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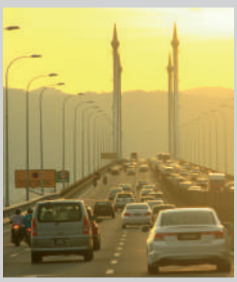

Research Report

Red Light Running Motorcyclists at Signalised Intersection in Malaysia: An Empirical Study

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Abstract

Malaysia currently ranked number five (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. Although the great majority of motorcycle fatal crashes in Malaysia are reported on straight road sections, motorcycle fatal crashes reported on major signalised intersections (SI) (i.e. 3-legged and 4-legged) is the next most common (18.5%). This study investigates the factors that are associated with red light running motorcyclist (RLR-MC) behaviour based on approaching and crossing movement type at the 3-legged and 4-legged SI along major roads in Malaysia and develops countermeasures in order to curb this risky behaviour. This study was conducted in early 2016 and ends in mid of 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. In general, the average rate of RLR-MC was 3.61%, by which the highest rate of RLR-MC recorded was 22.5%, while the lowest rate was 0.6% from the total traffic volume. Our observations have shown that there were three (3) movement types of RLR-MC approached the SI, - (a) approaching the SI with Weaving or Lane Splitting, (b) approaching the SI from the centre of the lane, and (c) approaching the SI from the left side or on the shoulder. There were three (3) movement types of RLR-MC cross the SI, - (a) crossing the SI by illegal manoeuvre (illegal U-turn, contra-flow, prohibited left-turn), (b) crossing the SI by stopping at or before the stop line, and (c) crossing the SI without stopping before the stop line. Among these crossing behaviours, crossing the SI without stopping at the stop line was the majority with 51.2% from the total observation and it may be associated with the high speed limit road. In order to curb the risky behaviour, it is recommended that the SI with high RLR-MC to be equipped with adequate traffic island, replace the SI signal type from PTTL to ATL system and installing traffic light on pole instead of gantry to restrict motorcyclist's view of the traffic light's indicator and discourage aggressive approach.

1. Introduction

According to the World Health Organization (WHO), close to a quarter (24.1%) of the world's road traffic deaths occur among motorcyclists or powered-two-wheelers (PTW) (WHO, 2013). 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. 65% of the world's motorcycles are in Asia, whereas Europe and North America account for only 16% (Haworth, 2012). The four (4) countries with the highest numbers of motorcycles per 1,000 of population are Malaysia, Thailand, Cambodia and Japan (Haworth, 2012; Senbil et al., 2007). 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 (Haworth, 2012; WHO, 2013). 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 (Abdul Manan, 2014; WHO, 2013). In 2013, Malaysia ranked as number five (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 (WHO, 2013). In addition to this, Malaysian motorcycles represent about 20% to 35% of motorised vehicle fleet, which are over-represented in road traffic crashes (as similar to Singapore (Haque et al., 2012) and Indonesia (ESCAP, 2009)); accounting for about 47% of total road traffic crashes and 59% of road fatalities (Abdul Manan & Várhelyi, 2012). On average, more than 70 motorcyclists are killed in road traffic crashes every week, and more than ten (10) motorcycle riders are killed every day (Abdul Manan & Várhelyi, 2012, WHO, 2013).

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 signalised intersections (SI) (i.e. 3-legged SI and 4-legged SI) is the next most common (18.5%) (Abdul Manan & Várhelyi, 2012). 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 SIs have a higher motorcycle fatal crash rate (23.9%: 4-legged, 19.8%: 3-legged) compare to the un-signalised intersections (USI) ($p < 0.01$), despite both 3-legged and 4-legged USI have a higher number of reported crash cases. Moreover, if we narrow down these motorcycle fatal crash rates based on various location types (Table 2), various road jurisdiction classifications (Table 3) and various area type (Table 4), **SIs** are shown to have a statistically significantly higher fatality risk (i.e. fatality rate) than USI ($p < 0.05$). In addition, **4-legged SI** have a higher fatality risk than a 3-legged SI ($p < 0.05$) while SI located in **towns** and along **State** owned roads have a higher fatality crash risk than those SI located in cities and rural areas, and on other type of road jurisdiction ($p < 0.05$). As for the area type on which the SI is located, those located in an **industrial**, **commercial** and **residential** area, are the most risky compared to those other type of area ($p < 0.05$).

Table 1 The percentage of motorcycle fatal crashes at intersections

Intersection type	SI	USI
4-legged	23.9% * (n = 522)	17.4% * (n = 1,404)
3-legged	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), analysed by MIROS

Table 2 The percentage of motorcycle fatal crashes at intersections based on various location type

Intersection at various location type	SI	USI
City	20.7% * (n = 87)	15.1% * (n = 411)
Town	26.3% * (n = 243)	15.4% * (n = 978)
Small town	23.6% * (n = 174)	18.4% * (n = 1,469)
Rural	19.3% * (n = 352)	15.7% * (n = 3,872)

n: Total number of reported crash cases involving motorcycle since 2010 – 2011.
Location type: City is classified as an area that has a population > 100,000, Town is classified as 100,000 < population < 50,000, Small town is classified as 50,000 < population < 5,000, Rural is classified as population < 5,000.
* Statistically significant difference according to Chi-sq. test ($p < 0.05$)
Source: PDRM (2011), analysed by MIROS

Table 3 The percentage of motorcycle fatal crashes at intersections based on various category of road jurisdiction

Intersection at various road jurisdiction	SI	USI
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), analysed by MIROS

Table 4 The percentage of motorcycle fatal crashes at intersections based on various area type

Intersection within the vicinity of various area type	SI	USI
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 signify an area with very few population, e.g. plantation, forest, etc.
* Statistically significant difference according to Chi-sq. test ($p < 0.05$)
Source: PDRM (2011), analysed by MIROS

1.2 Red Light Running among Malaysian Motorcyclists

One of the factors that influence fatal crashes among motorcyclists may be due to the red light running (RLR). Local studies such as Kulanthayan et al. (2007) and Law et al. (2003) have found out that, RLR among Malaysian motorcyclists 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 traffic light violations and the findings shows that motorcycle recorded higher violation of traffic lights with 13.5% motorcycles compared to 4-wheeled vehicles with 11.1%, and the odds ratio analysis shows that the violation increased by 1.24 times for motorcycles compared with 4-wheeled vehicles (Kulanthayan et al., 2007). Factors influencing motorcycle's RLR in Malaysia are found to be more on during the weekends (Kulanthayan et al., 2007), on intersection without enforcements (e.g. RLR cameras, police, etc.) (Hawa et al., 2014; Kulanthayan et al., 2007), longer cycle time (> 160s), 4-phase signal timing, 4-legged SIs and high motorcycle volume (Law et al. 2003).

The effects of number of lanes are still unknown with respect to the behaviour of Malaysian motorcycles. Studies have shown that road with higher number of lanes has shown the potential of increasing speed (Elvik et al., 2009; Várhelyi, 1996). This could lead to the assumption that motorcycle may increase their speed on SI with many lanes and thus, with given opportunity, my beat the red light.

Many factors, such as rider characteristics influencing or associated with RLR 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 characteristics associated with RLR 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. (2003), Kulanthayan et al. (2007), Che Puan and Ismail (2010) and Hawa et al. (2014).

1.3 Research Questions

This research project is driven in terms of two (2) scenarios, which involves only red light running motorcyclists (RLR-MC), i.e. (Scenario 1) RLR-MC behaviour when approaching the SI and (Scenarios 2) RLR-MC when crossing the SI (see Figure 1). Thus, reflecting on local research findings, the research questions for this study are that addresses these two (2) scenarios (see Figure 1):

i. Is there any risky behaviour prior to the RLR attempted by the motorcyclists?
ii. What is the most common risky behaviour of the RLR-MC when approaching (Scenario 1) and crossing (Scenario 2) the SI?
iii. Which road infrastructure, dimension or traffic volume factors are influencing the motorcyclists' risky behaviour when approaching (Scenario 1) and crossing (Scenario 2) the SI?
iv. How do Malaysian motorcyclists run the red light?
v. Is there any correlation between motorcyclists' risky behaviour approaching (Scenario 1) and crossing (Scenario 2) the SI when running the red light?
vi. Which motorcycle characteristics or movement that are influence the RLR behaviour among motorcyclists?
vii. Does the number of vehicle waiting on the major or minor road influence the red light occurrence?

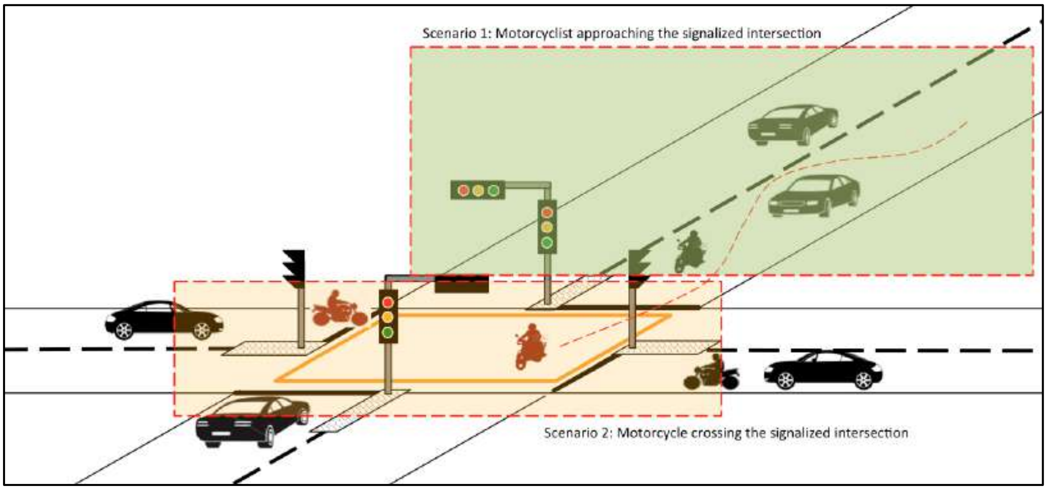

Figure 1 Scenarios of events of RLR-MC

1.4 Scope and Objectives of the Study

This study intends to investigate factors that are associated with RLR-MC behaviour at SI and develops countermeasures in order to curb the risky behaviour. To achieve this, we have layout several specific objectives, as per below:

i. To identify motorcyclists' risky behaviour prior and during their RLR behaviour
ii. To determine factors that are associated with RLR-MC
iii. To develop countermeasures based on the findings

1.5 Limitation of the Study

The study only focused on RLR-MC on selected SI. This study also focuses on 3-legged and 4-legged SI along major roads in Malaysia.

2. Literature Review

Literature reviews of human behaviours on traffic safety suggest that there are several human related behaviour categories, which can be explored to examine their impacts on the motorcycle safety at SI. Among these are: aggressiveness, sensation seeking or impulsivity, and risk-taking behavioural traits are identified and hypothesised as the most important personality traits to influence the crash risk (Shinar, 1998), especially for motorcyclists.

2.1 Motorcycle Risky Behaviour at SI

Weaving or lane splitting behaviour is among the aggressive riding behaviour when approaching an intersection. According to Shinar (1998) aggressive driving, or in this case riding motorcycle, is defined in terms of the frustration-aggression model. These behaviour categories can either take the form of instrumental aggression - that allows the frustrated rider to move ahead at the cost of infringing on other road users' rights (e.g., by weaving or lane splitting) - or hostile aggression which is directed at the object of frustration (e.g., cursing other drivers). In fact, a study have shown that majority of Malaysian car drivers has experience anger while driving and women tend to have more aggressive thoughts than men Ismail et al. (2009). However, it is not known the extent of aggressive behaviour among motorcyclists in Malaysia SI.

Sensation seeking and impulsivity such as RLR and speeding is another important behaviour category, which are both closely related. Impulsiveness and sensation seeking traits have common behavioural and biological correlates (Zuckerman, 1996). Jonah (1986) has reviewed the literature to investigate the relationship between sensation seeking and risky driving such as RLR, speeding, driving while impaired, and following too closely and consequent collision risks. It has been reported that sensation seekers are likely to experience risky driving activities, which in turn, increase their collision rate.

Impulsivity or impulsiveness is defined as the tendency to enter into situations, or rapidly respond to cues for potential award, without much planning and considerations of potential punishment or loss of reward (Zuckerman, 1996), for example RLR. Hence, impulsivity may also affect road safety if drivers behave impulsively in any road traffic situation, especially in a SI, which has many conflict points. Motorcyclist too have similar or not higher level of impulsive sensation seeking behaviour as other motorist driver, but a study by Haque et al. (2010) shows that it does not have a significant effect on his vulnerability but it has been found to be highly associated with aggression and risk-taking.

Risk-taking is another behaviour category, which may be significantly related to safety motorcyclists. Risk taking in motorcycling includes deliberately not following road rules (including excessive speeding), unlicensed riding, riding with dark clothing, riding while impaired by drugs and alcohol, and riding un-helmeted (Haworth et al., 2009; Lin et al., 2004). Risk taking is one contributor to the over-representation of motorcycles in fatal and serious injury crashes, along with vulnerability to injury, inexperience or lack of recent experience, driver failure to see motorcycles, instability and braking difficulties, and road surface and environmental hazards (Haworth et al., 2009).

The above-mentioned behavioural factors have been explored to relate with driver behaviour and associated crash risks. However, their impacts on the motorcyclists are still not well understood, especially at SI in Malaysia. Table 5 below shows the behaviour category associated with motorcycle risky behaviour (observed at intersection studies such as in Abdul Manan and Várhelyi (2015), Clarke et al. (2005), de Rome et al. (2011), Haque et al. (2009) (2010), Hawa et al. (2014) and Radin Umar (2005), which was used as a guide for this study). Noticed that in Table 5, all of the motorcyclist's risky behaviours are related to the risk taking behaviour category, which are the key indicator for these study.

