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RESEARCH ARTICLE

Motorcyclists' Stopping Position at 4-Legged Signalised Intersections

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ABSTRACT - Malaysia was ranked seventh in the world for having the highest percentage of motorcycle fatalities. The majority of motorcycle fatalities occurred at intersections as a result of other motor vehicles failing to notice them. However, little is known about the behaviour of motorcyclists when they come to a stop at an intersection. This study was designed to examine the position of motorcycles during the red phase at 4-legged signalised intersections. Data from 4,133 motorcycles were collected at four locations in peninsular Malaysia throughout peak and off-peak hours. Motorcycles stopped at signalised intersections by stopping behind the stop line, at/in front of the stop line, at the yellow box, at the pedestrian crossing and at the island marking were collected through video recording. Therefore, to facilitate the analysis, motorcycle positions were classified as either stopping behind the stop line or stopping forward. As per findings, more than 63 percent of motorcyclist's queue in front of the stop line and move forward during peak and off-peak hours to gain a clear view, which increases the likelihood of a motorcycle departing within a very short time during the initial period of the green signal. To improve the performance of signalised intersections, some traffic engineering approaches can be used, such as the provision of a dedicated area, known as a motorcycle red box, which separates motorcycles from other types of vehicles at traffic lights. Positioning motorcycles ahead of other drivers reduces the risk of motorcycles appearing out of nowhere when traffic begins. This segregation is expected to improve motorcyclist visibility and safety, as well as provide a buffer for pedestrian crossings at signalised intersections, providing better protection for vulnerable road users.

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1.0 INTRODUCTION

Motorcycles are the most popular mode of transportation in developing countries because of their ease of use, mobility, and low cost [1][2]. Through the lens of road safety perspective, Malaysia faces significant challenges related to motorcycles. As we can see each year, high crash rates, especially involving motorcycles, remain a pressing issue, thereby efforts to reduce fatalities and injuries, such as promoting safe riding practices and providing education to motorcyclists, are ongoing. However, some areas in Malaysia may have inadequate infrastructure for motorcycles, leading to risk to the safety of riders, considering that motorcycles are the most commonly used mode of transportation in Malaysia for daily commuting [2][3]. According to data from the Royal Malaysian Police (PDRM) in [4], covering the years from 2010 to 2020, the number of registered motorcycles kept growing, and the total motorcycle population is recorded to reach 14.9 million by 2020 (refer to Figure 1). Despite the historical decrease in motorcycle casualties, the year 2020 saw an increase, resulting in an overall gain of 0.4% compared to the 2019 data. The Covid-19 pandemic made 2020 a challenging year, causing severe disruptions in the manufacturers and suppliers, thus affecting motorcycle production at all levels. Due to favourable government legislation and manufacturer innovation, the number of motorcycle owners in Malaysia keeps increasing. Several factors synergize to flourish the motorcycle market in Malaysia such as growth in Gross Domestic Product (GDP), higher disposable incomes, and improved vendor capabilities [5]. A higher GDP often relates to increase consumer spending power and a greater demand for various goods, including motorcycles, thereby creating a larger customer base with the financial means to purchase motorcycles for personal transportation or recreational purposes [6]. Increasing disposable incomes among Malaysians means that people have extra income can be allocated towards discretionary purchases, such as motorcycles after covering essential expenses [7][8]. In terms of improved vendor capabilities, the manufacturers can produce motorcycles with better quality, innovative features, and competitive pricing [9][10]. These improvements collectively enhance the overall competitiveness of the Malaysian motorcycle market, attracting more consumers and potentially expanding the market, taking the industry to new heights [5].

