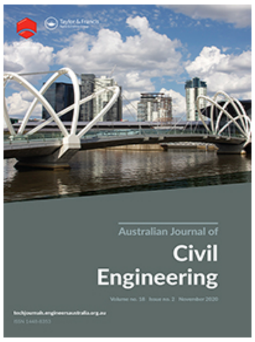

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ARTICLE

Effect of motorcycle on the critical gap at priority junctions

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ABSTRACT

The gap acceptance research is an essential research in the estimation of the values of capacity and delay at priority junction. This study was conducted to estimate and compare the value of critical gap using the equilibrium method, maximum likelihood method and Malaysia Highway Capacity Manual (MHCM), conditioned with and without presence of the motorcycles. The two priority junctions with multilane road were targeted and data were recorded using video camera technique. The equilibrium method estimated the critical gap at priority junction with motorcycles approximately 0.17 s shorter than that of priority junction without motorcycles. Similarly, this study has been carried out for maximum likelihood method, and the magnitudes of critical gap with motorcycles were estimated about 0.20 s less than the situation without motorcycles. In the case of MHCM, the results showed a differentiation around 0.04 s between both situations. These close results show that differences of critical gap between both scenarios are very small. However, considering the importance of critical gap for evaluating the operational conditions at priority junctions, we highly recommend the estimation of that gap in some Asian countries such as Malaysia with many motorcycles.

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KEYWORDS
Critical gap; motorcycle; equilibrium method; priority junction; maximum likelihood

1. Introduction

Research by Manan and Várhelyi (2012, 2015) described that motorcycles are one of the most crucial transportation modes in Malaysia and several other Asian countries such as Indonesia, Thailand and Vietnam. Generally, it is widely known to be inexpensive and easy to utilise in the countryside region because it can be manoeuvred along the narrow path of farms as well as the suburban or urban region among automobiles within a traffic congestion. Meanwhile, Hsu, Ahmad Farhan, and Nguyen (2003) and Jacobs, Aeron-Thomas, and Astropn (2017) stated that in the mentioned countries, motorcycles are usually utilised as the daily average of transportation of services, goods and persons rather than regarded as a suitable automobile utilised in developed European countries. In addition, Hsu, Ahmad Farhan, and Nguyen (2003) described that in Malaysia and Vietnam, a motorcycle is the principal personal vehicle option for transportation, while the greater part of the workers who ride motorcycles are from service working sector as well as the industrial area.

In two separate research conducted by Manan and Várhelyi (2012, 2015), it was asserted that Malaysia has the greatest fatality level within the ASEAN regions with more than 50% of the road accident deaths involving motorcyclists. In addition, motorcycle fatalities in Malaysia are usually three times greater than automobile deaths, followed by six times greater compared to pedestrian deaths, and almost 50 times greater than bus passenger deaths. Additionally, Manan and Várhelyi (2012, 2013) pointed out that motorcycle crash deaths on Malaysian principal roads are overrepresented, simply because motorcycles represent almost 25% of the overall traffic composition on the mentioned roads. Accordingly, 62% of motorcycle crash deaths seem to take place on the principal roads acting as the main category of road that forms the basic network throughout a state, which is further connected with the state capitals and major cities in Malaysia. More importantly, these principal roads are not mainly segregated because it was created as individual carriageway streets with several access points.

A critical gap is a significant factor that needs to be considered when analysing and describing traffic characteristics and traffic safety for priority junctions. In Highway Capacity Manual (HCM) (TRB 2000, 2010), critical gap is identified as the minimum time, in seconds, among successive main road automobiles whereby a minor road automobile is able to create a manoeuvre. Regarding the critical gap description at priority junctions, several techniques have been developed which are described by the summary of these methods from 68 years ago up to now.

