage in italics indicates the rate of RLR-MC based on type of SI
(%): Percentage in bold indicates the rate of RLR-MC based on period category,
Pearson $chi^2(1) = 0.3650$ Pr = 0.546

4.3 Observation of RLR-MC approach and crossing

Our observation on all of the selected sites has shown that there is a distinct or typical type of RLR-MC movement in both scenarios. In scenario 1, there are three type of movement performed by RLR-MC: Approaching the SI with Weaving / Lane Splitting, Approaching the SI from the center of the lane, and Approaching the SI from the left or shoulder (see Figure 4, note that the figure also apply for 3-leg SI). RLR-MC approaching the SI with Weaving / lane splitting is a rare behavior which require motorcyclists to move in between vehicles that are waiting at the SI with fast pace and often weave between vehicles when the spaces in between are limited. RLR-MC approaching the SI from the center of the lane is typical behavior seen during our observation. This behavior is seen when a RLR-MC move consistently in the middle of the lane or carriageway (either near the lane line or near the median) until the motorcyclist reaches the stop line to run the red light. RLR-MC approaching the SI from the left side or on the shoulder is another typical behavior in Scenario 1. This behavior occurs when a RLR-MC move consistently on the left side of the carriageway (near the edge line) or on the shoulder until the motorcyclist reaches the stop line to run the red light.

As for scenario 2, there are also three typical types of RLR-MC movement: Crossing the SI by Illegal maneuver (i.e. Illegal U-turn, contra-flow, prohibited left-turn), Crossing the SI by stopping first at or before the stop line, and Crossing the SI without stopping before the stop line (see Figure 4, note that the figure also apply for 3-leg SI). RLR-MC crossing the SI by illegal maneuver is a movement occurred when the RLR-MC make an illegal U-turn during the red-phase or moves in the opposite direction of the traffic (i.e. contra flow) into either into the major or minor road. RLR-MC crossing the SI by stopping

first at or before the stop line is one of the most common RLR behavior among motorcyclists. Motorcyclists in this scenario are seen to stop before or at the stop line before running the red light. Motorcyclists are also seen more observant of the opposite traffic (by turning their heads couple of times) before crossing it during the red phase. More often than not these RLR-MC are considered as running over the red light because they are already in the red phase of the SI. Another type of crossing detected during our observation, is the second most common RLR behavior among motorcyclists. This behavior shows that RLR-MC did not stop at the stop line or sometime slows down before they run the red light. More often than not, this kind of behavior is seen as trying to beat the red light rather than running over the red light, by which they are in the transition stage of traffic light phase from green to red or amber to red.
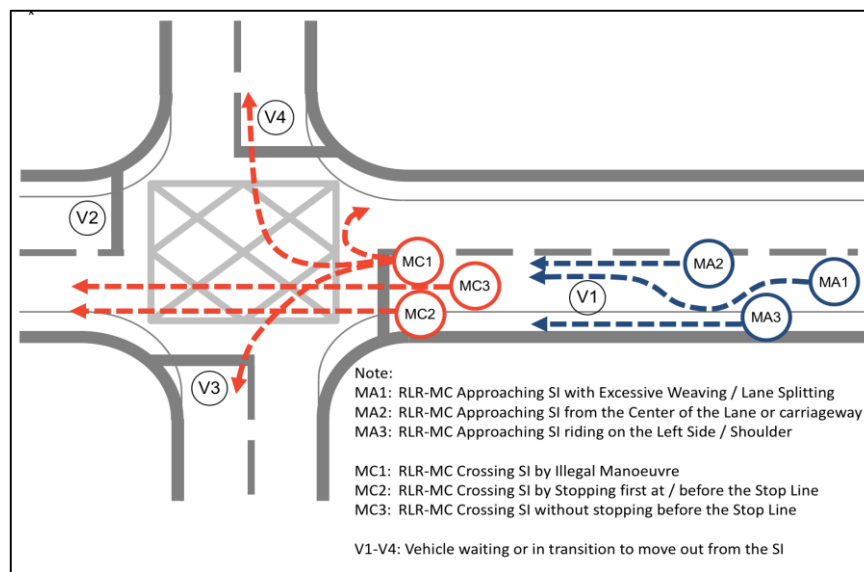

Figure 4. The behaviour of RLR-MC when approaching and crossing the SI

4.3.1*Association of Scenario 1 and 2 and signal timing.* In order to see the association of Scenario 1 and 2, we refer to Table 8 and Figure 5. As seen in Table 8, there is a statistically significantly different between the behaviours in Scenario 1 and 2 ($p<0.05$). In order to look at the association between these two scenarios, the MCA plot in Figure 8 was used. Figure 8 shows that RLR-MC who moves along the centre of the lane are likely to stop at the stop line before run the red light at a 4 leg signalized intersection. Meanwhile, those motorcyclists whom ride on the shoulder are like to run the red light without stopping at the stop line, i.e. beat the red light. These scenarios are like to occur at 3-leg signalized intersection.