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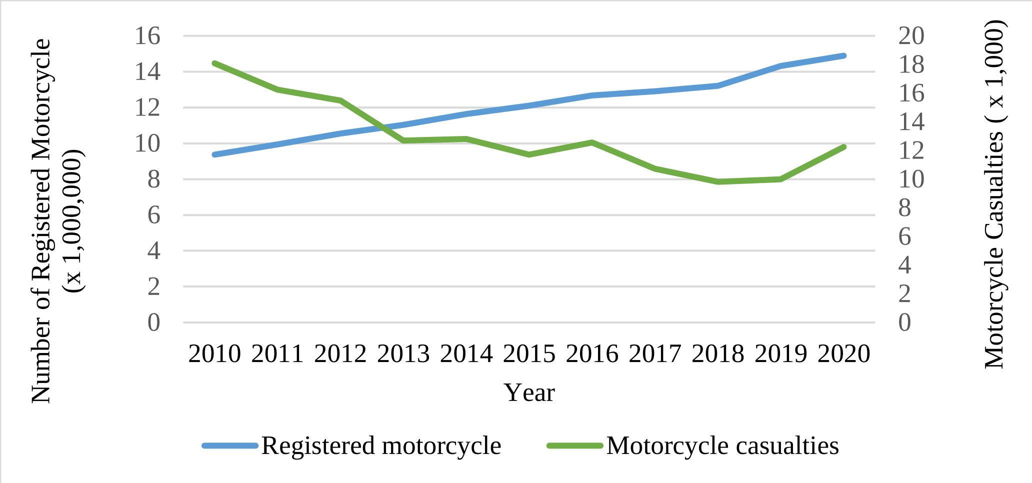

Figure 1. Registered motorcycles and motorcycle casualties in Malaysia [4]

At present, road traffic crashes rank as the eighth most common cause of death globally, claiming approximately 1.35 million lives a year and resulting in up to 50 million injuries [11]. The data reveal that the heaviest toll of road traffic fatalities and injuries falls upon low- and middle-income countries and the rate of road traffic death in Malaysia was estimated to be 23.6 per 100,000 population [11]. In 2020, Malaysia was ranked seventh in the world with a high percentage of fatalities due to motorcycle crashes [12]. According to PDRM in [13], motorcycle fatalities have made up the highest road fatalities at 71 percent in 2021. The statistic recorded on motorcycle fatalities indicates the magnitude of the road traffic problem among motorcyclists in Malaysia is a serious issue that requires immediate attention. Looking at the motorcycle fatal crashes by location, a study by Manan & Várhelyi (2012) discovered that the majority of fatal crashes involving motorcyclists (66 percent) occurred on straight road sections, with signalised intersections ranking second (19 percent) [14]. These findings are consistent with research conducted by Haque, Chin & Huang [15]. The occurrence of a higher fatal motorcycle crash on the road is more likely to be related to speeding [16], where a higher speed of collision may result in severe injury. Speeding has already been identified as one of the most important factors that contribute to traffic crashes, however, it is vital to consider other road environment factors, such as road design and layout, road condition, roadside hazards, visibility, and traffic control devices, along with behavioural factors like fatigue, distracted driving, aggressive driving, impaired driving, unobeyed traffic law, inexperienced drivers, and adverse weather conditions, are equally important contributors to road safety concerns [16][17]. Apart from speeding, insufficient infrastructure provided for motorcyclists, such as motorcycle lanes may also increase the risk for motorcyclists [11]. When motorcyclists travel in mixed traffic, there are possibilities to increase the tendency to collide with other bigger vehicles such as cars, vans, and lorries.

Observations from a study on motorcycle movements at 4-legged signalised intersections revealed that motorcycles are more vulnerable to certain risks compared to other vehicles [1]. This vulnerability arises from several factors. Firstly, motorcycles tend to move to the front of the intersection's queue, leading to a higher likelihood of multiple motorcycles leaving the intersection in a very short period after the initial period of the green signal. Secondly, due to their lightweight nature, motorcycles can accelerate more quickly and easily, raising the probability of being involved in crashes during the early period of the green signal. Furthermore, the presence of wider lanes and right-turn lanes allows motorcycles to weave through traffic more easily, leading to increased exposure to potential hazards. Conversely, when heavy vehicles present in the traffic stream, it hampers motorcycle weaving maneuvers, and this problem worsens in narrower lanes [1].