Raff (1950) developed a technique that remains one of the most popular techniques for unsaturated

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conditions owing to its simplicity and efficiency. The original Raff's process approximates critical lags based on the lag approved and declined but it has been statistically considered wasteful because it omits the whole gap data (Miller 1974). Accordingly, this led to the extension of Raff's technique for the purpose of calculating critical gaps by either taking into account the only gaps by Brilon, Koenig, and Troutbeck (1999) or mixing gaps and lags with each other by Ashalatha and Chandra (2011)and Devarasetty, Zhang, and Fitzpatrick (2012). Nevertheless, Miller (1971) found that this technique is statistically inefficient during high traffic flow because a significant number of valuable data is ignored even though it is reasonably acceptable with very small bias when the traffic flow is relatively light by taking into account only the lag data. In addition, Tupper et al. (2013) identified that the results of this technique produce a substantial error when data relating to only lags are utilised. Hence, cautious motorists get over represented since all the declined gaps were taken into consideration in this technique. Therefore, a few experts such as Troutbeck (1992) and Wu (2012) have taken into consideration only the maximum declined gaps in eliminating bias in data.

In previous studies conducted by Pollatschek, Polus, and Livneh (2002) and Yan, Radwan, and Guo (2007), the gap acceptance behaviour was taken into consideration. Accordingly, Pollatschek, Polus, and Livneh (2002) showed a microscopic decision method for motorist gap acceptance behaviour when waiting at a priority junction on the minor road. In particular, the method is dependent on the analysis of risk associated with not accepting short gaps against the potential benefit of their approval, which refers to the time saved as a result of shorter delays at the entry line. Moreover, the research demonstrated the difference among various behaviours of motorist populations (cautious vs. risk-loving) and displayed how this distinction actually affects several capacities on the minor street. In research conducted by Yan, Radwan, and Guo (2007), the effects of main traffic speed and motorist gender and age on gap acceptance behaviours were investigated.

Meanwhile, Sangole, Patil, and Patare (2011) developed a behaviour of right-turning manoeuvre from minor road gap acceptance method for two-wheelers at priority junctions, which is dependent on various motorists and traffic attributes in India. In this case, MATLAB software was utilised for the purpose of creating an Adaptive Neuro-Fuzzy Interface System (ANFIS) that offers an optimisation structure in acquiring the variables in the fuzzy system which can significantly fit the data. In their study, Sangole, Patil, and Patare (2011) described that stop or yield sign has no function in India which causes the processing of vehicles at priority junction to be complicated and very interactive, whereby each motorist tends to make personal decisions about where, when and how to complete the required manoeuvre. In addition, Sangole, Patil, and Patare (2011) confirmed that no research in the past has focused on the gap acceptance behaviour of two-wheelers at priority junctions. Therefore, it is significant to comprehend the behaviour of two-wheelers in the development of delay method for priority junctions.

On another note, Devarasetty, Zhang, and Fitzpatrick (2012) established a binary logit method to calculate the probability of rejecting or accepting a specified gap or lag for left-turning manoeuvre from main street (right-hand driving system). In particular, a number of potentially affecting elements at a priority junction was taken into consideration in their study. A stepwise selection technique was utilised for the purpose of discovering substantial factors in the method. In this regard, logistic regression method managed to be developed whereby the independent parameters are comprised of traffic characteristics and geometric of a field, followed by the dependent parameters which act as the values of gap/lag acceptance of a left-turning manoeuvre from the main street. Accordingly, it should be understood that this method can be utilised in calculating the values of the critical gap/lag for a specified set of field characteristics as well as traffic flow variables for the purpose achieving a more reliable evaluation of traffic operations.

Guo and Lin (2011) created a survey technique of refused and approved gaps which are dependent on the preceding presumptions. In their study, four new techniques for computing critical gap were suggested. More importantly, the Probability Distribution Function (PDF) of the refused and the approved gap can be deduced by introducing the exponential refused proportion function. Overall, it was concluded that the exponential model of refused proportion is more generally realistic compared to the linear method.

In research by Wu (2006, 2012), a new method was introduced for the evaluation of critical gaps at priority junction. Accordingly, a method for calculating the critical gap and its empirical distribution was created by utilising the equilibrium of probabilities for refused and approved gaps. Interestingly, this method does not need any presumptions concerning the distribution function of critical gaps and motorist behaviours. Finally, the outcome of the new method is an unparameterised empirical distribution of critical gaps.