Table 5 Behaviour categories associated with motorcyclist's risky behaviour at SI

Motorcyclists' risky behaviour	Behaviour category		
	Aggressive riding	Sensation seeking or impulsivity	Risk taking
Weaving between motorists	✓	✓	✓
Running red lights	✓	✓	✓
Speeding	✓	✓	✓
Lane splitting while speeding	✓	✓	✓
Not stopping at the stop line	✓		✓
Not wearing helmet			✓
Wearing dark clothing			✓
Not using headlight			✓

Note: The tick (✓) represent the association of behaviour traits based on literatures

2.2 RLR among Road Users

Among all the risky behaviour discussed previously, RLR among road users stood out as the most extreme or highly risky behaviour, which leads to a crash. This is because road crashes occur when there are conflicting vehicle movements (Elvik et al., 2009; ITE, 1999; JKR, 2002). One such cause of these road crashes to occur is due to RLR. Research has revealed that increasing numbers of RLR related crashes in recent years were reported in many studies across some continents (Elmitiny et al., 2010; ITE 2003; Johnson et al., 2011; Retting et al., 1999b; Romano et al. 2005) emphasizing the significance of RLR as a major traffic safety concern. For example, 43% of all roadway crashes and 23% of fatal crashes occur at intersections or intersection related sites in the United States and preliminary estimates revealed that there were nearly 218,000 RLR crashes at intersections, which resulted as many as 181,000 injuries and 880 fatalities (ITE, 2003; Porter & England, 2000). In Australia, RLR is a significant road safety problem whereby 10% to 30% of crashes at SIs involve RLR (Green, 2003; Johnson et al., 2011).

Generally, a driver is defined as a red light runner when he or she proceeds across the stop bar of intersection after the signal has changed to red. Retting and Williams (1996) however added crossing 0.5 sec after the red signal as the definition of RLR. Previous studies categorised groups of red light runners based on the following situation: indecision due to slower traffic (Retting & Williams, 1996); caught in the dilemma zone (Porter & England, 2000); and deliberately run the light.

RLR is also a complex problem and there is no simple or single reason to explain why drivers run red lights. There is a tendency to cite driver error either intentional or unintentional disregard of the traffic signal (ITE, 2003). There are also elements of driver psychology and sociology behind the violations and any driver may be susceptible to committing a violation (Grayson et al., 2003; Groeger & Rothengatter, 1998; Ulleberg & Rundmo, 2003). There is also evidence that drivers may be induced into running red lights because of improper signal design or operation (ITE, 2003) and these elements make RLR difficult to predict and a difficult problem to solve (ITE, 2003). In general, RLR crashes were more likely than other crashes to produce some degree of injury, more likely to occur on urban roads than other fatal crashes and were somewhat more likely to occur during the day (ITE, 2003; Retting & Williams, 1996).

Many research in developed countries, e.g. U.S., U.K, European countries, etc., has put more focus on discovering the driver (including motorcyclists) characteristics and road traffic environment factors associated with red light runners behaviour. The driver's characteristics which are associated with red light runners behaviour are found to be: young drivers/riders (Lawson, 1991; Retting et al., 1999a), male (Porter & England, 2000; Martinez & Porter 2006), less likely to wear safety belts (Porter & England, 2000), poor driving records (Green, 2003; Retting et al., 1999b), under the influence of alcohol (Bonneson & Zimmerman, 2004; Romano et al., 2005) and drive smaller or older vehicle (ITE, 2003; Retting & Williams, 1996). 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 (Elvik et al., 2009; ITE, 2003). As for road traffic environment factors, Porter and England (2000) and Martinez and Porter (2006) 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 RLR rate and crash risk would increase (Elmitiny et al., 2010). 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 61.3 m to 128.0 m from the intersection (Elmitiny et al., 2010).

3. Methodology

This study was conducted in early 2016 and ends in mid-2017, with three (3) main phases: (1) Site selection criteria and identification, (2) Site verification and data collection, (3) Statistical analysis.

3.1 Site Selection Criteria and Identification

There are two (2) types of traffic light signal time in Malaysia based on Kulanthayan et al. (2007) 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 maximises 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 optimise the usage of the traffic junction. Another type of traffic light has a countdown timer (CTTL). It is a 2-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 (2) types of traffic light signal time, i.e. Pre-timed traffic light (PTTL) and Actuated traffic light (ATL), on each 3-legged and 4-legged SI. As for the location, we prioritised the SIs that connect a major road with a minor road, for example a Primary road with a Secondary road, or Collector with a Local road, etc. The location of these SIs were also narrowed down into ***town*** area nearby an ***industrial***, a ***residential*** or ***commercial area***. This is based on the fact that the fatality rate involving motorcycles at SI are higher compared to their respective category.

Additional selection criteria for each SI are as follow:

i. 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.
ii. 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.
iii. The SI shall have a vantage point for the researches to conduct the observations and to collect speed data obscurely from other road users.
iv. 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 (4)** SI with each type of SI signal time (PTTL and ATL) and each for 3-legged and 4-legged intersection on every major town in their respected region. For example, the central region has three (3) 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 (2) synchronised camera (see Figure 2) position on a strategic location in the vicinity of the SI. These cameras was mounted on a customised 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 seven (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 (7.00 am – 8.00 am, 5.00 pm – 6.00 pm) and off peak hour (10.00 am – 11.00 am, 4.00 pm – 5.00 pm) with duration of one (1) hour each.

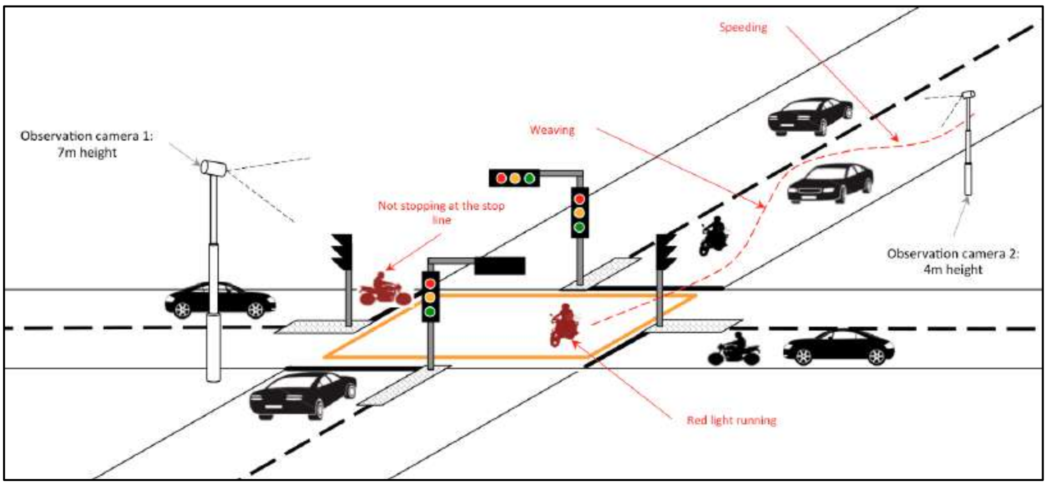

Figure 2 Position of observation camera

3.2.2 Types of Variables for Acquisition

Once all the sites have been identified, each SI's characteristics, infrastructure measurements, signal timings, traffic volume and motorcycle characteristics were captured and categorised accordingly (see Table 6, Table 7 and Table 8).

Table 6 Variables on SI characteristics

No.	Factors	Variables (categorical)
1.	SI type	3-legged, 4-legged
2.	Region	North, East, South, West
3.	SI signal type	Actuated, Pre-timed

Table 7 Variables on SI timing and infrastructure

No.	Factors	Variables (continuous / categorical)
1.	Red time category [a]	Actuated, 40s - 80s, 80s – 120s, 120s – 160s, 160s – 200s
2.	Green time category [a]	Actuated, 10s – 20s, 20s – 40s, 40s – 60s, 60s – 80s, > 80s
3.	Amber time category	Actuated, 1s, 2s, 3s
4.	Major road signal infrastructure	Signal on Pole, Signal on Gantry
5.	Minor road signal infrastructure	Signal on Pole, Signal on Gantry
6.	Total number of lanes on Major road	4 lanes, 5 lanes, 6 lanes
7.	Total number of lanes on Minor road	2 lanes, 3 lanes, 4 lanes
8.	Speed limit on Major road	50 km/h, 60 km/h, 70 km/h, 90 km/h
9.	Speed limit on Minor road	50 km/h, 60 km/h, 70 km/h, 90 km/h
10.	Number of traffic island	0, 1, 2, 3, 4
11.	Lane width – Major road [a]	3.00 m – 3.25 m, 3.25 m – 3.50 m, 3.50 m – 4.00 m, > 4.00 m
12.	Lane width – Minor road [a]	< 3.00 m, 3.00 m – 3.25 m, 3.25 m – 3.50 m, 3.50 m – 4.00 m, > 4.00 m
13.	Shoulder width – Major road [a]	0 m, 0.0 m – 0.5 m, 0.5 m – 1.0 m, 1.0 m – 2.5 m, 2.5 m – 3.0 m
14.	Shoulder width – Minor road [a]	0 m, 0.0 m – 0.3 m, 0.3 m – 0.5 m

15.	Median width – Major road [a]	0 m, 0.0 m – 1.0 m, 1.0 m – 2.0 m, 2.0 m – 3.0 m, > 3.0 m
16.	Median width – Minor road [a]	0 m, 0.0 m – 1.0 m, 1.0 m – 2.0 m, 2.0 m – 3.0 m, 3.0 m – 4.0 m
17.	Major road crossing length [ab]	0 m – 10 m, 10 m – 15 m, 15 m – 20 m, 20 m – 25 m
18.	Minor road crossing length [ab]	10 m – 15 m, 15 m – 20 m, 20 m – 25 m, 25 m – 30 m, 30 m – 35 m

Note:
[a] – Indicates that the factors were measures on site and later categorised into few categories.
[b] – Crossing distance is measured from the stop line to stop line for each leg.

Table 8 Variables on SI traffic volume

No.	Factors	Variables (continuous / categorical)
1.	Time of observation	Peak, Off peak
2.	Traffic volume – Major leg	800 – 1000, 1000 – 2000, 2000 – 3000, 3000 – 4000, > 4000
3.	Traffic volume – Minor leg	< 250, 250 – 500, 500 – 1000, 1000 – 1500, > 1500
4.	% of MC passing on Major leg	< 15%, 15% - 25%, 25% - 50%, > 50%
5.	% of MC passing on Minor leg	< 15%, 15% - 25%, 25% - 50%, > 50%
6.	No. of vehicles on Major leg 1	- Count -
7.	No. of vehicles on Major leg 2	- Count -

Note:
Traffic volume: Number of vehicles passing the intersection during 1 hour of observation
PC: Passenger car / sport utility vehicles / van / mini van
MC: Motorcycle
HV: Heavy vehicles / trucks / bus / semi
Presence of vehicle: Refers to the presence of vehicle waiting on the opposite leg when the RLR occurs
RLR-MC: Red light running motorcyclist
No. of vehicles on Major leg 1 and leg 2: Count of vehicles on each leg during each RLR-MC occurrence

For every RLR-MC, all of its characteristics, movement and motorcyclists' riding behaviour was identified and recorded (see the variables in Table 9). 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' RLR Behaviour Data Management Software), dedicated for data collection and management of motorcycle characteristics and motorcyclists' RLR behaviour at SI. MECHRED consists of two (2) video interfaces and a data logger interface (see Figure 3). For every passing motorcycle in the video, the observer goes through each factor (see Table 9) and chooses the suitable option for the motorcycle and motorcyclist.

There are four (4) main categories, which the user needs to go through for each RLR motorcycle - (a) General information (SI measurements), (b) Motorcycle characteristics and movement, (c) Motorcyclists' characteristics, (d) Motorcyclists' riding behaviour approaching the SI and Motorcyclists' riding behaviour crossing the SI. The observers (MECHRED users) are the main author, co-authors and six (6) 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.

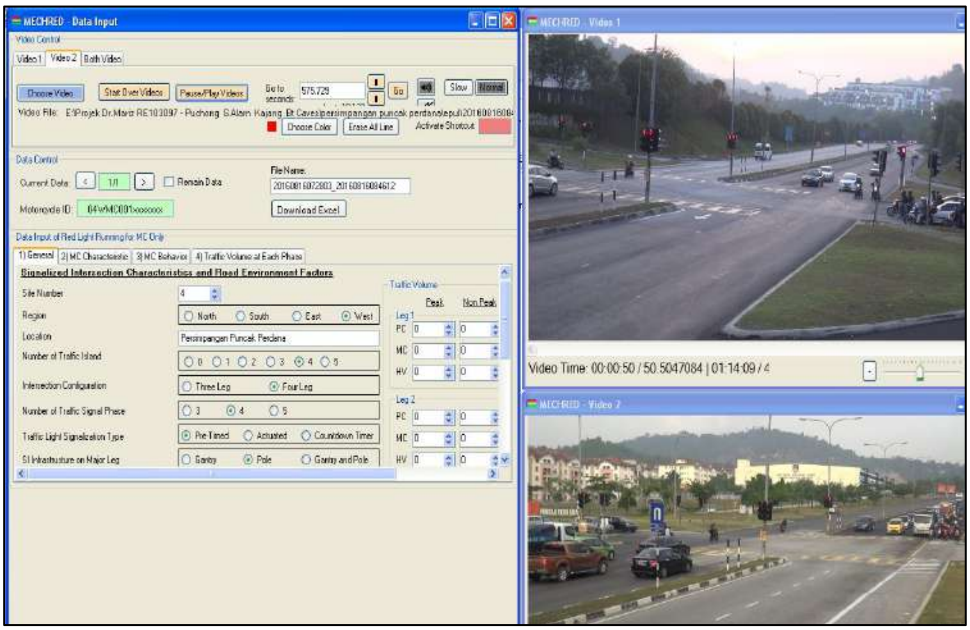

Figure 3 Screenshot of MECHRED software

Table 9 Variables on motorcycle and motorcyclists' characteristics and movement

No.	Factors	Variables (continuous / categorical)
i.	Motorcycle characteristics and movement	
1.	Motorcycle type based on c.c.	< 250cc, > 250cc
2.	Motorcycle number of occupancy [a]	1, 2, > 2
3.	Location of RLR-MC	From Major road, From Minor road
4.	Destination of RLR-MC	To Major road, To Minor road
ii.	Motorcyclists' characteristics	
5.	Gender	Male, Female
6.	Presence of clothing with reflector	Yes, No
7.	Helmet wearing	With helmet, no helmet

Note:
Illegal manoeuvre / crossing: The motorcyclists either make an illegal U-turn or moves in the opposite direction while running the red light

3.3 Statistical Analysis

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

MCA are methods for analysing observations on categorical variables. MCA is usually viewed as an extension of simple correspondence analysis (CA) to more than two (2) variables. CA analyses a 2-way contingency table; MCA and JCA (Joint Correspondence Analysis) analyse a multiway table.