An intersection is a location where drivers meet and crosses the street. When modes of transportation and volume increase, the situation at the intersection becomes more complicated. When there are a huge number of motorcycles on the road, the performance of signalised intersections is reduced, this is due to the disorderly movement of motorcyclists as they approach the signalised intersection, which causes massive traffic conflicts between motorcycles and other vehicles [18]. The disorderly movement of motorcyclists at intersections includes their risky behaviour and violations such as weaving between motorists, splitting while speeding, running red lights, blocking the authorised left turn (ALT) vehicle, stopping in front of the stop line, speeding, obstructing pedestrian crossing area, not wearing a helmet, wearing dark clothing and not used headlight [18][19].

The smaller size of the motorcycle compared to other vehicles provides an advantage for motorcycle riders for easier manoeuvring within traffic. Motorcycles are able to deviate from the "First in First Out" rule at intersections with queues (i.e., line up when arriving at the signalised intersection) as they are very manoeuvrable and constantly try to move to the front of the line by squeezing between queuing vehicles at intersections [20]. In other studies, Muttart et al. [21] found that motorcyclists are much less likely to stop at a stop line at intersections. Muttart et al. in [21] observed only 39% of motorcycle riders stopped behind the stop line when approaching the intersection. Additionally, when other motorcyclists approach the stop line, a rider frequently avoids placing a foot on the ground and riders were observed performing weaving maneuvers while moving slowly enough to stay atop of motorcycles [21]. This result is in line with Manan & Várhelyi in

[22] and Kooijman & Schwab in [23] who found that motorcycle riders avoid stopping or yielding at intersections because doing so requires more effort to prevent gravity from pulling the motorcycle onto its side. The decision either to stop or proceed at signalised intersections may influenced by factors such as the distance from the stop line, the vehicle's approach speed, and the type of intersection [24].

Other than motorcyclists, pedestrians are also an at-risk group to be involved in fatal crashes at signalised intersections [25]. The same finding was made by Mukherjee & Mitra (2019), where signalised intersections were the scene of nearly 30% of fatal pedestrian collisions [26]. The National Traffic Safety Administration (NHTSA) estimates about 23% of pedestrian deaths in the US at intersections [27]. In Malaysia, approximately 25% of pedestrian collisions at intersections result in fatalities [28].

Therefore, it was great that a designated space was provided for vulnerable road users at signalised intersections. Advanced stop lines (ASL) or a dedicated area for two-wheeler vehicles can be provided by using road markings before the stop line at an intersection. Research by Pérez & Santamariña-Rubio in [29] and Newman in [30] mentioned advanced stop lines (ASL) have been widely used in Europe to increase cyclist safety. ASLs, also known as advanced stop boxes or bicycle boxes, are road markings at signalised intersections that place some vulnerable road users, like cyclists and motorcyclists, in front of queueing vehicles, giving them a head start when the traffic light turns from red to green. By providing motorcyclists with a dedicated space like ASL at intersections, motorcyclists no longer queue together with other vehicles, but only wait for traffic lights at intersections in dedicated space in front of other vehicles. The ASL marked with a coloured box on the road before the stop line will improve the visibility of motorcyclists at the intersection. Positioning motorcyclists in front of vehicle drivers reduced the risk of motorcyclists suddenly appearing out of nowhere when traffic is starting.

Based on research by Organisation for Economic Cooperation and Development (2015), ASL should be implemented for motorcyclists to lessen the risk of them weaving through traffic to get to the front of the line at signalised intersections [31]. According to Mulyadi in [32], the ASL with the largest dimension and the longest red time operation has the lowest occupancy, which is approximately 31%. Meanwhile, the intersection with the smallest dimension and the fastest red-time operation has the highest occupancy rate of up to 47% and the ANOVA test reveals no significant difference in the dependency of the ASL occupancy rate on ASL dimension and red time operation [32].

A study by Khaidir, Johari, Jamaluddin & Roslan (2019) in [33] was also conducted to examine the current condition of ASL implementation in Kuala Lumpur, Malaysia. Findings show the low compliance and high rate of ASL misuse by other vehicles may be attributed to a lack of knowledge of the ASL marking and since the marking is new to Malaysian road users, researchers suggested that the implementation of ASL be done in tandem with the addition of more road signs to let know where motorcycles and other motorised vehicles should stop [33].