McGowen and Stanley (2012) suggested an unbiased alternative method for calculating the critical gap which can be utilised with naturalistic data. However, the suggested method requires the gap distribution of the main road to be identified. Moreover, this suggested method can be compared with the Troutbeck (1992) developed by Monte-Carlo simulation. Overall, it is interesting to note that the suggested model yields precise approximations of the mean critical gap as long as the precise estimates of the main road traffic are utilised.

Guo, Wang, and Wang (2014) proposed two new techniques on the supposition of independence between the arrival times of minor road automobiles as well as the ones of main road automobiles. More importantly, new methods managed to be successfully confirmed by the simulation of headway data as well as the comparison of several critical gap techniques. Specifically, it should be noted that both M3 description technique and revised Raff's technique tend to utilise the total rejected values. Accordingly, M3 description technique is simple and valid, whereas the revised Raff's technique has more general application compared to the original Raff's technique. Nevertheless, both techniques have accordant outcomes, but Raff's technique has greater fluctuation in various situations. According to this investigation, Guo, Wang, and Wang (2014) mentioned that the M3 description technique and revised Raff's technique are clearly suitable for recommendation.

A research by Sahraei et al. (2014) and Sahraei and Puan (2018) managed to assess priority junctions in Malaysia. In his assessments, the value of the critical gap was computed by utilising HCM and Malaysia Highway Capacity Manual (MHCM). In addition, it should be noted that another research by Sahraei and Akbari (2019) considered the drivers' gap acceptance at priority junctions. In the said investigation, the evaluation of gap data was carried out by utilising the PDF.

Regarding the described condition at priority junction in Malaysia, it was part of the aim to conduct research on the effect of a motorcycle on the critical gap at priority junctions that may lead to accident risk. In particular, the following research questions were developed in order to determine an appropriate result for the research:

- What is the critical gap values in the presence of motorcycles based on the existing methods such as equilibrium method, maximum likelihood method and eventually MHCM that are popular in Malaysia?
- What is the critical gap values in the absence of motorcycles based on the existing methods?
- How much difference should be expected between two situations including with and without motorcycles?
- What is the effect of a motorcycle on critical gap values at priority junction based on the existing methods in Malaysia?

Therefore, the aim of the present study is to calculate and compare the magnitude of a critical gap in the presence and absence of motorcycles at a priority junction based on the mentioned methods.

2. Methodology

The vast majority of researchers used different approaches in order to estimate the value of a critical gap. In this case, a few researchers (Ashton 1971; Raff 1950) used only data related to lags. On the other hand, some of them (Fitzpatrick 1991; Mahdi 1991) agreed that useful data would be lost and the calculation of the critical lag or gap distribution would be imprecise, particularly if the analysis is dependent only on the lag information. Furthermore, a number of researchers including Solberg and Oppenlander (1966), Hewitt (1983, 1985), Adebisi and Sama (1989), Velan and Van Aerde (1996) and Sahraei and puan (2014) pointed out that the acceptance of lags is not substantially distinct from the acceptance of gaps; hence, it is more appropriate for both of them to be used. In the current research, the values of the critical gap were calculated using Wu (2006, 2012), in which both gap and lag information were mixed and not differentiated in the evaluation.

Meanwhile, Troutbeck (1992) created a process for calculating the magnitude of critical gaps depending on the Maximum Likelihood methods which are a microscopic model. Accordingly, only the maximum declined gaps are mainly evaluated, whereas the declined gap is only regarded asarelatedaccepted gap. Consequently, the magnitude of the likelihood of a driver's critical gap is generally between accepted and rejected gaps as shown in Equation (1). Therefore, if the probability distribution function of the critical gaps is presented, the variables of the PDF can be acquired by maximising the likelihood L^*. In this method, two presumptions are needed: (a) a log-normal distribution for critical gaps, and (b) a homogeneous and consistent behaviour of the motorists. Generally, it is important to note that the maximisation of the likelihood L^* can easily be carried out by utilising the iteration and numerical methods.

$$L^* = \prod_{i=1}^{n} [F_a(a_d) - F_r(r_d)] \tag{1}$$

where a_d = accepted gap, r_d = rejected gap, L^* = likelihood, n = number of observed drivers.