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 (Greenacre & Blasius, 1994). As mention in Kalayci and Basaran (2014), 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 (Kalayci & Basaran, 2014). MCA can be a particularly powerful 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) (Kalayci & Basaran, 2014).

The use of MCA is, thus, particularly relevant in studies where a large amount of qualitative data is collected (Greenacre & Blasius, 1994; Kohler & Luniak, 2005). Following (Greenacre & Blasius, 1994; Kalayci & Basaran, 2014), MCA is a weighted PCA (Principal Correspondence Analysis) process applied to the indicatory matrix X, i.e. to the set of the J-binary variables but with the chi-square metric on row/column profiles, instead of the usual Euclidean metric. The chi-square metric is in fact a special case of the Mahalanobis metric used in Generalised Canonical Analysis (Kalayci & Basaran, 2014). The inner product of such a matrix, is called the Burt Table or Burt Matrix by which the result of the inner product of a design or indicator matrix, and the multiple correspondence analysis results are identical to the results would obtain for the column points from a simple correspondence analysis of the indicator or design matrix (STATA, 2013). Thus, based on (Kalayci & Basaran, 2014), the interpretation of MCA is given as follows:

i. MCA is best suited for exploratory research and is not appropriate for hypothesis testing and its correspondence graphs allow spotting the strongest relationships in a set n-way crosstabs.
ii. MCA is very sensitive to outliers, which should be using as supplementary points or eliminated prior to using the technique.

iii. The number of dimensions to be retained in the solution is based on dimensions with inertia (Eigenvalues) in Greenacre and Blasius (1994) suggested an adjusted inertia which gives a better idea of the quality of the maps.
iv. The distance between categories is based on a chi-square metric.
v. Categories, which are closer together, have higher chi-squares if analysed in a conventional cross-tabular format. The contributions, the test values and the squared cosines help in the interpretation of the results.
vi. The interpretation in MCA is often based upon proximities between points in a low-dimensional map (i.e., two (2) or three (3) dimensions).

According to Aitchison and Greenacre, 2002 and Kalayci and Basaran, 2014, for the proximity between categories we need to distinguish two (2) 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 (2) levels are themselves similar.

3.3.1 Notation

We use notation that is fairly standard in the literature on correspondence analysis (for example Greenacre and Blasius, 1994). Let $x_1, \ldots, x_q$ be categorical variables on N observations that are active in the analysis. To simplify notation, but without loss of generality, we assume that x_j is coded with consecutive integers $1, \ldots, n_j$. Let $Z^{(j)}$ be the $N \times n_j$ binary indicator matrix associated with x_j , $Z_{ih}^{(j)} = 1$ if and only if $x_{ij} = h$. Let

$$Z = (Z^{(1)}, Z^{(2)}, \ldots, Z^{(q)})$$

be the $N \times J$ indicator matrix of the set of active x-variables, where $J = n1 + \cdots + n_q$.

We will be consistent in letting i index observations $1,\ldots,N$, j index variables $1,\ldots,q$, and h index categories $1,\ldots,nj$, or $1,\ldots,J$.

The $J \times J$ Burt matrix is defined as $B = Z'Z$, or $B = Z'D(w)Z$, where w is the weight for the analysis and $D(w)$ is a $J \times J$ square matrix with the weights on the diagonal and 0 off diagonal. The diagonal block of B associated with variable x_j is a diagonal matrix with the frequencies of x_j on the diagonal. The off-diagonal block of B associated with variables x_j and x_k is the 2-way cross-tabulation of x_j and x_k.

In an analogous way, we define B^*, the Burt matrix with more rows containing cross-tabulation from the supplementary variables. $B^* = Z^{*\prime}Z$, where Z^* is the indicator matrix with more columns for the supplementary variables.

$D(v)$, in general, represents a diagonal matrix with the elements of vector v on the diagonal and 0 off diagonal; 1 is a column vector of ones where length is defined by the context.

4. Results

This section discusses the results and findings of the study. This section is divided into four (4) subsections: Site selection, Analysis on scenario 1, Analysis on scenario 2 and Overall analysis.

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 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 10. 48% from the screened 50 sites were rejected due to insufficient number of RLR-MC and unsuitable vantage point for observation. Figure 4 shows photos of RLR-MC occurrences at selected sites.

Figure 4 Photos of RLR-MC at selected sites

Table 10 Selected location of SI

	Region	State	N	Location	SI type		Crash history
					4L	3L	
i	Southern	Johor Bharu	1	Persimpangan Jalan Padi Mahsuri (Bandar Baru Uda)	√		6
			2	Persimpangan Jalan Pendidikan (Taman Universiti Skudai)		√	81
			3	Persimpangan Kampung Ungku Mohsin (Jalan Tampoi)	√		10
			4	Persimpangan Kampung Melayu (Jalan Tampoi)		√	0

ii	Northern	Perlis	5	Persimpangan Jalan Tuanku Syed Sirahjuddin		√	0
			6	Persimpangan Jalan Tuanku Syed Alwi	√		5
			7	Persimpangan Jalan Tuanku Syed Putra		√	0
			8	Persimpangan Masjid Batu 2	√		2
		Kedah	9	Persimpangan Jalan Kubang Rotan (Jalan Alor Star – Kangar)	√		0
			10	Persimpangan Jalan 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	Eastern	Kuala Terengganu	14	Persimpangan Medan Selera Batu Burok (FR3)	√		2
			15	Persimpangan Jalan Batu Burok (FR3) – Jalan Tok Adis	√		0
			16	Persimpangan Kamarudding (FR3) – Jalan Pusara		√	0
		Kuantan	17	Persimpangan Jalan Beserah - Jalan Air Putih (FR2)	√		0
iv	Central	Selangor	18	Persimpangan Tesco Bukit Puchong		√	0
			19	Persimpangan Puncak Perdana	√		0
			20	Persimpangan Jalan UPM Sri Serdang		√	68
			21	Persimpangan Jalan Wan Siew Sg Chua	√		51
			22	Persimpangan Padang Jawa	√		47
			23	Persimpangan Persiaran Kewajipan, Subang Jaya		√	350 (3)
			24	Persimpangan Persiaran Sukan Shah Alam		√	60
			25	Persimpangan UiTM (Pintu 2) Shah Alam	√		0
			26	Persimpangan Jalan Batu Caves	√		102
			27	Persimpangan Sunway Suria	√		0

Crash history = Total number of crash from 2012 – 2014
N: Site number
(): The number in the parenthesis is the total number of fatal crash cases over 2012 – 2014
4L: 4-legged SI
3L: 3-legged SI

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 1, the average rate of RLR-MC is **3.61%**, by which the highest rate of RLR-MC recorded was 22.1% at Site 24, while the lowest rate was 0.6% at Site 8 during off peak hours. RLR among other vehicles were also recorded, which is 1.2%. Moreover, average rate of number of RLR-MC during peak hours is higher (4.66%) than the off peak (3.6%).

Table 11 Number of RLR MC at the selected sites based on peak and non-peak hour

Site	Traffic volume - Major leg	Number of RLR - MC		Site	Traffic volume - Major leg	Number of RLR - MC	
		Off peak	Peak			Off peak	Peak
1	1,055	20 (1.90%)		15	2,771	45 (1.62%)	
	1,249		18 (1.44%)		2,844		37 (1.30%)
2	1,583	49 (3.10%)		16	2,195	107 (4.87%)	
	2,063		94 (4.56%)		2,950		145 (4.92%)
3	2,226	111 (4.99%)		17	2,940	109 (3.71%)	
	2,635		161 (6.11%)		3,047		136 (4.46%)
4	2,751	27 (0.98%)		18	3,818	55 (1.44%)	
	3,006		38 (1.26%)		4,058		139 (3.43%)
5	2,250	33 (1.47%)		19	2,194	106 (4.83%)	
	2,010		46 (2.29%)		3,528		370 (10.49%)
6	963	26 (2.70%)		20	2,644	92 (3.48%)	
	1,292		6 (0.46%)		3,327		79 (2.37%)

7	1,624	16 (0.99%)		21	1,358	37 (2.72%)	
	1,979		36 (1.82%)		1,326		27 (2.04%)
8	840	5 (0.60%)		22	878	30 (3.42%)	
	1,188		21 (1.77%)		1,159		22 (1.90%)
9	1,894	106 (5.60%)		23	2,449	27 (1.10%)	
	2,209		154 (6.97%)		3,084		116 (3.76%)
10	1,434	33 (2.30%)		24	2,007	443 (22.07%)	
	1,930		44 (2.28%)		3,008		677 (22.51%)
11	2,964	54 (1.82%)		25	2,571	38 (1.48%)	
	3,116		50 (1.60%)		2,630		62 (2.36%)
12	1,918	79 (4.12%)		26	1,489	53 (3.56%)	
	2,490		94 (3.78%)		2,141		55 (2.57%)
13	2,549	227 (8.91%)		27	3,449	112 (3.25%)	
	2,163		276 (12.76%)		3,404		188 (5.52%)
14	2,110	15 (0.71%)		**Average**	**2,108**	**76 (3.61%)**	
	2,840		21 (0.74%)		**2,469**		**115 (4.66%)**

(%): The rate of RLR-MC from the total volume count in percentage
Traffic volume: Vehicle count for one (1) hour period

Figure 5 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.

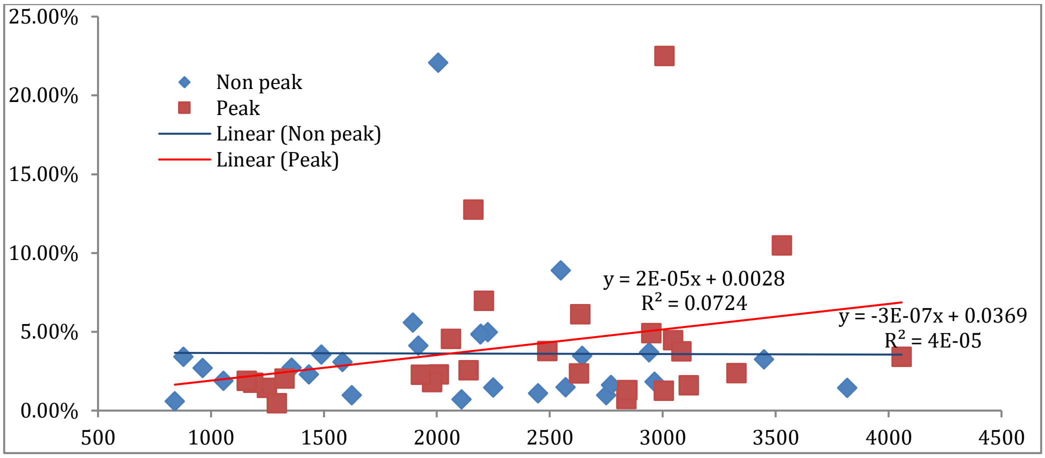

Figure 5 Distribution of RLR-MC rate based on the major road traffic volume

Table 12 shows that 3-legged SI has the highest RLR-MC rate (60.8%) compared to 4-legged 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-legged. This analysis however, is not statistically significantly different ($p > 0.05$), or in other term, RLR-MC on 3-legged SI occurrences are not much difference on 4-legged SI, regardless the period.

Table 12 Number of RLR-MC based on period category and type of SI

Period category	4-legged SI	3-legged SI	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	

(%): 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 (3) types of movement performed by RLR-MC: Approaching the SI with weaving / lane splitting, approaching the SI from the centre of the lane and approaching the SI from the left or shoulder (see Figure 6, note that the figure also applies for 3-legged SI). As for scenario 2, there are also three (3) typical types of RLR-MC movement: Crossing the SI by illegal manoeuvre (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 7, note that the figure also applies for 3-legged SI).

4.3.1 RLR-MC Approaching the SI

RLR-MC approaching the SI with weaving / lane splitting is a rare behaviour 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 (see Figure 6 for MA1).

RLR-MC approaching the SI from the centre of the lane is typical behaviour seen during our observation. This behaviour 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 behaviour in scenario 1. This behaviour 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.