How far the ASL needed is depends on the motorcyclist's stopping position at signalised intersections. However, the study regarding the behaviour of motorcycle riders when they stop at intersections remains limited. To address this gap, this investigation looked at how motorcycles were positioned when approaching 4-legged signalised intersections during the red phase. The study's findings have the potential to assist traffic authorities in devising effective countermeasures to reduce collisions between motorcycles and pedestrians as well as increase the safety levels of all road users at signalised intersections. This is in line with Sustainable Development Goals 2030, specifically Goal 9 (Industry, innovation, and infrastructure), which focuses on a sustainable transportation system for all, and a National Transport Policy (NTP) was implemented in Malaysia to provide strategic directions for a sustainable transport sector from 2019 to 2030, which coincides with the Agenda on Sustainable Development 2030 [34]. This study is also related to Thrust 3 in Strategy 3.2, which is to improve safety, integration, connectivity, and accessibility for a more seamless journey. An urgent need to reduce road crashes and fatalities, improving safety guidelines, regulations, and enforcement are highlighted in the National Transport Policy [34] owing to Malaysia's high rate of road fatalities and the nation's expected losses from road crashes in 2017, which totalled more than RM8.8 billion.

2.0 METHOD

This study focused on 4-legged signalised intersections operating under a fixed-time operating system. These four (4) intersections were selected as the study area because it was identified as high-risk roads for both federal and state routes based on the crash data in Malaysia. The study's sites are located in Sitiawan, Kluang, Teluk Intan, and Hutan Melintang. Data collection during the peak hours was set from 7:00 to 9:00 in the morning (peak hour) and from 10:00 to 12:00 in the afternoon (off-peak hour). The selected time frames were made by examining the peak motorcycle traffic volume on the roads, which was determined through continuous observations of traffic volume at each site throughout the day.

During on-site data collection, measuring wheels, laser distance metres, video cameras (1.6m, 3m, and 4m), and tally-counters were used. The camera was placed about 15 metres behind the stop line at each leg to get a better view of the traffic situation at the intersection. Figure 2 depicts the placement of a video camera at the 4-legged signalised intersection.

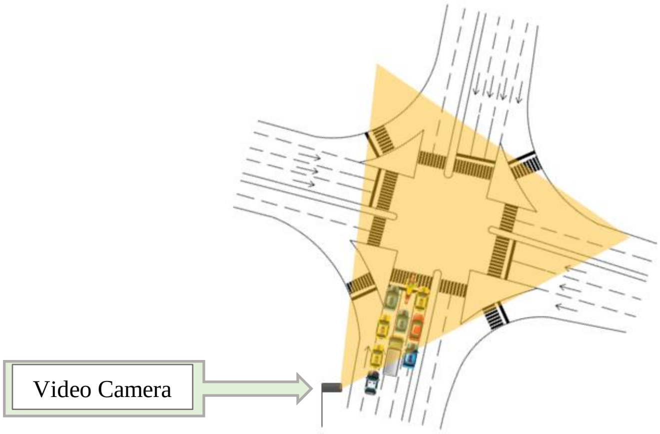

Figure 2. Illustration of video camera placement on-site

Video data for motorcycle positions were extracted from observational data via video recording method to identify where motorcycles stopped during red phase at signalised intersections. Motorcyclists were identified as stopping behind the stop line, at/in front of the stop line, at the yellow box, at the pedestrian crossing, and at the island marking. Therefore, motorcycle positions were classified as either stopping behind the stop line or stopping forward to facilitate analysis and the motorcycle position was classified as follows and is depicted in Figure 3.