Furthermore, Wu (2006, 2012) describes that the method of Troutbeck (1992) is dependent on the theory of maximum likelihood evaluation. In this case, declined gaps must be smaller than the approved gaps, while only the maximum declined gap and the approved gap of single vehicles can be utilised pairwise. In other words, it has been made clear that data pairs with declined gaps being bigger than approved gaps cannot be utilised at all. In some situations, more than 50% of the calculated gaps cannot be employed which leads to a large waste of gathered data. Additionally, the method of Troutbeck is very complex and the outcomes produced are not very strong. Moreover, this method also needs a big sample size in order to create stable results. Therefore, regarding the above disadvantages, the value of the critical gap should be estimated using equilibrium of probabilities method introduced by Wu (2006, 2012).

Apart from that, it should be noted that this method has a strong theoretical background (concerning the Markov Chain and equilibrium of probabilities) and robust outcomes. In addition, this method is able to consider all appropriate gaps (not only the maximum declined gaps as is the case of the Troutbeck's (1992) method) as well as directly create the empirical PDF of the critical gaps. The property of the new method is that all declined and approved gaps such as approved gaps which are smaller than the declined gaps should be considered. Therefore, this particularly creates the main distinction between the new method and the most utilised method of Troutbeck. In other words, the new method is deemed to provide similar outcomes for the critical gaps as those from Troutbeck if only the maximum declined gaps with corresponding approved gaps greater than the declined gaps are utilised. Accordingly, it should be understood that the calculated critical gaps are generally smaller when all gaps are utilised. A practical computation process suggested by Wu (2006, 2012) is deemed suitable for the implementation of the suggested macroscopic model. Moreover, this process can be quickly applied to a spreadsheet in EXCEL software as shown in Figure 1. In this case, whether the whole gaps or only the maximum declined gaps, i.e. gaps (t), must be inserted into column 1 in order to calculate the value of critical gap. The accepted and the declined gap must be marked with (a) and (r) into column 2. Then, the whole gaps (column 1) must be sorted in ascending order. Meanwhile, the values of accumulate frequencies of the declined gaps (n_{rj}) must be estimated in column 3 which assumes $n_{r0} = 0$. In this matter, for a particular row (j), $n_{rj} = n_{rj}+1$, if the gap marked is (r), otherwise $n_{rj} = n_{rj}$. Other than that, the values of accumulate frequencies of the accepted gaps (n_{aj}) must be estimated in column 4 which assumes $n_{a0} = 0$. In this matter, for a particular row (j), $n_{aj} = n_{aj}+1$, if the gap marked is (a), otherwise $n_{aj} = n_{aj}$. The values of PDF of the declined gaps ($F_r(j)$) must be estimated in column 5. Therefore, for a particular row (j), $F_r(j) = n_{rj}/n_{max}$, where n_{max} = number of gaps. Next, the values of PDF of the accepted gaps ($F_a(j)$) must be estimated in column 6. Therefore, for a particular row (j), $F_a(j) = n_{aj}/n_{max}$. Overall, the PDF of the calculated critical gap can be estimated depending on Equation (2).

$$F_{tc}(t) = \frac{F_a(t)}{F_a(t) + 1 - F_r(t)} \tag{2}$$

where

$F_a(t)$ = approved gap, $F_r(t)$ = refused gap and $F_{tc}(t)$ = PDF of the critical gaps.