Table 8. Number of RLR-MC based on Scenario 1 and Scenario 2

RLR-MC approaching the SI (Scenario 1)	RLR-MC crossing the SI (Scenario 2)			
	Illegal maneuver	Stopping first at stop line	Without stopping at stop line	Grand Total
Weaving / lane splitting	7	20	62	89 (1.72%)
From the center of the lane	23	1,629	806	2,458 (47.57%)
From the Left Side or Shoulder	71	774	1775	2,620 (50.71%)
Grand Total	101 (1.95%)	2,423 (46.89%)	2,643 (51.15%)	5,167

Pearson chi2(4) = 722.0462   Pr = 0.000

Note that the Table 14 was not used as a reference in interpreting the MCA plot but rather to tabulate in order to calculate the statistical difference via Person Chi2

From the cluster of variable (see Figure 5: left side) which sits closely together in the plot, those RLR-MC who approach the SI by riding on the center lane and run the red light after stopping at stop line, are mostly found on 4 leg SI which are associated with green time of 20s – 40s and 60s – 80s, red time of 80s – 120s and amber time of 1s and 2s. RLR-MC behavior such as not stopping at the stop line, preforming lane splitting / weaving and riding on the shoulder are not associated with any of the signal timings, however, those RLR-MC who approach the SI via riding on the left or shoulder are closely associated with traffic signal green time of 10s – 20s. Where else, Illegal maneuver are associated with amber time of 3s and red time of about 40s to 80s. Interestingly enough, the all of the actuated signal time phase are plotted away from the behavior variables which may indicate that RLR-MC behavior are not associated or rarely occurs on SI with actuated signals.
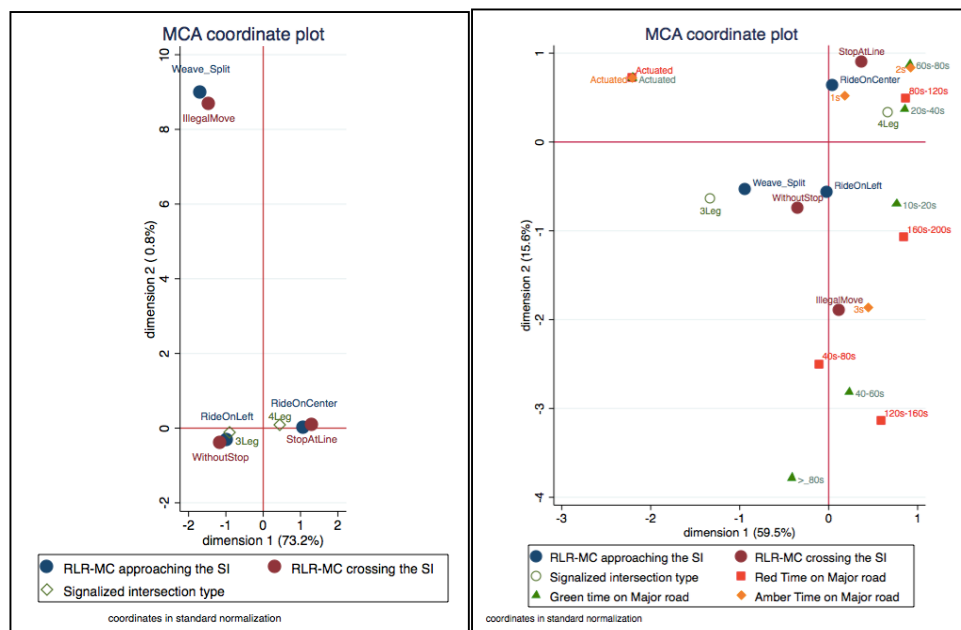

Figure 5. MCA plot for RLR-MC crossing and approaching the SI and association with signal timing