1) Behind stop line
2) In front stop line / Forward include:
    a. Stop at or in front of the stop line
    b. Stop after the stop line and wait the red light on yellow box
    c. Stop after the stop line and wait the red light on pedestrian crossing
    d. Stop after the stop line and wait the red light on front of the island marking

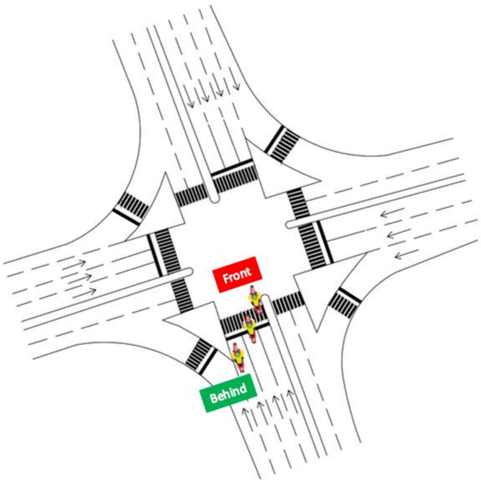

Figure 3. Illustration of motorcycle positions

The data was using both descriptive and statistical analyses. The descriptive analysis employed manual calculation using Microsoft Excel to determine percentages, whereby SPSS software was utilised for the Chi-Square Test of Independence, which categorized the data and calculated a chi-square statistic by assessing the observed versus expected frequencies within each group [35][36]. The decision to use SPSS software was based on its effectiveness for data management, analysis capabilities, and the ability to perform various statistical tests, including the chi-square test, thereby enhancing the credibility and trustworthiness of research outcomes [35]. The hypothesis of this study is to investigate whether there is any relationship between motorcycle stopping positions during different observation periods.

3.0 RESULTS AND DISCUSSION

The videos captured 4,133 motorcyclists stopping at the four (4) signalised intersections during peak and off-peak hours. Table 1 summarises the number of motorcycles and the percentage of stopping positions among motorcyclists at the study locations during peak hours. By looking at locations (the intersection layout remains consistent across all four intersections), risky behaviour among motorcyclists is well shown since more than 76% stop forward stop lines at Perak locations consist of Sitiawan and Teluk Intan signalised intersections as compared to Hutan Melintang and Kluang. From our observations, motorcyclists tend to position themselves at the front of intersections because the riders can initiate movement before other vehicles, given the ample space available. Additionally, this behaviour increases the risk of a motorcycle being struck by another vehicle crossing the intersection [37] and this group of motorcyclists occupying the front position may lead to a tendency to beat the red light. Besides that, the motorcycle group's actions, such as stopping in front of the stop line, also created difficulties for pedestrians to cross at the signalised intersection [38]. Delays might lead pedestrians taking greater risks in terms of their safety as well as their own rights [39]. In contrast, more than half of drivers abide by the stop line marking at Hutan Melintang and Kluang.

Table 1. Stopping position among motorcyclist at 4 locations during peak hour

Location	Stop behind	Stop forward
Sitiawan	134 (24%)	427 (76%)
Hutan Melintang	296 (53%)	259 (47%)
Teluk Intan	114 (16%)	611 (84%)
Kluang	477 (53%)	427 (47%)
Overall	1021 (37%)	1724 (63%)

Based on off-peak data as in Table 2, all locations indicated risky behaviour among motorcyclists. Since there are fewer other vehicles at signalised intersections, more than 50% of motorcyclists stop in front of the stop line to speed up their journey.

Table 2. Stopping position among motorcyclist at 4 locations during off-peak hour

Location	Stop behind	Stop forward
Sitiawan	82 (24%)	253 (76%)
Hutan Melintang	177 (48%)	194 (52%)
Teluk Intan	37 (10%)	321 (90%)
Kluang	114 (35%)	210 (65%)
Overall	410 (30%)	978 (70%)

A Chi-Square Test of Independence as shown in Table 3 was performed to assess the relationship between motorcycle stopping positions and observation periods. The sample size for the Chi-Square test is sufficient as the expected frequencies for each category is at least 5 [35]. Therefore, the results indicated the chi-square statistic is 23.87. The *p*-value is less than 0.001 and this indicates there is a statistically significant relationship between the two variables (motorcycle stopping positions and observation periods).