The value of frequencies of the calculated critical gaps between the particular row (j) and (j-1) must be calculated in column 8, which can be indicated as $f_{tc}(j)-f_{tc}(j-1)$. Meanwhile, the class mean ($t_{d,j}$) can be estimated in column 9 between the particular row (j) and (j-1), thus can be indicated as $t_{d,j} = (t_j+t_{j-1})/2$. Finally, the value of critical gap can be estimated by $t_{c,mean} = \text{sum}[p_{tc}(t_j)*t_{d,j}]$.

In the case of the current research, the value of critical gap for all movements at priority junctions

0		1	2	3	4	5	6	7	8	9	
				nr	na	Fr	Fa	Ftc	ftc	cl.m	
Index j	Vehicle	Gap (t)	Accept/ Reject	if(2)="r", nr=nr+1	if(2)="a", na=na+1	(3)/nr,max (sum)	(4)/nr,max (sum)	(6)/(6)+1-(5)	(7)j-(7)j-1	(1)j+(1)j-1/2	(8)*(9)
		0		0				0			
1	c	2	r	1	0	0.0011	0	0	0	1	0
2	c	2	r	2	0	0.0021	0	0	0	2	0
3	c	2	r	3	0	0.0032	0	0	0	2	0
4	m	2	r	4	0	0.0043	0	0	0	2	0
5	c	2	r	5	0	0.0053	0	0	0	2	0
6	m	2	r	6	0	0.0064	0	0	0	2	0
7	c	2	r	7	0	0.0075	0	0	0	2	0
8	c	2	r	8	0	0.0085	0	0	0	2	0
9	c	2	r	9	0	0.0096	0	0	0	2	0
10	c	2	r	10	0	0.0107	0	0	0	2	0
11	c	2	r	11	0	0.0117	0	0	0	2	0
12	m	2	r	12	0	0.0128	0	0	0	2	0
13	c	2	r	13	0	0.0139	0	0	0	2	0
14	c	2	r	14	0	0.0149	0	0	0	2	0
15	c	2	r	15	0	0.016	0	0	0	2	0
16	v	2	r	16	0	0.0171	0	0	0	2	0
17	c	2	r	17	0	0.0181	0	0	0	2	0
18	v	2	r	18	0	0.0192	0	0	0	2	0
19	c	2	r	19	0	0.0203	0	0	0	2	0
20	m	2	a	19	1	0.0203	0.0003	0.0003	0.0003	2	0.0006
21	c	2	r	20	1	0.0213	0.0003	0.0003	3E-07	2	7E-07

Figure 1. Spreadsheet for calculation of the critical gap.

with four lanes major/four lanes minor road was calculated using the above procedures.

3. Data collection and site description

In the present study, several priority junctions were visited around Johor Bahru in Malaysia for the purpose of data collection using the methodology adopted for the current research. According to the recording technique, some criteria were chosen to select the junctions as follows: (1) a safety and appropriate access for the counting and equipment throughout the data gathering process, (2) appropriate points with good height to install the equipment, (3) prevention of any interaction between vehicles, (4) junctions must have appropriate sight distance and (5) a suitable traffic volume on major and minor road. The site studies in the current research were chosen by compromising the above criteria.

Data for this research were gathered at two priority junctions in the suburban area using the video camera technique. As shown in Figure 2(a), one video camera was placed in the direction of the minor road (camera1), while the other was placed in the direction of a major road (camera2). Consequently, all data including accepted and rejected gap for vehicles stopped back of the departure line (on the major and minor roads) could be collected. More importantly, Ashworth(1976), Ke et al. (2017) and Huang (2018) have provided a clear explanation on the benefits of utilising a video recording technique for traffic data collection. In addition, it should be noted that this technique has also been utilised in past researches including Ashalatha and Chandra (2011), Sangole, Patil, and Patare (2011), McGowen and Stanley (2012) and Sahraei et al. (2018).

Each of the video recordings was played back for a number of times in order to obtain the most suitable data including accepted and rejected gaps for all vehicle's movement from a minor road as well as right-turning manoeuvre from a major road. Meanwhile, a laptop was used to obtain and evaluate the data gathered from the video recording. The video recordings were played back in real-time in order to determine appropriate gap time for all movements.