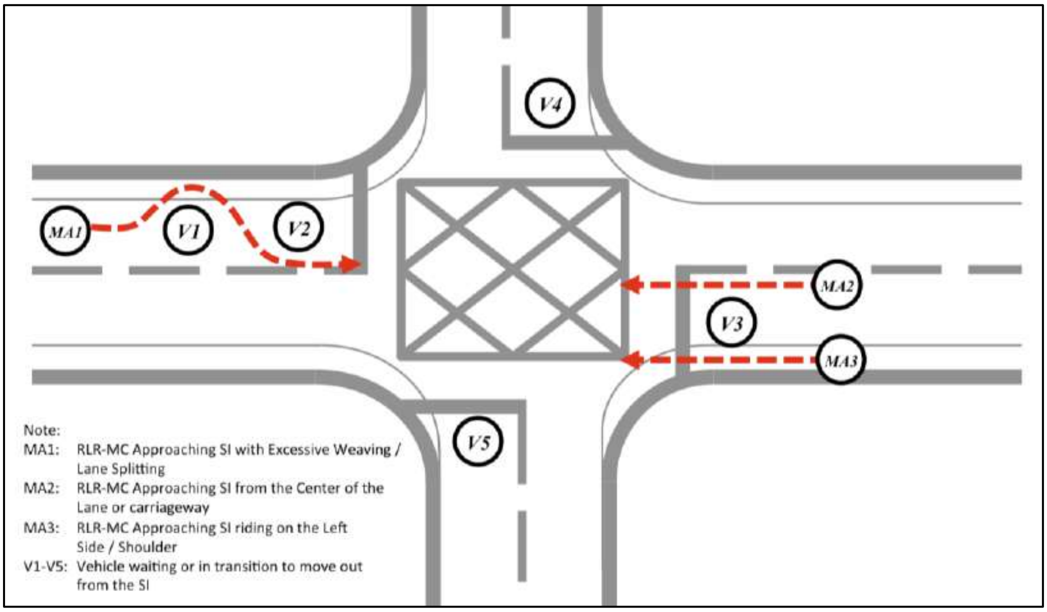

Figure 6 The behaviour of RLR-MC when approaching the SI (Scenario 1)

4.3.2 RLR-MC Crossing the SI

RLR-MC crossing the SI by illegal manoeuvre 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 (see Figure 7 for MC1).

RLR-MC crossing the SI by stopping at or before the stop line is one of the most common RLR behaviour 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.

RLR-MC crossing the SI another type of crossing detected during our observation, and is one of the most common RLR behaviour among motorcyclists. This behaviour 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 behaviour 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. However, this study still considers these motorcyclists as red light runners.

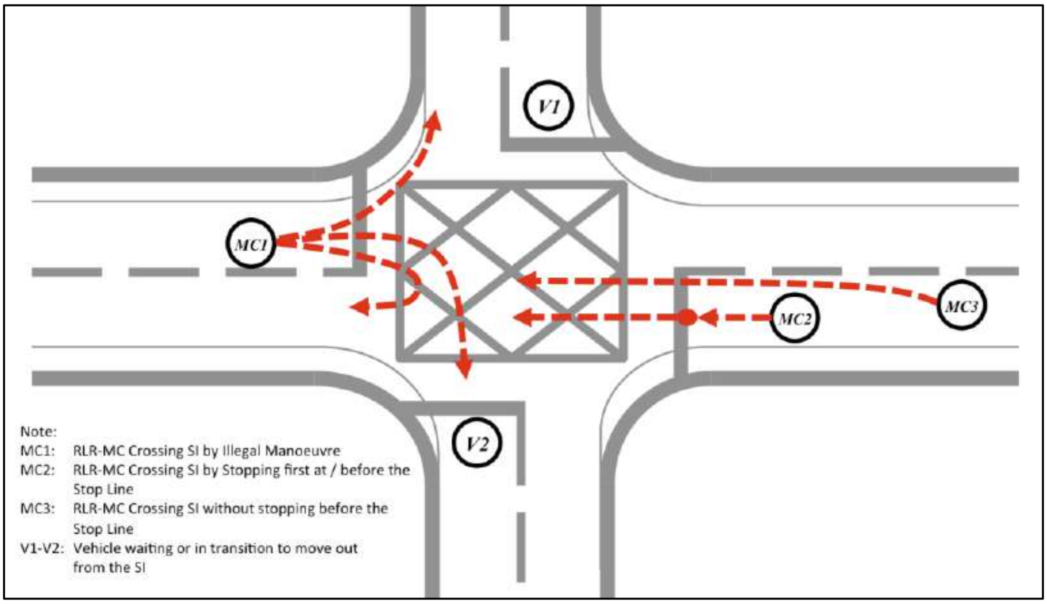

Figure 7 The behaviour of RLR-MC when crossing the SI (Scenario 2)

4.3.3 Association of Scenario 1 and 2

In order to see the association of Scenario 1 and 2, Table 13 and Figure 8 were referred. As seen in Table 13, 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 (2) scenarios, the MCA plot in Figure 8 was used. (Note that the Table 13 was not used as a reference in interpreting the MCA plot but rather to tabulate in order to calculate the statistical difference via Person Chi^2) 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 SI. 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 most likely to occur at 3-legged SI.

Table 13 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 Manoeuvre	Stopping first at stop line	Without stopping at stop line	Grand total
Weaving / lane splitting	7	20	62	89 (1.72%)
From the centre 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				

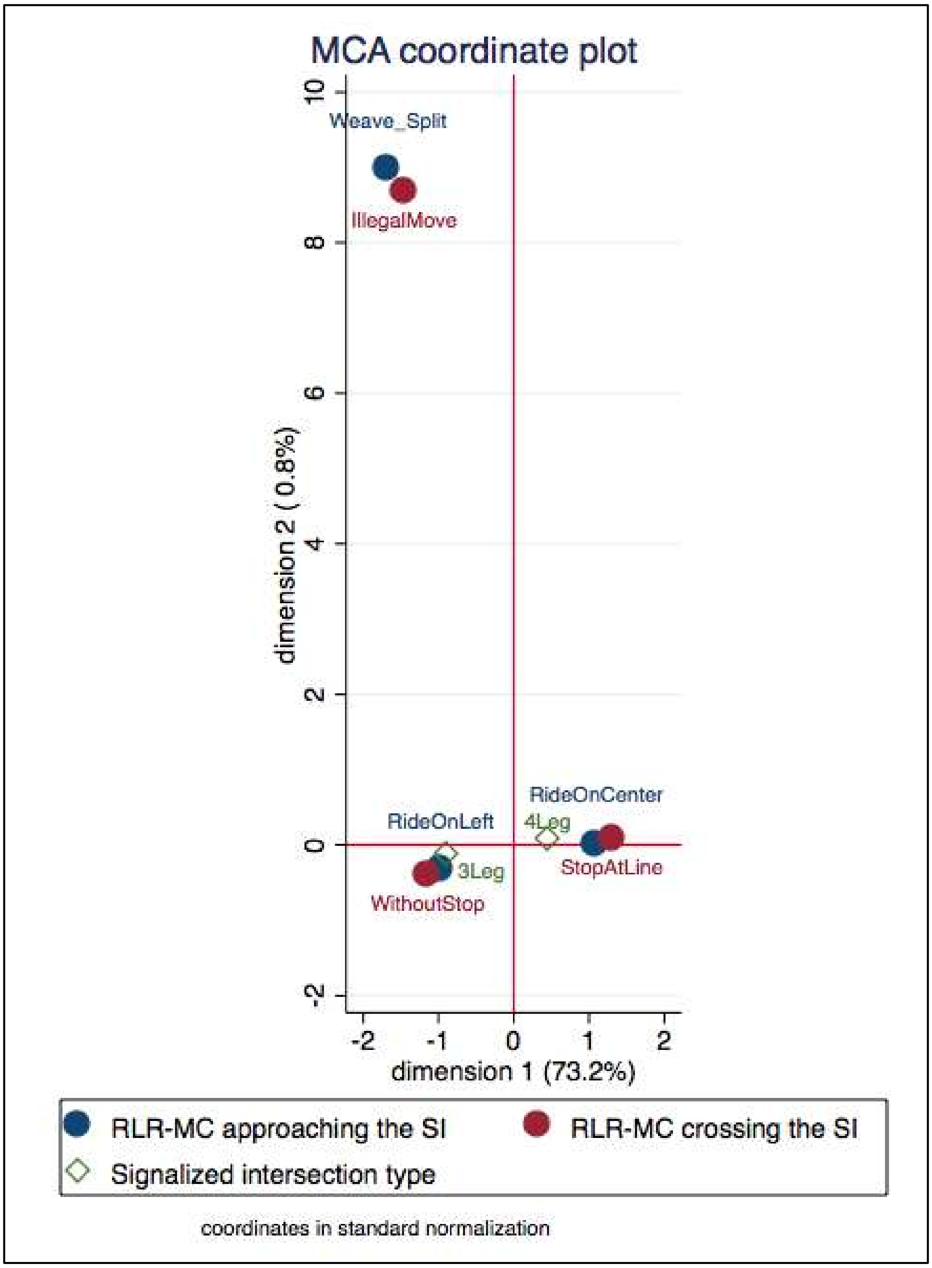

Figure 8 MCA plot for RLR-MC crossing and approaching the SI

4.3.4 Analysis of RLR-MC Based on SI Characteristics

In order to find the association between both scenarios and the SI characteristics (i.e. SI type, region and SI signal type), Table 14 and Figure 9 was generated. Based on Table 14, all of the SI characteristics variables are statistically significantly different with the RLR-MC behaviour ($p < 0.05$), except for the type of intersection (3-legged and 4-legged) ($p > 0.05$). This shows that the type of SI does not affect the movement type of a RLR-MC approaches the SI. For a better understanding on the associated factors, Figure 9 shows that (in the bottom part of the plot) motorcyclists who run the red light without stopping (i.e. beat the red light), moves along the shoulder, or perform lane splitting are associated with SI that are in the **Southern** and **Northern** region of Malaysia. While those RLR-MC who ride on the centre lane and stop first at the stop line before running the red light and are more associated in the **Western** region.

Table 14 Tabulation between RLR-MC behaviour with SI characteristics

SI characteristics	RLR-MC approaching the SI			RLR-MC crossing the SI			Total
	Weaving / lane splitting	From the centre of the lane	From the Left Side / Shoulder	Illegal manoeuvre	Stopping first at stop line	Without stopping at stop line	
SI type							
3-legged	832	866	37	40	1,157	538	1,735
	47.95%	*49.91%*	*2.13%*	*2.31%*	*66.69%*	*31.01%*	
4-legged	1,626	1,754	52	61	1,486	1,885	3,432
	47.38%	*51.11%*	*1.52%*	*1.78%*	*43.30%*	*54.92%*	
	Pearson chi2(2) = 2.955 Pr = 0.228			Pearson chi2(2) = 265.433 Pr = 0.000			
Region							
East	200	410	5	8	414	193	615
	32.52%	*66.67%*	*0.81%*	*1.30%*	*67.32%*	*31.38%*	
North	357	926	23	13	1,093	200	1,306
	27.34%	*70.90%*	*1.76%*	*1.00%*	*83.69%*	*15.31%*	
South	257	255	6	13	362	143	518
	49.61%	*49.23%*	*1.16%*	*2.51%*	*69.88%*	*27.61%*	

West	1,644	1,029	55	67	774	1,887	2,728
	60.26%	*37.72%*	*2.02%*	*2.46%*	*28.37%*	*69.17%*	
	Pearson chi2(6) = 466.751 Pr = 0.000			Pearson chi2(6) = 1.3e+03 Pr = 0.000			
SI Signal type							
Actuated	720	1,019	40	15	1,255	509	1,779
	40.47%	*57.28%*	*2.25%*	*0.84%*	*70.55%*	*28.61%*	
Pretimed	1,738	1,601	49	86	1,388	1,914	3,388
	51.30%	*47.26%*	*1.45%*	*2.54%*	*40.97%*	*56.49%*	
	Pearson chi2(2) = 56.217 Pr = 0.000			Pearson chi2(2) = 410.030 Pr = 0.000			

Note: *Red* italics: indicates the highest % of RLR-MC based on the **SI characteristics** with reference to each behaviour