Table 3. Relationship of motorcycle stopping position between different observation periods

Location	Stop behind n (expected frequency)	Stop forward n (expected frequency)
Peak	1021 (950.42)	1724 (1794.58)
Off-peak	410 (480.58)	978 (907.42)

Many important considerations are required to design pedestrian accesses and crossings at the signalised intersection without compromising pedestrian safety and vehicular traffic performance [40]. Thus, traffic engineers are making efforts to mitigate congestion and increase intersection efficiency. Yang (2002) found that refuge islands at larger signalised intersections are required to improve pedestrian crossing safety [41]. As stated by Li, Yang, & Yin in [42], a pedestrian refuge island in roadway medians serves as a risk-free waiting area for two-step crossings, a scenario where pedestrians typically cross half of the road first and then remain within the median, awaiting the next green light. However, pedestrians are often exposed to the risk of being hit by traffic on both sides of the road and this safety measure is particularly crucial at signalised intersections, benefiting both pedestrians and drivers [42]. In a study of the effects of right-turn channelization on pedestrian safety, Jiang et al. [43] discovered that right-turn lanes increase the risks for pedestrians at signalised intersections. Thus, implementing an exclusive pedestrian phase results in both improved overall safety and an increase in pedestrian compliance with traffic rules [44].

Therefore, by using the JKR (2015) guidelines as a reference, the best practise at intersection as shown in Figure 4 was proposed [45]. However, the proposed should only be used as a road designer's guide. The environment of the road and the surrounding traffic must always be taken into account, and the use of engineering judgement based on principles of road safety is highly recommended.

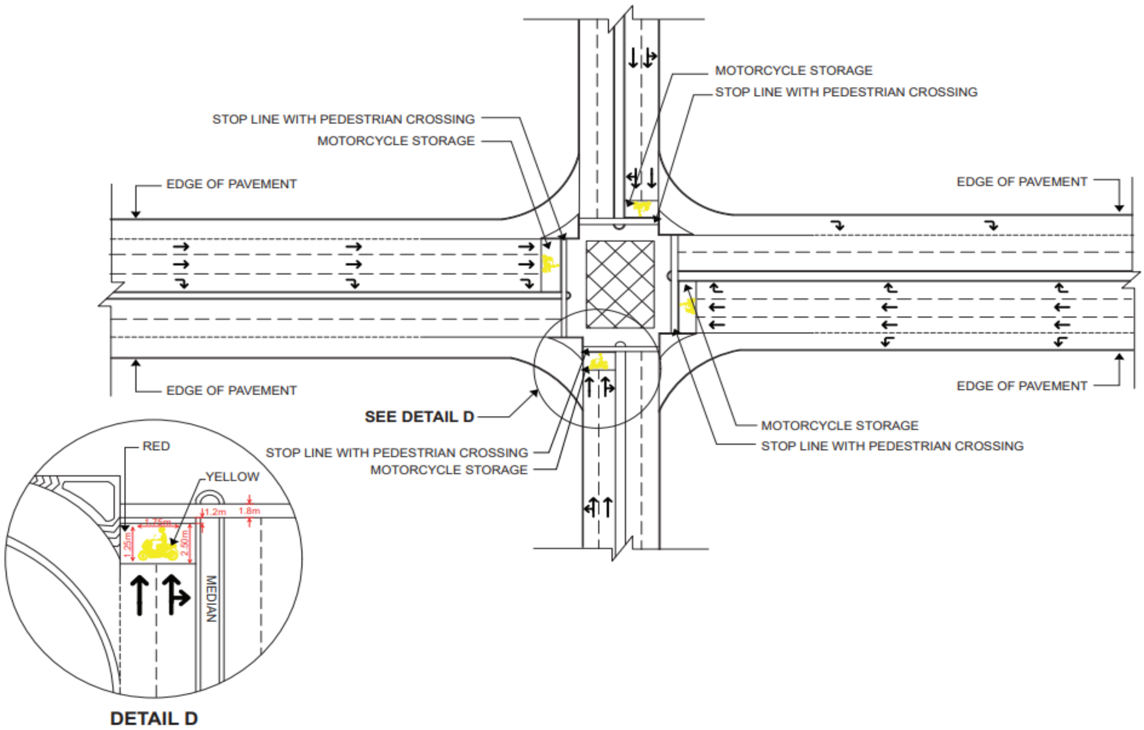

Figure 4. Best practice at 4-legged signalised intersection [45]