In the case of the current research, data were gathered from the morning until evening, precisely from 9:00 am until 6:00 pm on weekdays. Hence, this indicates that 18-h data (i.e. 9 hours for each junction) were gathered. The geometric features of all junctions were similar which include four lanes (i.e. two lanes in each direction) on the major and minor roads. Moreover, the data collection process revealed that the total numbers of left and right turn vehicles from the minor road were about 2252 and 5522, respectively, with around 1652 vehicles for right-turning manoeuvre from a major road. Furthermore, the total number of 563, 991 and 358 motorcycles for left and right turn from a minor road as well as right-turning manoeuvre from major road managed to be obtained, respectively. Figure 2(b) shows traffic lane configurations of priority junctions. The purpose of selecting these junctions was due to the preliminary short traffic counts that have confirmed reasonable volumes of turning movements which was deemed appropriate for the objectives of the current research.

The total data gathering for the present study was carried out during daylight time where the driving performance and behaviour differ from day to night time period (Ivey, Lehtipuu, and Button 1975) as well as without rainy weather condition (Rahman and Lownes 2012) in order to prevent the impact of adverse weather and environmental situations. Furthermore, all gap acceptances throughout the main road blockage and pedestrian blockage were removed. The main reason of the removal was due to the fact that these conditions could influence the precision and reliability of the sampling as well as accepted and rejected gaps; hence, it was excluded from the data collection process.

4. Analysis and discussion

The objective of the present study was to determine the effect of a motorcycle on the critical gap at priority junctions. Accordingly, first, the value of a critical gap

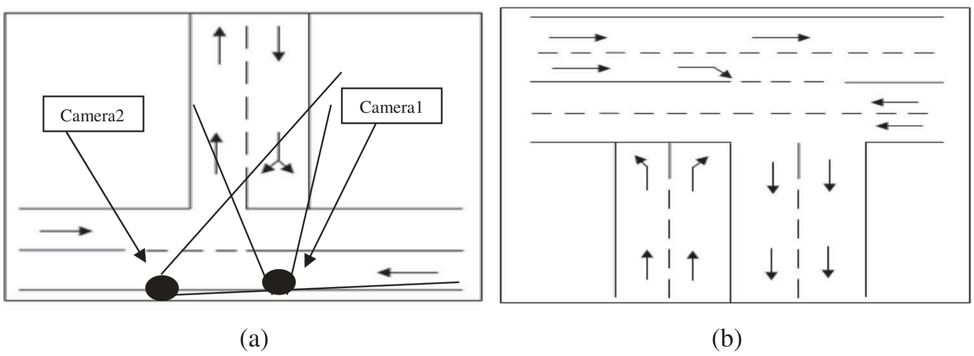

Figure 2.. (a) Location of cameras (b) Traffic lanes configuration on each priority junctions.

in the presence of all vehicles and motorcycles at a priority junction was successfully estimated. Next, the calculation was performed in the absence of motorcycles for the purpose of comparing it with the first situation. In this case, all accepted and rejected gaps in all movements (i.e. right and left turn from a minor road, and right turn from the major road) were determined using a stopwatch. In doing so, the time distances (in second) were recorded on the major road by which a minor road vehicle accepts to manoeuvre. Similarly, this procedure was the same for right-turning vehicles from a major road. Regarding this matter, it is important to note that the direction of the vehicle in Malaysia is Left-hand Driving System (LDS). The left-turning motorists from the minor road must only consider the near side gap, while the right-turning motorists from the minor road must be concerned with the two gaps in the major road (i.e. near and far side). Consequently, they are able to merge only if both near and far side gaps are deemed to be suitable.

To analyse, the rejected and accepted gaps for all vehicles were determined in the present study as one data set on a minor (i.e. right and left turn, separately) as well as right-turning manoeuvre from a major road. Next, the values of rejected and accepted gaps for motorcycles were removed because it will be used in another data set. Table 1 indicates the results of accepted and rejected gaps for all vehicles and its values without motorcycles for left and right turn from a minor road, as well as right-turning manoeuvre from the major road at all junctions during the observation period.