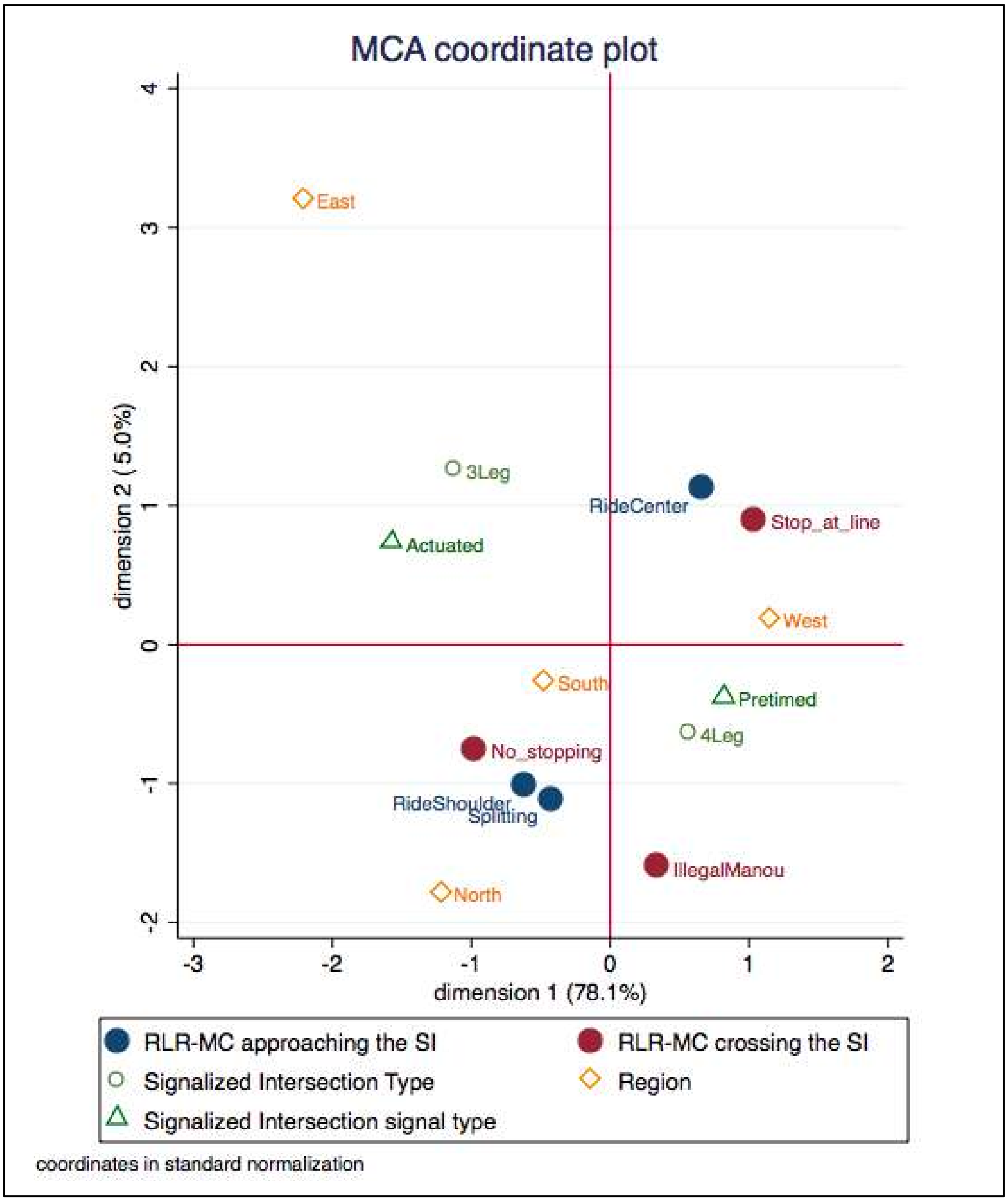

Figure 9 MCA plot for RLR-MC behaviour and SI characteristics

4.3.5 Analysis of RLR-MC Based on SI Signal Timing

Based on Table 15, all of the SI signal timing variables are statistically significantly different with the RLR-MC behaviour ($p < 0.05$), however, in order to assess the relationship between RLR-MC and the SI signal timing, we looked at the MC plot in Figure 10. From the cluster of variable which sits closely together in the plot, those RLR-MC who approach the SI by riding on the centre lane and run the red light after stopping at stop line, are mostly found on **4-legged** 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 behaviour 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 manoeuvre are associated with **amber time time phase** are plotted away from the behaviour variables which may indicate that RLR-**Mof 3s** and **red time of about 40s to 80s**. Interestingly enough, the all of the **actuated signal** C behaviour are not associated or rarely occurs on SI with actuated signals.

Table 15 Tabulation between RLR-MC behaviour with SI signal timing

SI signal timing	RLR-MC approaching the SI			RLR-MC crossing the SI			Total
	Weaving / lane splitting	From the centre of the lane	From the Left Side / Shoulder	Illegal manoeuvre	Stopping first at stop line	Without stopping at stop line	
Red time on Major road							
Actuated	624	612	40	15	796	465	1,276
	48.90%	*47.96%*	*3.13%*	*1.18%*	*62.38%*	*36.44%*	
40s - 80s	244	249	11	38	300	166	504
	48.41%	*49.40%*	*2.18%*	*7.54%*	*59.52%*	*32.94%*	
80s - 120s	1,492	1,478	29	27	1,313	1,659	2,999
	49.75%	*49.28%*	*0.97%*	*0.90%*	*43.78%*	*55.32%*	
120s - 160s	80	247	9	20	223	93	336
	23.81%	*73.51%*	*2.68%*	*5.95%*	*66.37%*	*27.68%*	

160s - 200s	18	34	-	1	11	40	52
	34.62%	*65.38%*	-	*1.92%*	*21.15%*	*76.92%*	
	Pearson chi2(8) = 113.204 Pr = 0.000			Pearson chi2(8) = 356.001 Pr = 0.000			
Green time on Major road							
Actuated	624	612	40	15	796	465	1,276
	48.90%	*47.96%*	*3.13%*	*1.18%*	*62.38%*	*36.44%*	
10s - 20s	45	19	0	2	30	32	64
	70.31%	*29.69%*	*0.00%*	*3.13%*	*46.88%*	*50.00%*	
20s - 40s	1,097	1,024	13	34	1,044	1,056	2,134
	51.41%	*47.99%*	*0.61%*	*1.59%*	*48.92%*	*49.48%*	
40s - 60s	271	428	14	18	450	245	713
	38.01%	*60.03%*	*1.96%*	*2.52%*	*63.11%*	*34.36%*	
60s - 80s	342	518	16	29	271	576	876
	39.04%	*59.13%*	*1.83%*	*3.31%*	*30.94%*	*65.75%*	
> 80s	79	19	6	3	52	49	104
	75.96%	*18.27%*	*5.77%*	*2.88%*	*50.00%*	*47.12%*	
	Pearson chi2(10) = 156.825 Pr = 0.000			Pearson chi2(10) = 262.680 Pr = 0.000			
Amber time on Major road							
Actuated	624	612	40	15	796	465	1,276
	48.90%	*47.96%*	*3.13%*	*1.18%*	*62.38%*	*36.44%*	
1s	83	23	2	2	50	56	108
	76.85%	*21.30%*	*1.85%*	*1.85%*	*46.30%*	*51.85%*	
2s	1,314	918	28	35	621	1,604	2,260
	58.14%	*40.62%*	*1.24%*	*1.55%*	*27.48%*	*70.97%*	
3s	437	1,067	19	49	1,176	298	1,523
	28.69%	*70.06%*	*1.25%*	*3.22%*	*77.22%*	*19.57%*	
	Pearson chi2(6) = 385.1220 Pr = 0.000			Pearson chi2(6) = 1.1e+03 Pr = 0.000			

Note: *Red* italics: indicates the highest % of RLR-MC based on the **SI signal timing** with reference to each behaviour

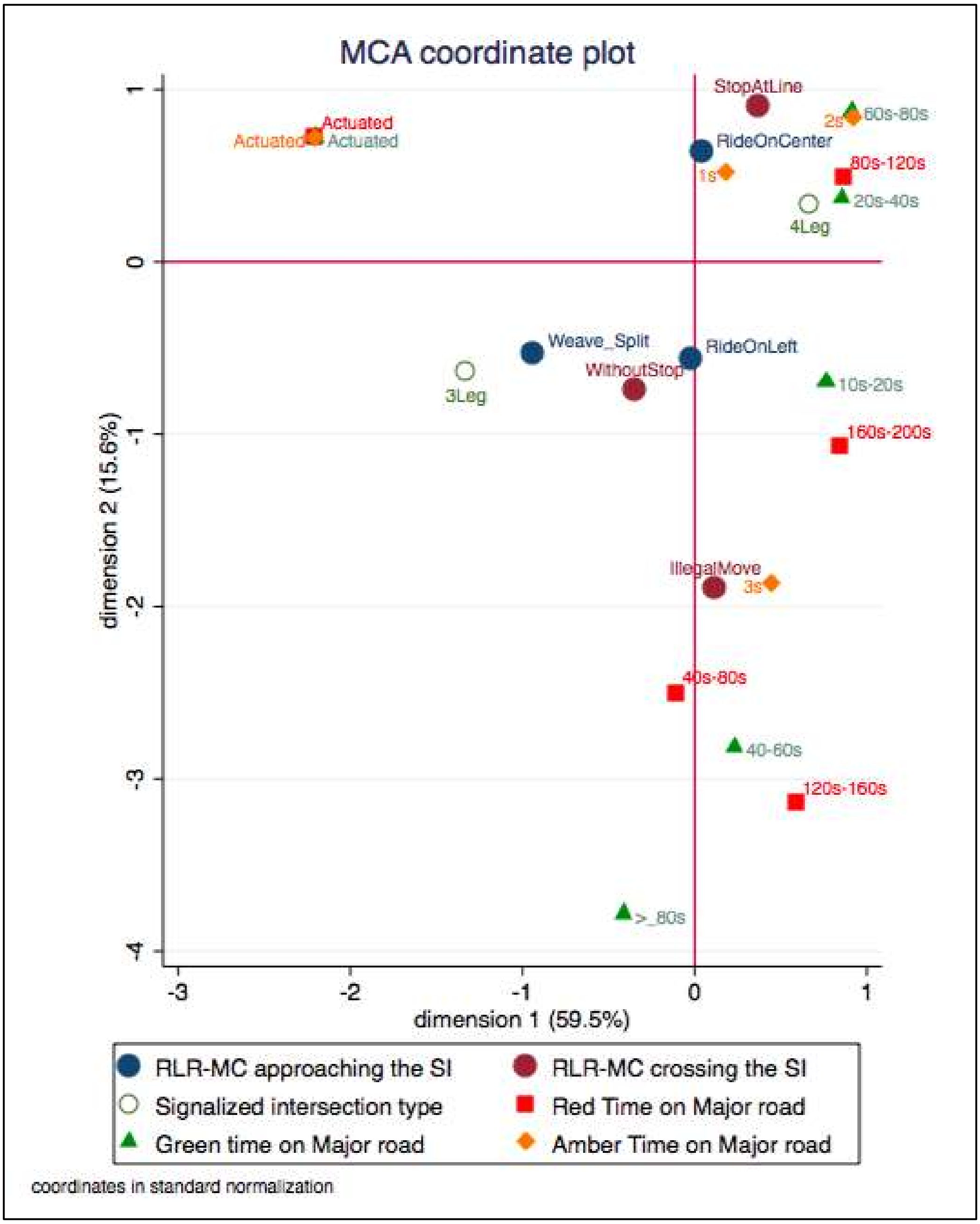

Figure 10 MCA plot for RLR-MC behaviour and SI signal timing

4.3.6 Analysis of RLR-MC Based on SI Infrastructure

Table 16 shows that all of the SI infrastructure variables are statistically significantly different with RLR-MC behaviour ($p < 0.05$). To assess the association between RLR-MC and the SI infrastructure, we now turn to the MC plot in Figure 11. 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-legged SI with a total of 4-lanes on the major roads** with **70 km/h speed limit**.

RLR-MC that are approaching the SI by riding on the centre lane and stopping at the stop line before running the red light are closely associated with: **4-legged SI with 4-lanes minor roads with median** and **along major road with 60 km/h speed limit**. In addition to this, RLR-MC that performs illegal manoeuvre 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 behaviour variables, which may indicate that RLR-MC behaviours are not associated or rarely occurs on SI with these infrastructures.

Table 16 Tabulation between RLR-MC behaviour with SI infrastructure

SI infrastructure	RLR-MC approaching the SI			RLR-MC crossing the SI			Total
	Weaving / lane splitting	From the centre of the lane	From the left side / shoulder	Illegal manoeuvre	Stopping first at stop line	Without stopping at stop line	
SI signal infrastructure							
Pole	610	980	34	38	804	782	1,624
	37.56%	*60.34%*	*2.09%*	*2.34%*	*49.51%*	*48.15%*	
Gantry and pole	1,848	1,640	55	63	1,839	1,641	3,543
	52.16%	*46.29%*	*1.55%*	*1.78%*	*51.91%*	*46.32%*	
	Pearson chi2(2) = 95.1665 Pr = 0.000			Pearson chi2(2) = 3.8498 Pr = 0.146			
Total number of lanes on Major road							
4 lanes	812	1,629	33	25	1,874	575	2,474
	32.82%	*65.84%*	*1.33%*	*1.01%*	*75.75%*	*23.24%*	
5 lanes	594	654	45	36	454	803	1,293
	45.94%	*50.58%*	*3.48%*	*2.78%*	*35.11%*	*62.10%*	
6 lanes	1,052	337	11	40	315	1,045	1,400
	75.14%	*24.07%*	*0.79%*	*2.86%*	*22.50%*	*74.64%*	
	Pearson chi2(4) = 677.7753 Pr = 0.000			Pearson chi2(4) = 1.2e+03 Pr = 0.000			
Total number of lanes on Minor road							
2 lanes	425	1,185	26	22	1,304	310	1,636
	25.98%	*72.43%*	*1.59%*	*1.34%*	*79.71%*	*18.95%*	
3 lanes	200	410	5	8	414	193	615
	32.52%	*66.67%*	*0.81%*	*1.30%*	*67.32%*	*31.38%*	
4 lanes	1,833	1,025	58	71	925	1,920	2,916
	62.86%	*35.15%*	*1.99%*	*2.43%*	*31.72%*	*65.84%*	
	Pearson chi2(4) = 659.5921 Pr = 0.000			Pearson chi2(4) = 1.0e+03 Pr = 0.000			
Speed limit on Major road							
50 km/h	33	28	3	7	18	39	64
	51.56%	*43.75%*	*4.69%*	*10.94%*	*28.13%*	*60.94%*	
60 km/h	1,917	1,444	52	60	1,372	1,981	3,413
	56.17%	*42.31%*	*1.52%*	*1.76%*	*40.20%*	*58.04%*	
70 km/h	460	1,087	33	26	1,171	383	1,580
	29.11%	*68.80%*	*2.09%*	*1.65%*	*74.11%*	*24.24%*	