As shown in Figure 5, the minimum space width needed to store one motorcycle in static conditions during the red phase is 1 meter. According to Manan et al. in [46], Malaysia has 19 different types of motorcycles. As a result, the largest motorcycles with less than 250cc that were frequently seen in Malaysia are used to represent motorcycle design in this study [45].

Figure 5. Static space for motorcycle in Malaysia [45,47]

By referring to research conducted by Mulyadi (2017), the following formula can be used to calculate the maximum motorcycle storage or red box occupancy [32]:

$$\text{Maximum red box occupancy} = \text{area red box } (m^2) \,/\, \text{required area for one motorcycle while waiting in the red box } (m^2) \tag{1}$$

With the assumption that the minimum requirement (refer Figure 4) is followed in this example and that the standard road width is 3.5 metres per lane (10.5 metres for 3-lanes on major roads), only 10 motorcycles can be occupied the storage area during the red phase, according to the calculation example provided below:

$$\text{Maximum red box occupancy} = \frac{(10.5\text{m} \times 2.5\text{m})}{(1\text{m} \times 2.6\text{m})} = 10 \text{ motorcycles}$$

Given the limitations of individual sites, it is advised that motorcycle storage is provided within the study locations even though the findings and suggestions made here are particular to the chosen geometric features. It is recommended that when a road authority implements similar design concepts at signalised intersections, particularly when adjusting factors like vehicle speeds, geometric features (for example the shape and layout of the intersection), and signal settings (like traffic light timings), it is crucial for the authority to exercise caution and deliberate judgement. This is because adjusting these elements can have a significant impact on the overall performance and safety of the signalised intersection, and decisions should be made with precision and expertise.

4.0 CONCLUSION

This study is aimed to explore motorcycle position during the red phase at the 4-legged signalised intersections. The observations were conducted at four (4) sites distributed in Perak and Johor, city areas. Retrieved data from video recording for every signalised legged was conducted for morning peak and off-peak hours on weekdays. Overall, stopping position observation shows that more than 63% of motorcyclist tends to stop forward of the stop line. Positioning motorcycles at the front of the vehicle queue enhances their field of vision and, concurrently, may contribute to increased motorcycle safety. Based on specific time periods, off-peak hours have 7% more motorcycles stopping in front of the stop line than peak hours. Nevertheless, the exposed motorcyclists in front of the stop line marking may increase the likelihood of being struck by an errant vehicle in the event of run-off crashes. Additionally, this behaviour poses greater risks to the group of pedestrians. In conclusion, motorcycles move in a distinctive way when they come to a stop at signalised intersections. This study also advised the use of proper motorcycle storage or motorcycle red box. Further research is required to assess the impact of the red box dimension and red time operation differences. The results of this study could assist traffic authorities in developing appropriate countermeasures to lessen collisions between motorcycles, other vehicles, and pedestrians as well as to increase the safety levels of all road users at signalised intersections.

5.0 AUTHOR CONTRIBUTIONS

Nora Sheda Mohd Zulkiffli and Ho Jen Sim: Conceptualization, Design, Draft manuscript preparation

Nora Sheda Mohd Zulkiffli, Rizati Hamidun, Azzuhana Roslan, Mohd Shafie Nemmang, Syed Tajul Malik Syed Tajul Arif and Nur Zarifah Harun: Data collection, Data analysis, Interpretation of results

Nor Aznirahani Mhd Yunin.: Writing- Reviewing and Editing

All authors reviewed the results and approved the final version of the article.

6.0 FUNDING

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7.0 DATA AVAILABILITY STATEMENT

The data used to support the findings of this study are included within the article. Data sharing is not applicable to this article.

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9.0 CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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