As can be observed in the above table, the total number of accepted and rejected gaps extracted for the right turn and left turn from the minor road are around 5888 and 2281 gaps, respectively. In addition, these values show 1703 gaps for left-turning manoeuvre from a major road. On the other hand, the total number of gaps (accepted and rejected gaps) in the second situation including non-motorcycles movements are 4739, 1622 and 1274 gaps for right- and left-turning from a minor road as well as right-turning movements from a major road, respectively. As can be seen in Table 1, the highest and lowest number of rejected gaps determined for right and left turns from a minor rod are around 912 and 313 gaps. Accordingly, this was caused by the fact that the right-turning motorists from the minor road had to take into account two gaps in the major road, i.e. near and far side, while the left-turning motorists from the minor road only had to consider near side gaps.

A practical computation process recommended by Wu (2006, 2012) using Excel spreadsheet was employed to apply the suggested macroscopic method, as described in detail in the methodology section. Figures 3 and 4 show schematic relationships between the probability distribution functions for the accepted, rejected and critical gaps for all vehicles, i.e. with motorcycles, for left- and right-turning movements from a minor road, as well as right-turning manoeuvre from a major road. As can be clearly observed, the PDF of critical gaps lies between the accepted and rejected gaps.

Figure 3 shows the relationship between the PDF's for the approved and maximum rejected gaps in comparison of the estimated critical gaps which are dependent on the maximum likelihood method as well as Wu's technique for all three movements at priority junctions. According to Wu's method, the probability distribution function of the estimated critical gaps should utilise Equation (2).

The results of the evaluation from the present study managed to identify the values of a critical gap at multilane junctions based on Wu's method. The respective calculated results were about 6.18 , 4.08 and 4.32 s for right and left turns from a minor road, as well as right-turning manoeuvre from a major road. In the case of critical gaps computed based on the maximum likelihood method, it was estimated to be around 5.95 s for a right turn and 4.15 s for a left turn from a minor road; and it was estimated to be almost 4.25 s for right-turning movements from the major road. These values clearly showed that the average differences between approximated values of the critical gap with equilibrium technique and Troutbeck's method were less than 0.20 s.

Figure 4 shows the outcomes for similar relationships obtained from the equilibrium method that utilised all the rejected gaps. Accordingly, the values of the critical gap were, respectively, calculated to be around 5.38, 3.68 and 3.87 s for right and left turns from a minor road, as well as right-turning movement from a major road, respectively. More importantly, this clearly shows that the values of the critical gap based on equilibrium method all rejected gaps, seemed to be calculated shorter compared to the same method with the maximum rejected gaps were around 0.80 s for a right turn from a minor road and about 0.50 s for the other two movements.

Table 1. Results of accepted and rejected gaps.

	Left turn from the minor road		Right turn from the minor road		Right turn from the major road	
Type	Rejected	Accepted	Rejected	Accepted	Rejected	Accepted
All vehicles	313	1968	912	4976	357	1346
Without motorcycles	217	1405	754	3985	286	988