4.3.2 *Analysis of RLR-MC based on motorcycle characteristics and movement*. From the MCA plot in Figure 6, it is clear that male RLR-MC performs most of the behaviours (approaching by riding on the centre or the left side, RLR before stopping or without stopping) and with or without a pillion rider. However, male RLR-MC are more incline to display these behaviour on 4-leg SI, where their most frequent RLR movement are when they are moving from a major to minor road and also minor to minor road. As for the female RLR-MC, they can be considered as an outlier in this analysis but the plot show that they are closer to behaviours such as approaching the SI on the left or shoulder or running the red light without stopping. On 3-leg SI, we can see that most of the RLR movement occurs when the RLR-MC crosses from a major road to a major road (i.e. straight movement), and they are occasionally associated with behaviour such as approaching the SI by weaving or lane splitting or crossing it via illegal movement.

Based on the bottom left quadrant of the graph, we can see that RLR-MC that are approaching the SI by riding on the left or shoulder and crossing the SI without stopping at the stop line are associated with: 3-leg SI with a total of 4-lanes on the major roads with 70km/h speed limit (see Figure 6). RLR-MC that are approaching the SI by riding on the center lane and stopping at the stop line before running the red light are closely associated with: 4-leg SI with 4-lanes minor roads with median and along major road with 60km/h speed limit. In addition to this, RLR-MC that performs illegal maneuver are also

associated with these variables, but can be found more on SI with minor road with no shoulder. As for those RLR-MC that perform weaving or lane splitting, there are no clear association with any of the infrastructure variable as it is plotted away from it.

Variables such as: road with 50km/h speed limit, SI with 1, 2, 3 and 4 traffic island, 6-lanes major roads, 3-lanes and 5-lanes minor roads, SI with pole traffic signal, and major road with shoulder, are plotted away from these behavior variables, which may indicate that RLR-MC behaviors are not associated or rarely occurs on SI with these infrastructures.
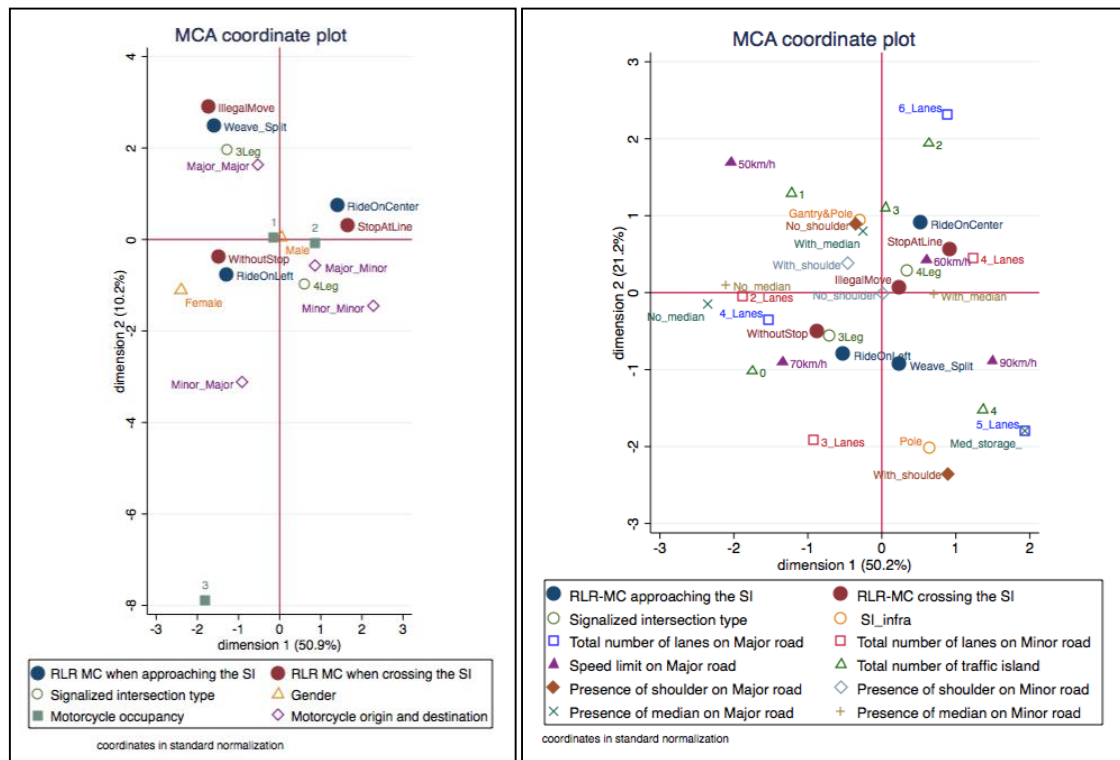