90km/h	48	61	1	8	82	20	110
	43.64%	*55.45%*	*0.91%*	*7.27%*	*74.55%*	*18.18%*	
	Pearson chi2(6) = 322.9892 Pr = 0.000			Pearson chi2(6) = 590.4894 Pr = 0.000			
Total number of traffic island							
0	410	1,188	24	44	1,281	297	1,622
	25.28%	*73.24%*	*1.48%*	*2.71%*	*78.98%*	*18.31%*	
1	174	34	-	-	140	68	208
	83.65%	*16.35%*	-	-	*67.31%*	*32.69%*	
2	1,199	532	25	39	570	1,147	1,756
	68.28%	*30.30%*	*1.42%*	*2.22%*	*32.46%*	*65.32%*	
3	101	57	2	3	61	96	160
	63.13%	*35.63%*	*1.25%*	*1.88%*	*38.13%*	*60.00%*	
4	574	809	38	15	591	815	1,421
	40.39%	*56.93%*	*2.67%*	*1.06%*	*41.59%*	*57.35%*	
	Pearson chi2(8) = 794.1446 Pr = 0.000			Pearson chi2(8) = 879.7869 Pr = 0.000			
Presence of road shoulder on Major road							
No shoulder	67	1,975	1,718	89	1,704	1,967	3,760
	1.78%	*52.53%*	*45.69%*	*2.37%*	*45.32%*	*52.31%*	
With shoulder	22	483	902	12	719	676	1,407
	1.56%	*34.33%*	*64.11%*	*0.85%*	*51.10%*	*48.05%*	
	Pearson chi2(2) = 140.0470 Pr = 0.000			Pearson chi2(2) = 22.9560 Pr = 0.000			
Presence of road shoulder on Minor road							
No shoulder	84	2,301	2,513	91	2,290	2,517	4,898
	1.71%	*46.98%*	*51.31%*	*1.86%*	*46.75%*	*51.39%*	
With shoulder	5	157	107	10	133	126	269
	1.86%	*58.36%*	*39.78%*	*3.72%*	*49.44%*	*46.84%*	
	Pearson chi2(2) = 13.6648 Pr = 0.001			Pearson chi2(2) = 5.9353 Pr = 0.051			
Presence of road median on Major road							
Med storage lane	45	594	654	36	803	454	1,293
	3.48%	*45.94%*	*50.58%*	*2.78%*	*62.10%*	*35.11%*	
No median	15	199	526	7	132	601	740
	2.03%	*26.89%*	*71.08%*	*0.95%*	*17.84%*	*81.22%*	
With median	29	1,665	1,440	58	1,488	1,588	3,134
	0.93%	*53.13%*	*45.95%*	*1.85%*	*47.48%*	*50.67%*	

	Pearson chi2(4) = 197.3181 Pr = 0.000			Pearson chi2(4) = 401.7548 Pr = 0.000			
Presence of road median on Minor road							
No median	24	443	832	20	269	1,010	1,299
	1.85%	*34.10%*	*64.05%*	*1.54%*	*20.71%*	*77.75%*	
With median	65	2,015	1,788	81	2,154	1,633	3,868
	1.68%	*52.09%*	*46.23%*	*2.09%*	*55.69%*	*42.22%*	
	Pearson chi2(2) = 127.2468 Pr = 0.000			Pearson chi2(2) = 495.2979 Pr = 0.000			

Note: *Red* italics: indicates the highest % of RLR-MC based on the **SI signal infrastructure** with reference to each behaviour

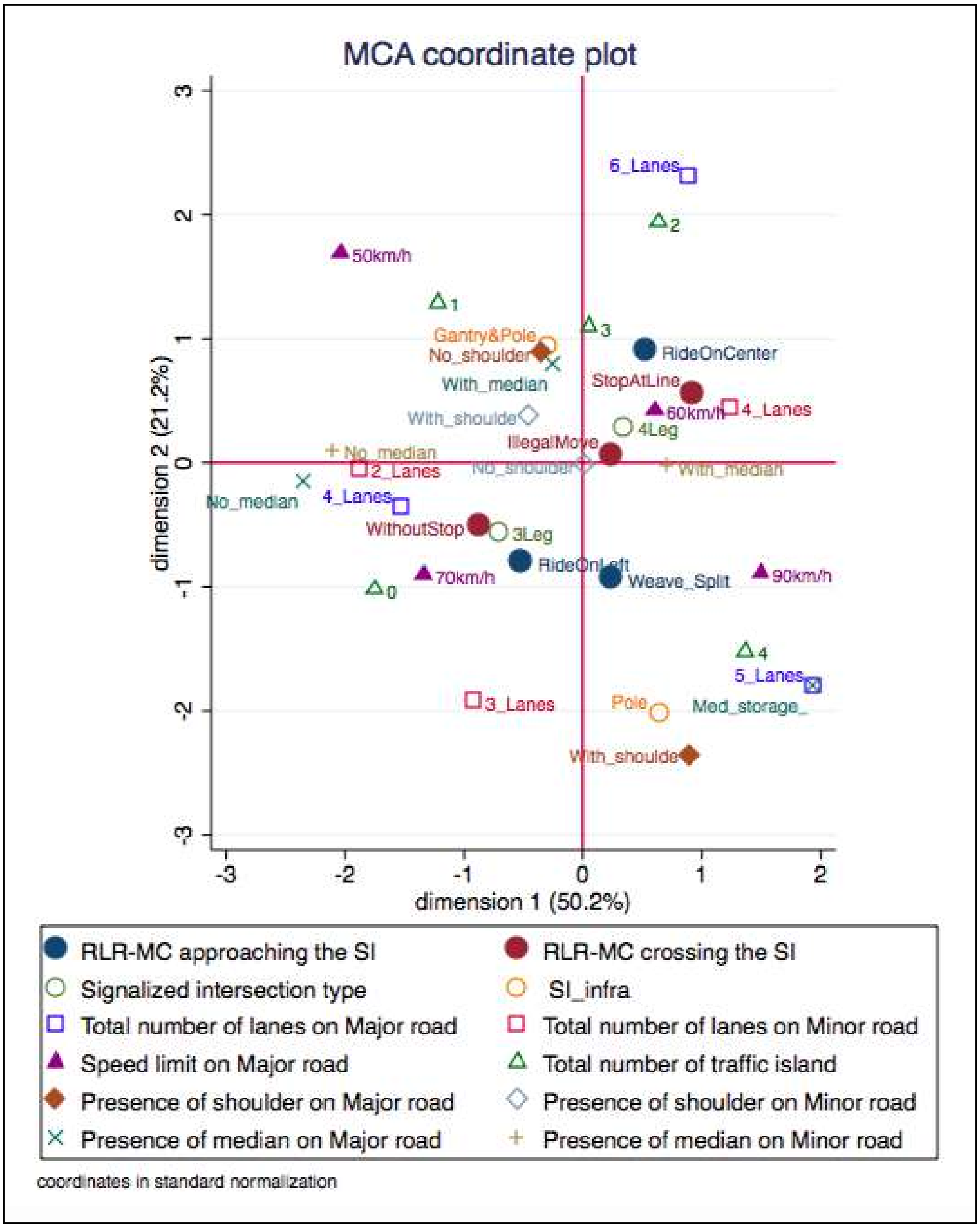

Figure 11 MCA plot for RLR-MC behaviour and SI infrastructure

4.3.7 Analysis of RLR-MC Based on SI Dimension

The association between RLR-MC and the SI dimension can be seen in the MC plot in Figure 12. Meanwhile in Table 17 shows that all of the SI dimension variables are statistically significantly different with RLR-MC behaviour ($p < 0.05$). From Figure 12, RLR-MC who made illegal manoeuvres is associated with SI with **major road crossing length of 20 m – 25 m and minor road of 3.0 m - 3.5 m**, while those who perform weaving or lane splitting are mostly can be found on **3-legged SI** with **major road with of 4.0 m above and minor road width of 3.5 m – 4.0 m**.

As for RLR-MC who rides on the centre of the lane and stop at the stop line before running the red light, they are associated with SI dimension such as: **major road crossing length of 15 m – 20 m** and **minor crossing length of 10 m – 15 m** and **25 m – 30 m**. Meanwhile, RLR-MC who approach the SI by riding on the left or shoulder and crossing the SI without stopping at the stop line, are not associated with any of the dimension variables.

Interestingly, RLR-MC behaviour may be seen as a rare occurrence on SI with minor road width of 3.5 m – 4.0 m, major road crossing length of 5 m – 10 m and minor road crossing length of 15 m – 20 m or 30 m – 25 m, as they are plotted away from the behaviour variables.

Table 17 Tabulation between RLR-MC behaviour with SI dimension

SI dimension	RLR-MC approaching the SI			RLR-MC crossing the SI			Total
	Weaving / lane splitting	From the centre of the lane	From the left side / shoulder	Illegal manoeuvre	Stopping first at stop line	Without stopping at stop line	
Major road lane width (m)							
3.00 - 3.25	1,184	727	11	29	826	1,067	1,922
	61.60%	*37.83%*	*0.57%*	*1.51%*	*42.98%*	*55.52%*	
3.25 - 3.50	803	1,244	46	22	1,121	950	2,093
	38.37%	*59.44%*	*2.20%*	*1.05%*	*53.56%*	*45.39%*	

3.50 - 4.00	448	596	29	50	632	391	1,073
	41.75%	*55.55%*	*2.70%*	*4.66%*	*58.90%*	*36.44%*	
> 4.00	23	53	3	0	64	15	79
	29.11%	*67.09%*	*3.80%*	*0.00%*	*81.01%*	*18.99%*	
	Pearson chi2(6) = 259.0732 Pr = 0.000			Pearson chi2(6) = 175.8629 Pr = 0.000			
Major road crossing length (m)							
5 - 10	285	822	5	9	911	192	1,112
	25.63%	*73.92%*	*0.45%*	*0.81%*	*81.92%*	*17.27%*	
10 - 15	536	747	20	25	865	413	1,303
	41.14%	*57.33%*	*1.53%*	*1.92%*	*66.39%*	*31.70%*	
15 - 20	1,270	577	51	32	531	1,335	1,898
	66.91%	*30.40%*	*2.69%*	*1.69%*	*27.98%*	*70.34%*	
20 - 25	367	474	13	35	336	483	854
	42.97%	*55.50%*	*1.52%*	*4.10%*	*39.34%*	*56.56%*	
	Pearson chi2(6) = 585.7779 Pr = 0.000			Pearson chi2(6) = 1.0e+03 Pr = 0.000			
Minor road lane width (m)							
< 3.00	1,232	597	18	41	683	1,123	1,847
	66.70%	*32.32%*	*0.97%*	*2.22%*	*36.98%*	*60.80%*	
3.00 - 3.25	469	548	21	10	325	703	1,038
	45.18%	*52.79%*	*2.02%*	*0.96%*	*31.31%*	*67.73%*	
3.25 - 3.50	500	914	33	11	999	437	1,447
	34.55%	*63.17%*	*2.28%*	*0.76%*	*69.04%*	*30.20%*	
3.50 - 4.00	164	417	2	39	448	96	583
	28.13%	*71.53%*	*0.34%*	*6.69%*	*76.84%*	*16.47%*	
> 4.00	93	144	15	0	188	64	252
	36.90%	*57.14%*	*5.95%*	*0.00%*	*74.60%*	*25.40%*	
	Pearson chi2(8) = 509.2054 Pr = 0.000			Pearson chi2(8) = 831.6686 Pr = 0.000			
Minor road crossing length (m)							
10 - 15	166	162	10	0	126	212	338
	49.11%	*47.93%*	*2.96%*	*0.00%*	*37.28%*	*62.72%*	
15 - 20	432	889	16	10	1,064	263	1,337
	32.31%	*66.49%*	*1.20%*	*0.75%*	*79.58%*	*19.67%*	
20 - 25	576	835	49	19	933	508	1,460
	39.45%	*57.19%*	*3.36%*	*1.30%*	*63.90%*	*34.79%*	
25 - 30	1,245	690	13	66	451	1,431	1,948
	63.91%	*35.42%*	*0.67%*	*3.39%*	*23.15%*	*73.46%*	

30 - 25	39	44	1	6	69	9	84
	46.43%	*52.38%*	*1.19%*	*7.14%*	*82.14%*	*10.71%*	
	Pearson chi2(8) = 403.8426 Pr = 0.000			Pearson chi2(8) = 1.2e+03 Pr = 0.000			
Note: *Red* italics: indicates the highest % of RLR-MC based on the **SI dimension** with reference to each behaviour							

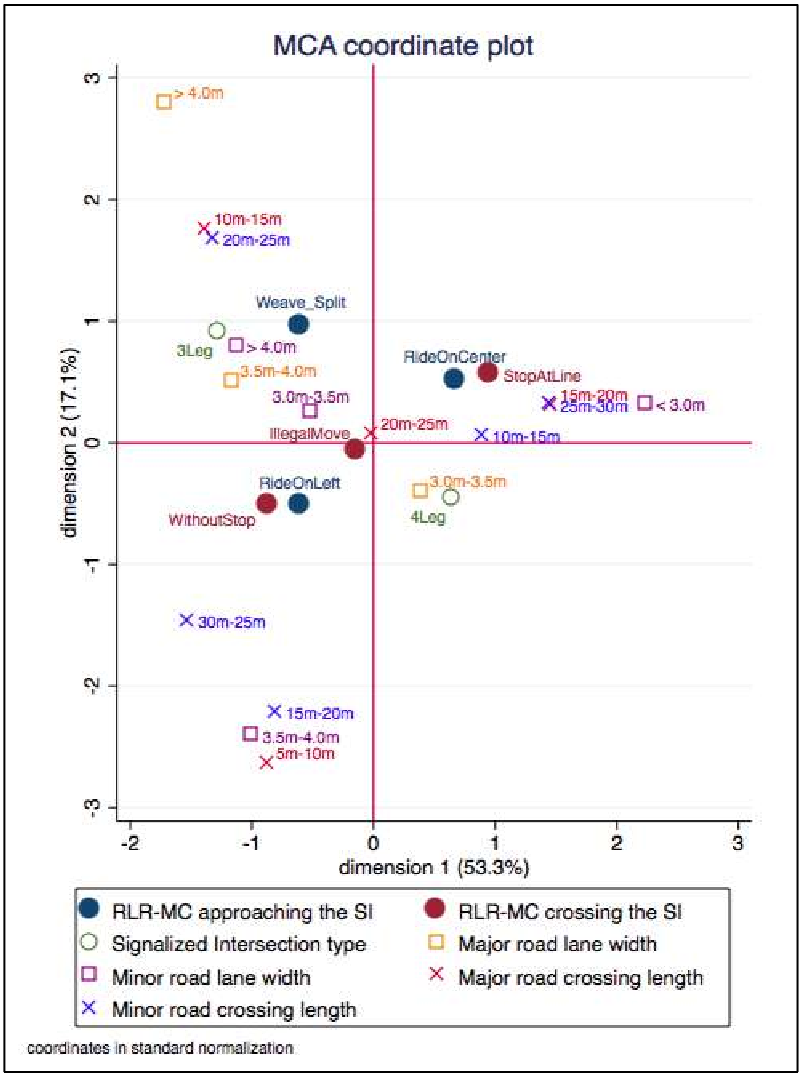

Figure 12 MCA plot for RLR-MC behaviour and SI dimension

4.3.8 Analysis of RLR-MC Based on SI Traffic Volume

Based on Table 18, all of the SI characteristics variables are statistically significantly different with the RLR-MC behaviour ($p < 0.05$), except for time of observation (Peak and Off Peak) ($p > 0.05$), thus dropped from the MCA analysis (see Figure 13). This shows that the time of observation does not affect the movement type a RLR-MC approaches and crossing the SI.