Figure 6. MCA plot for RLR-MC behaviour, motorcycle and infrastructure characteristics

4.3.3 *Analysis of RLR-MC based on number of vehicles waiting*. Figure 7 indicates that general, as the number of vehicles waiting increases either on the major or minor road, the number of RLR-MC occurred at 3-leg SI decreases significantly. When comparing the number of vehicles waiting on each road (leg), Figure 7 shows that 90.9% of RLR-MC occurred at 3-leg SI, when zero to five vehicles are waiting on the minor road, while 54.5% of RLR-MC occurred when zero to five vehicles are waiting on the major road instead. However, when there are five to ten vehicles waiting on the minor road, RLR-MC rate decrease down to 7.7% while 22.6% RLR-MC occurred when five to ten vehicles waiting on the major road.
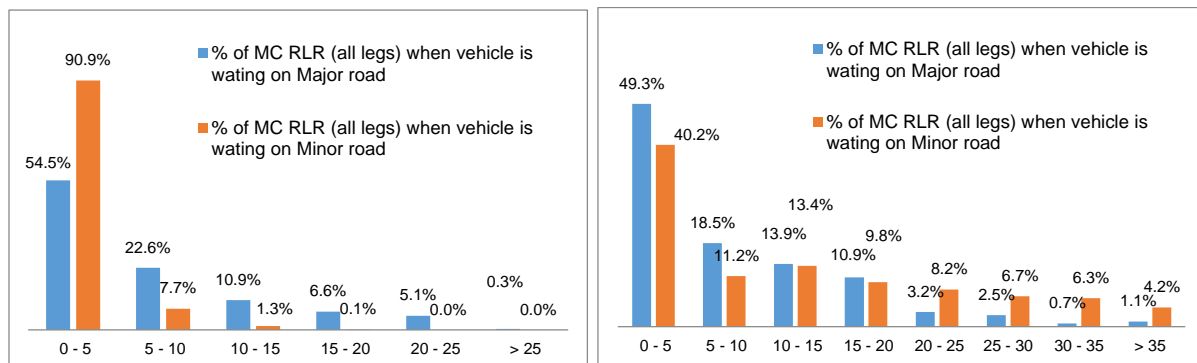
Figure 7. Rate of RLR-MC at 3-leg (left) and 4-leg (right) SI based on the number of vehicle waiting

When comparing between the two types of SI, the 4-leg SI has a lower rate of RLR-MC when there are zero to five vehicles waiting on both major and minor road (see Figure 7). In contrast to 3-leg SI, the rate of RLR-MC is higher (49.3%) when there are zero to five vehicles waiting on major road compared to those same number waiting on the minor road (40.2%). In addition, as the number of vehicle increases on the minor road, 4-leg SI has a higher rate of RLR-MC occurrence compared to 3-leg SI, but has a lower rate of RLR-MC when there is an increase of vehicle waiting on the major road.

5. Discussion

This study investigates the factors that are associated with red light running motorcycle (RLR-MC) behavior during their approach and crossing the signalized 3-leg and 4-leg intersections along majors in Malaysia and develops countermeasures in order to curb these risky behavior. This study was conducted in early 2016 and ends in mid 2017, where only **27** intersections with Pre-timed traffic light (PTTL) and Actuated traffic light (ATL) were selected based on a strict selection criteria and observed during peak and off peak hour period. As part of the data collection and analysis process, the research team developed state-of-the-art prototype software called MECHRED, dedicated for data collection and management. In analyzing these variables, a Multiple Correspondence Analysis (MCA) was used in order to clustered or find a pattern relating RLR-MC behavior to the SI characteristics, infrastructure, dimension, signal timing, traffic volume and motorcycle characteristics.

In general, the average rate of RLR-MC was 3.61%, by which the highest rate of RLR-MC recorded was 22%, while the lowest rate was 0.6% from the total traffic volume. This rate is quite small as compared to the done by Kulanthayan, et al. [8], however our rate remains higher as compared to other vehicle (RLR by other vehicle is 1.2%), which also corresponds to the study done by Kulanthayan, et al. [8]. In addition, this study show that RLR-MC on 3-leg SI occurrences are not much difference on 4-leg SI, regardless of the peak and off peak period. Furthermore, the rate of RLR-MC occurrence increases as the traffic volume along the major road increases, especially during peak hour.