RLR-MC with behaviour such as approaching via weaving or lane splitting and crossing the SI via illegal manoeuvre during red phase, may be seen occurring more when the **motorcycle volume passing the major road are within 15% - 50%** from the total volume.

Meanwhile, RLR-MC who are approaching the SI by riding on the centre of the lane are associated with **major traffic volume of 800 – 1,000 vehicle per hour** while those RLR-MC crossing the SI before stopping at the stop line are associated with **major road traffic volume of 3,000 – 4,000 vehicle per hour**, and also with **motorcycle volume passing the minor road are within 25% - 50%** from the total volume (see Figure 13).

As for the RLR-MC with behaviour such as approaching via riding on the left or on the shoulder and crossing the SI without stopping at the stop line (beating the red light), are likely to occur when the **major road traffic volume are within 2,000 – 3,000 vehicle per hour** and when there are **motorcycle volume passing the minor road are within 15% - 25%** from the total volume.

Table 18 Tabulation between RLR-MC behaviour with SI traffic volume

SI traffic volume	RLR MC when approaching the SI			RLR MC when crossing the SI			Total
	Weaving / lane splitting	From the centre of the lane	From the left side / shoulder	Illegal manoeuvre	Stopping first at stop line	Without stopping at stop line	
Time of observation							
Off peak	957	1,053	45	43	1,084	928	2,055
	46.57%	*51.24%*	*2.19%*	*2.09%*	*52.75%*	*45.16%*	

Peak	1,501	1,567	44	58	1,559	1,495	3,112
	48.23%	*50.35%*	*1.41%*	*1.86%*	*50.10%*	*48.04%*	
	Pearson chi2(2) = 5.2379 Pr = 0.073			Pearson chi2(2) = 4.2260 Pr = 0.121			
Major leg traffic volume range							
800 - 1000	31	30	0	3	29	29	61
	50.82%	*49.18%*	*0.00%*	*4.92%*	*47.54%*	*47.54%*	
1000 - 2000	267	293	7	17	377	173	567
	47.09%	*51.68%*	*1.23%*	*3.00%*	*66.49%*	*30.51%*	
2000 - 3000	1,046	1,482	51	55	1,613	911	2,579
	40.56%	*57.46%*	*1.98%*	*2.13%*	*62.54%*	*35.32%*	
3000 - 4000	1,027	764	30	26	542	1,253	1,821
	56.40%	*41.95%*	*1.65%*	*1.43%*	*29.76%*	*68.81%*	
> 4000	87	51	1	0	82	57	139
	62.59%	*36.69%*	*0.72%*	*0.00%*	*58.99%*	*41.01%*	
	Pearson chi2(8) = 123.1667 Pr = 0.000			Pearson chi2(8) = 561.4026 Pr = 0.000			
Minor leg traffic volume range							
< 250	198	271	7	4	359	113	476
	41.60%	*56.93%*	*1.47%*	*0.84%*	*75.42%*	*23.74%*	
250 - 500	732	623	29	40	722	622	1,384
	52.89%	*45.01%*	*2.10%*	*2.89%*	*52.17%*	*44.94%*	
500 - 1000	437	1,245	21	16	1,179	508	1,703
	25.66%	*73.11%*	*1.23%*	*0.94%*	*69.23%*	*29.83%*	
1000 - 1500	971	452	10	38	350	1,045	1,433
	67.76%	*31.54%*	*0.70%*	*2.65%*	*24.42%*	*72.92%*	
> 1500	120	29	22	3	33	135	171
	70.18%	*16.96%*	*12.87%*	*1.75%*	*19.30%*	*78.95%*	
	Pearson chi2(8) = 783.6706 Pr = 0.000			Pearson chi2(8) = 825.5567 Pr = 0.000			
Percentage of MC passing on Major road							
<15%	2	84	100	9	55	122	186
	1.08%	*45.16%*	*53.76%*	*4.84%*	*29.57%*	*65.59%*	
15%-25%	25	622	975	57	626	939	1622
	1.54%	*38.35%*	*60.11%*	*3.51%*	*38.59%*	*57.89%*	
25%-50%	52	1059	964	9	1091	975	2075
	2.51%	*51.04%*	*46.46%*	*0.43%*	*52.58%*	*46.99%*	
>50%	10	693	581	26	651	607	1284
	0.78%	*53.97%*	*45.25%*	*2.02%*	*50.70%*	*47.27%*	

	Pearson chi2(6) = 103.8869 Pr = 0.000			Pearson chi2(6) = 139.4732 Pr = 0.000			
Percentage of MC passing on Minor road							
<15%	25	729	816	36	611	923	1570
	1.59%	*46.43%*	*51.97%*	*2.29%*	*38.92%*	*58.79%*	
15%-25%	26	312	553	22	304	565	891
	2.92%	*35.02%*	*62.07%*	*2.47%*	*34.12%*	*63.41%*	
25%-50%	33	1166	634	43	1182	608	1833
	1.80%	*63.61%*	*34.59%*	*2.35%*	*64.48%*	*33.17%*	
>50%	5	251	617	-	326	547	873
	0.57%	*28.75%*	*70.68%*	-	*37.34%*	*62.66%*	
	Pearson chi2(6) = 394.1397 Pr = 0.000			Pearson chi2(6) = 393.4256 Pr = 0.000			

Note: *Red* italics: indicates the highest % of RLR-MC based on the **SI traffic volume** with reference to each behaviour

Interestingly, looking at the outlier variables gives us an indication that the RLR-MC behaviour may be rarely seen during this circumstances such as on **major road traffic volume with more then 4,000 vehicle per hour**, on **4-legged SI with major road motorcycle volume of more than 50%**, and **minor road with motorcycle volume of more than 50% from the total volume** (see Figure 13).

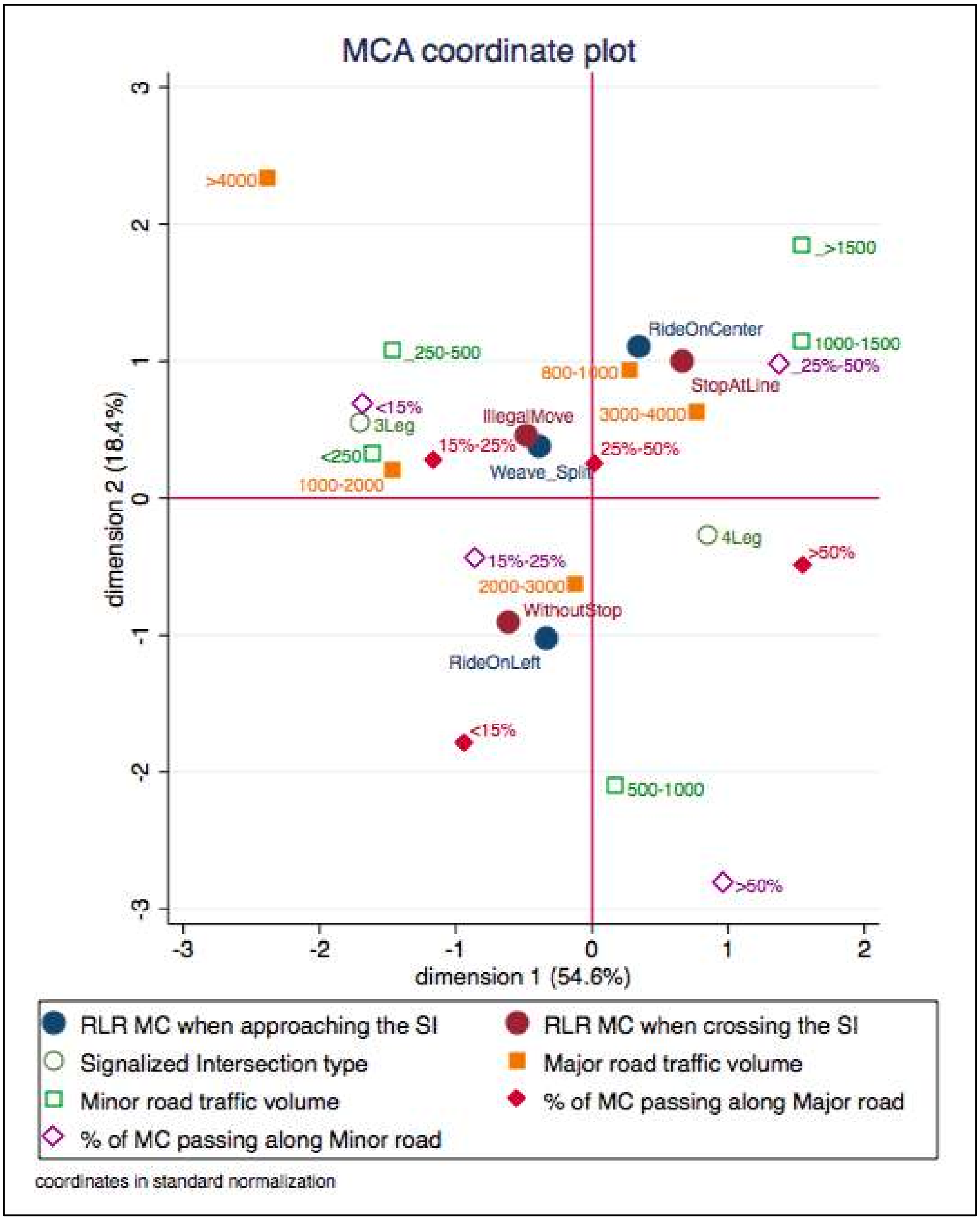

Figure 13 MCA plot for RLR-MC behaviour and SI traffic volume

4.3.9 Analysis of RLR-MC Based on Motorcycle Characteristics and Movement

Based on Table 19, the number of occupancy and helmet wearing of RLR-MC does not statistically significantly influence the outcome of their crossing behaviour but instead has may have an association with their approaching behaviour ($p > 0.50$). On the other hand, the variable of 'clothing with reflector' is not statistically significantly different on both the movement type of RLR-MC approach and crossing the SI, thus it is dropped from the MCA analysis (see Figure 14).

From the MCA plot in Figure 14, 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-legged 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-legged 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.

Table 19 Tabulation between RLR-MC behaviour with MC characteristics and movement

Motorcycle characteristics and movement	RLR MC when approaching the SI			RLR MC when crossing the SI			Total
	Weaving / lane splitting	From the centre of the lane	From the left side / shoulder	Illegal manoeuvre	Stopping first at stop line	Without stopping at stop line	
Gender							
Female	36	70	5	3	87	21	111
	32.43%	*63.06%*	*4.50%*	*2.70%*	*78.38%*	*18.92%*	

Male	2,422	2,550	84	98	2,556	2,402	5,056
	47.90%	*50.44%*	*1.66%*	*1.94%*	*50.55%*	*47.51%*	
	Pearson chi2(2) = 13.9779 Pr = 0.001				Pearson chi2(2) = 35.6953 Pr = 0.000		
Motorcycle occupancy							
1	2,081	2,302	78	91	2,303	2,067	4,461
	46.65%	*51.60%*	*1.75%*	*2.04%*	*51.63%*	*46.33%*	
2	374	311	11	10	333	353	696
	53.74%	*44.68%*	*1.58%*	*1.44%*	*47.84%*	*50.72%*	
> 2	3	7	0	0	7	3	10
	30.00%	*70.00%*	*0.00%*	*0.00%*	*70.00%*	*30.00%*	
	Pearson chi2(4) = 13.6975 Pr = 0.008				Pearson chi2(4) = 6.7710 Pr = 0.148		
Presence of clothing with reflector							
No	2,444	2,603	88	100	2,630	2,405	5,135
	47.59%	*50.69%*	*1.71%*	*1.95%*	*51.22%*	*46.84%*	
Yes	14	17	1	1	13	18	32
	43.75%	*53.13%*	*3.13%*	*3.13%*	*40.63%*	*56.25%*	
	Pearson chi2(2) = 0.5037 Pr = 0.777				Pearson chi2(2) = 1.5242 Pr = 0.467		
Helmet wearing							
Helmet	2,426	2,607	87	100	2,620	2,400	5,120
	47.38%	*50.92%*	*1.70%*	*1.95%*	*51.17%*	*46.88%*	
Without helmet	32	13	2	1	23	23	47
	68.09%	*27.66%*	*4.26%*	*2.13%*	*48.94%*	*48.94%*	
	Pearson chi2(2) = 10.9310 Pr = 0.004				Pearson chi2(2) = 0.0950 Pr = 0.954		
Origin and Destination of RLR-MC							
From Major to Major road	45	1,105	1,236	64	1,130	1,192	2,386
	1.89%	*46.31%*	*51.80%*	*2.68%*	*47.36%*	*49.96%*	
From Major to Minor road	33	953	828	31	933	850	1,814
	1.82%	*52.54%*	*45.64%*	*1.71%*	*51.43%*	*46.86%*	

From Minor to Major road	4	306	507	4	278	535	817
	0.49%	*37.45%*	*62.06%*	*0.49%*	*34.03%*	*65.48%*	
From Minor to Minor road	7	94	49	2	82	66	150
	4.67%	*62.67%*	*32.67%*	*1.33%*	*54.67%*	*44.00%*	
	Pearson chi2(6) = 90.2982 Pr = 0.000			Pearson chi2(6) = 96.6590 Pr = 0.000			

Note: *Red* italics: indicates the highest % of RLR-MC based on the **MC characteristics and movement** with reference to each behaviour

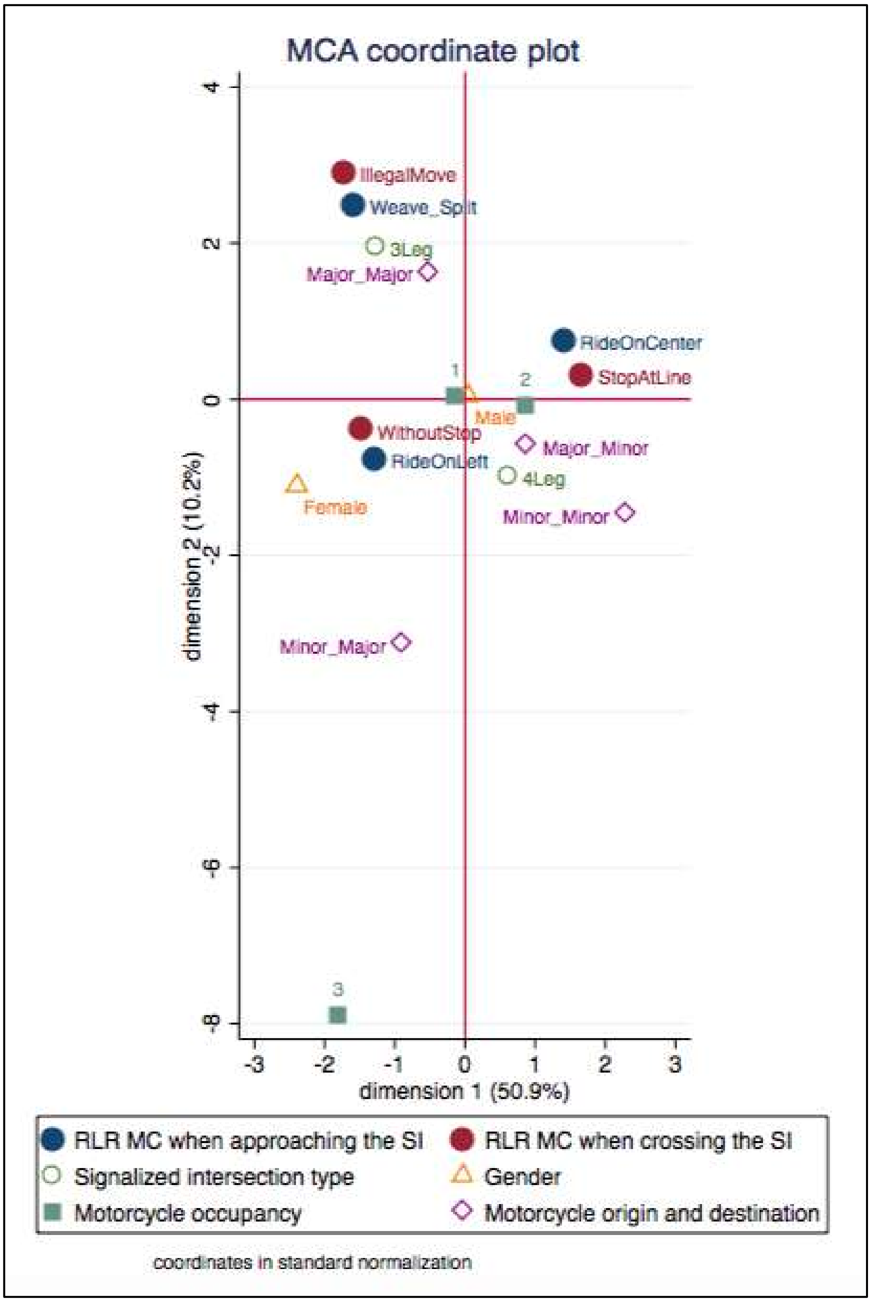

Figure 14 MCA plot for RLR-MC behaviour and motorcycle characteristics

4.3.10 Analysis of RLR-MC Based on Number of Vehicle Waiting

Figure 15 indicates that general, as the number of vehicle waiting increases either on the major or minor road, the number of RLR-MC occurred at 3-legged SI decreases significantly. When comparing the number of vehicle waiting on each road (leg), Figure 15 shows that 90.9% of RLR-MC occurred at 3-legged SI, when zero (0) to five (5) vehicles are waiting on the minor road, while 54.5% of RLR-MC occurred when zero (0) to five (5) vehicles are waiting on the major road instead. However, when there are five (5) to ten (10) vehicles waiting on the minor road, RLR-MC rate decrease down to 7.7% while 22.6% RLR-MC occurred when five (5) to ten (10) vehicles waiting on the major road.

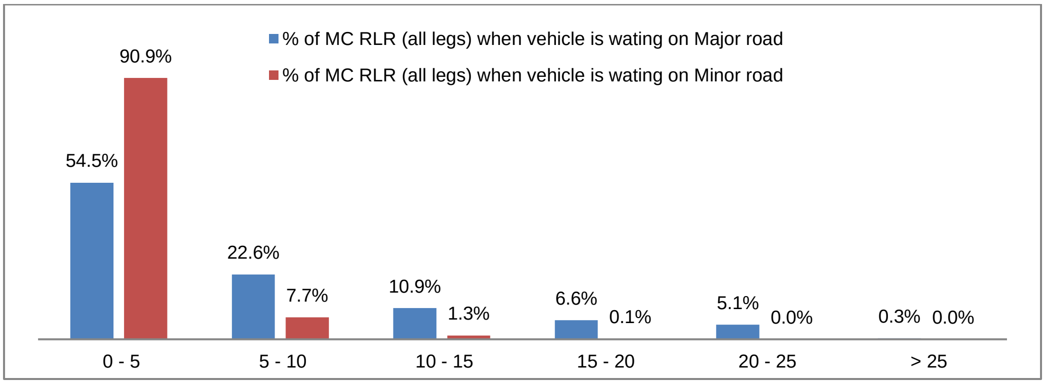

Figure 15 Rate of RLR-MC at 3-legged SI based on the number of vehicle waiting

When comparing between the two (2) types of SI, the 4-legged SI has a lower rate of RLR-MC when there are zero (0) to five (5) vehicles waiting on both major and minor roads (Figure 16). In contrast to 3-legged SI, the rate of RLR-MC is higher (49.3%) when there are zero (0) to five (5) 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-legged SI has a higher rate of RLR-MC occurrence compared to 3-legged SI, but has a lower rate of RLR-MC when there is an increase of vehicle waiting on the major road.

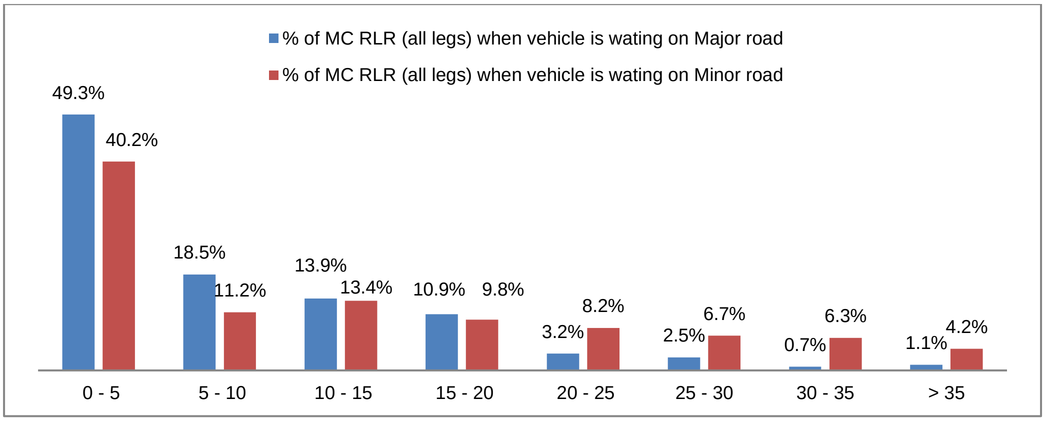

Figure 16 Rate of RLR-MC at 4-legged SI based on the number of vehicle waiting

5. Discussion

This study investigates the factors that are associated with RLR-MC behaviour during their approach and crossing the 3-legged and 4-legged SIs along majors in Malaysia and develops countermeasures in order to curb these risky behaviour. 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 analysing these variables, a Multiple Correspondence Analysis (MCA) was used in order to clustered or find a pattern relating RLR-MC behaviour 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 22.5%, 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. (2007), 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*.* (2007). In addition this study show that RLR-MC on 3-legged SI occurrences are not much difference on 4-legged 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 (3) movement types of RLR-MC approached the SI - (a) approaching the SI with weaving or lane splitting, (b) approaching the SI from the centre of the lane, and (c) approaching the SI from the left side or on the shoulder. Among these approaching behaviours, 'approaching the SI with weaving or lane splitting' is the least common with only 1.72% from the total observation.

Among all the RLR-MC approaching behaviours, the weaving or lane splitting is a considered a form of an aggressive riding behaviour see Shinar (1998). This study shows that weaving or lane-splitting behaviour is associated with **3-legged SI** with dimension of **major road width of 4.0 m above and minor road width of 3.5 m – 4.0 m**. In addition, this aggressive approach may be associated when the **motorcycle volume passing the major road are within 15% - 50%** from the total volume. Moreover, we can see that most of the RLR-MC approach the 3-legged SI by weaving or lane splitting is associated with movement from **a major road to a major road** (i.e. straight movement). This shows that RLR-MC approach the SI with aggressive behaviour when the road is wider and their RLR movement would only require them to move straight (3-legged SI) instead of turning left or right into the minor road. Moreover, this study has shown that the weaving or lane splitting approach is not associated or affected with any of the intersection signal timings or infrastructure (i.e. speed limit sign, shoulder, median, number of lanes, etc.). In general, we can say this aggressive approach is only presence when the road is wider and they are in the presence of high motorcycle volume passing the major road.

This study has shown that there are three (3) movement types of RLR-MC cross the SI - (a) crossing the SI by Illegal manoeuvre (i.e. illegal U-turn, contra-flow, prohibited left-turn), (b) crossing the SI by stopping first at or before the stop line, and (c) crossing the SI without stopping before the stop line. Among these crossing behaviours, 'crossing the SI without stopping at the stop line' is the majority with 51.15% from the total observation.

RLR-MC crossing the SI without stopping at or before the stop line is the most dangerous among all behaviour. We would classify this RLR-MC crossing without stopping as a form of risk taking behaviour, 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 location in the **Northern** and **Southern region**, or **3-legged SI with a total of 4-lanes on the major roads** with **70 km/h speed limit**. This risky crossing behaviour is also associated with **major road traffic volume of 2,000 – 3,000**

vehicle per hour and when there are **motorcycle volume passing the minor road are within 15% - 25%** from the total volume. This risky behaviour however, is also not associated with any of the signal timings or any of the dimension variables, which indicate that this behaviour occurrence may be highly dependent by the motorcyclist's personality or other factors previously mention. After viewing the analysis on this particular behaviour, 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 (70 km/h) and also location that has RLR-MC behaviour as a norm.

We also detected another risk-taking behaviour is the RLR-MC crossing via illegal manoeuvre. This is a rare behaviour, which only records up to 1.95% from the total observation, but its movement stood out as risk-taking behaviour because this RLR-MC behaviour is unpredictable to other road user at the SI. 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 generalised that RLR-MC crossing via illegal manoeuvre 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 behaviours. It seems that, at a 4-legged SI, RLR-MC who moves along the centre of the lane are likely to stop at the stop line before run the red light. Meanwhile at 3-legged SI, 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 centre 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-legged SI provides the RLR-MC more space to cross without stopping.

The number of vehicle waiting on the major or minor road influences the red light occurrence among motorcyclists. Our analysis shows that as the number of vehicle 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 generalised 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 RLR-MC behaviour at SI and develops countermeasures in order to curb the risky behaviour. 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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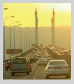

Research Report

Red Light Running Motorcyclists at Signalised Intersection in Malaysia: An Empirical Study

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