Our observations have shown that there are three-ways RLR-MC approached the signalized intersection, i.e. (1) approaching the SI with Weaving or Lane Splitting, (2) approaching the SI from the center of the lane, and (3) approaching the SI from the left side or on the shoulder. Among these approaching behaviors, 'approaching the SI with Weaving or Lane Splitting' is the least common one with only 1.72% from the total observation.
Among all the RLR-MC approaching behaviors, the weaving or lane splitting is a considered a form of an aggressive riding behavior (see Shinar [35]).

RLR-MC crossing the SI without stopping at or before the stop line is the most dangerous among all behavior. We would classify this RLR-MC crossing without stopping as a form of risk taking behavior, because the RLR-MC would not stop and most of the time beat the red light after they slow down while have a 'quick look' of the traffic (i.e. turn their head quickly to scan the traffic). Moreover, most of the time, they are seen risking their lives by beating the red light with high speed in order to surpass the incoming crossing vehicles.

Our analysis has shown that motorcyclists who run the red light without stopping are associated with 3-leg SI with a total of 4-lanes on the major roads with 70km/h speed limit. This risky behavior however, is also not associated with any of the signal timings or any of the dimension variables, which indicate that this behavior occurrence may be highly dependent by the motorcyclist's personality or other factors previously mention. After viewing the analysis on this particular behavior, we can see that RLR-MC who cross the SI without stopping at the stop line requires a SI which has a high-speed limit (70km/h) and also location that has RLR-MC behavior as a norm.

We also detected another risk-taking behavior is the RLR-MC crossing via illegal maneuver. This is a rare behavior, which only records up to 1.95% from the total observation, but its movement stood out as risk-taking behavior because this RLR-MC behavior is unpredictable to other road user at the signalized intersection. Our observation has revealed that RLR-MC performs sudden illegal U-turn during the red-phase and sometimes moves in the opposite direction of the traffic (i.e. contra flow) into either into the major or minor road. Based on the analysis, we can generalize that RLR-MC crossing via illegal maneuver are mainly perform from those crossing from a major road into a major road and when the SI has a long and predictable amber time and red time and combined the presence of high motorcycle volume along the major road.

Our analysis has shown that there is an association between the approaching and crossing behaviors. It seems that, at a 4 leg signalized intersection, RLR-MC who moves along the center of the lane are likely to stop at the stop line before run the red light. Meanwhile at 3-leg signalized intersection, those motorcyclists whom ride on the shoulder are like to run the red light without stopping at the stop line. This shows that by riding on the shoulder or center of the lane, a motorcyclist may have to opportunity to be away from the main traffic and maintaining a distance further away from the crossing vehicles when they run the red light. The only difference is that, a shoulder on a 3-leg SI provides the RLR-MC more space to cross without stopping.

The number of vehicles waiting on the major or minor road influences the red light occurrence among motorcyclists. Our analysis shows that as the number of vehicles waiting increases either on the major or minor road, the number of RLR-MC occurrence decreases significantly. Between the 2 types of SI, we can generalize the rate of RLR-MC would significantly drop when there are 5 – 10 vehicles waiting on either the major or minor road. This shows that the RLR-MC are cautious on the presence of vehicle regardless of the road type, and would stop for the red light as the number of vehicle waiting increases.

The limitation of this study was more towards the site selection process, where we had to undergo painstaking process of visiting each screened location in order to verify its conductivity of data and location suitability. This process has taken a long time to accomplished and has consumed much of our resources. We hope that in the future that all information pertaining the intersection design, crash information and traffic volume in Malaysia to be collected and stored in a database so that it can be useful for future research such as this.

6. Conclusion and Recommendations

This study intends to investigate factors that are associated with motorcyclist red light running behavior at signalized intersection and develops countermeasures in order to curb the risky behavior. Despite the low rate of RLR-MC reported in this study, their aggressive approach and risk-taking crossing should not be taken easy. Thus, we are recommending some measures in order to curb the behaviour:

- Construct traffic island (i.e. protective left turn channelizing island) in order to restrict illegal movement and also discourage RLR-MC crossing the SI without stopping.
- Replace the SI signal type from pretimed to actuated signal time phase. This is to make the SI signal phase less predictable thus discourage RLR-MC.
- Building traffic light pole instead of gantry is encouraged on location where there is a high volume of motorcycle. This is to restrict their view of the traffic light ahead and discourage them from approaching the SI aggressively (via. Weaving or lane splitting)

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