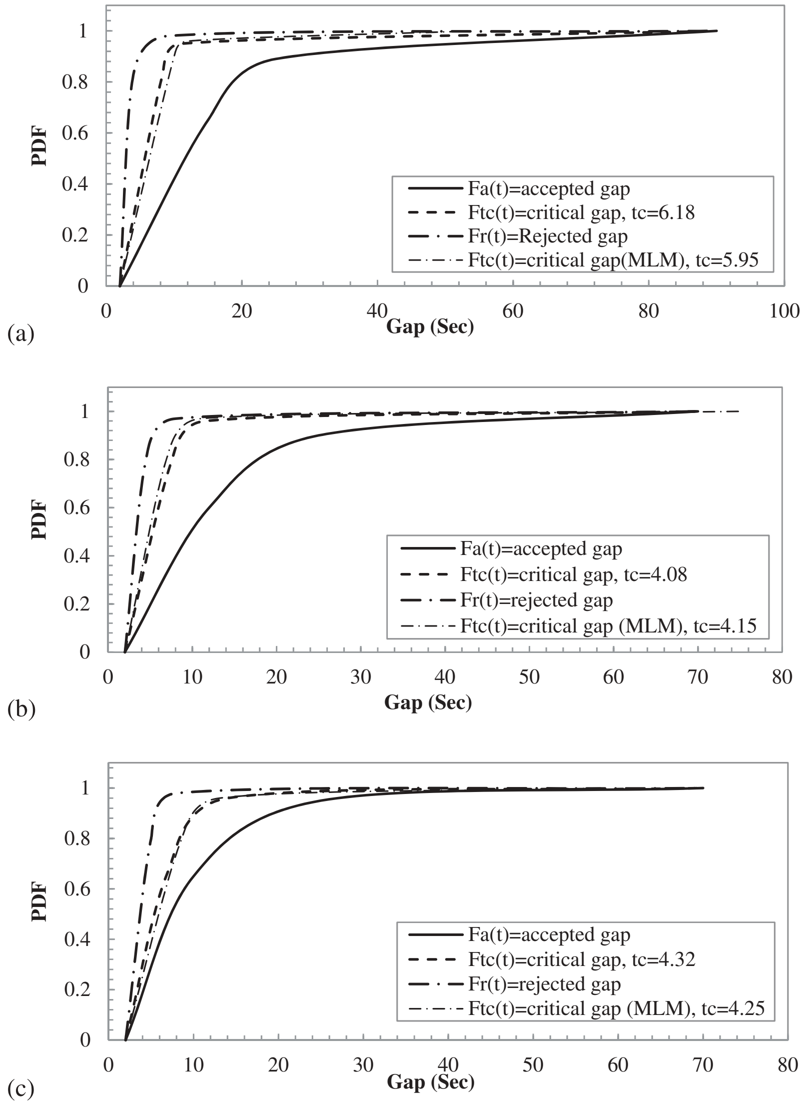

Figure 3. Relationship between the PDF's for the approved and maximum rejected gaps, as well as comparison of the estimated critical gaps based on the maximum likelihood method and equilibrium technique for (a) right turns, (b) left turns from the minor road and (c) right turn from the major road.

Regarding the objective of the current research, the value of the critical gap was suggested to be calculated based on the second situation, i.e. non-motorcycle. Figure 5 shows the PDF between the approved gaps, maximum rejected gaps with a corresponding critical gap of non-motorcycle traffic using the equilibrium technique and maximum likelihood method for right and left turns from a minor road, as well as right-turning movements from a major road. As previously described, the PDF of a critical gap is often situated between accepted and rejected gaps. In this case, the values of critical gaps were estimated to be around 6.25 s for the right turn, 4.20 s for the left turn, and 4.43 s for right-turning manoeuvre from the major road. Accordingly, it can be clearly observed that the critical gap values for right-turning manoeuvre from the minor road were higher than other movements. This was because the right-turning vehicles that were required to cross the near side lane and merge with the traffic in the far side lane. More importantly, the results of this evaluation clearly shows that the values of critical gap using the equilibrium method, i.e. only the maximum rejected gaps managed to provide comparable outcomes with the deviations that are smaller than 0.10 s from the Troutbeck's method which were found to be 6.15, 4.25 and 4.35 s for right and left turns from a minor road, as well as right-turning movement of a major road, respectively.

Figure 6 demonstrates the relationship of estimation PDF for the accepted gaps, all rejected gaps, and a critical gap of non-motorcycle traffic based on the equilibrium method which utilised Equation (2). In reference to the described procedure, the value of the critical gap was, respectively, estimated to be around 5.55 and 3.78 s for right and left turns from a minor road. Furthermore, the vehicles movements from major to the minor road was calculated to be about 4.00 s. Nevertheless, these magnitudes were estimated

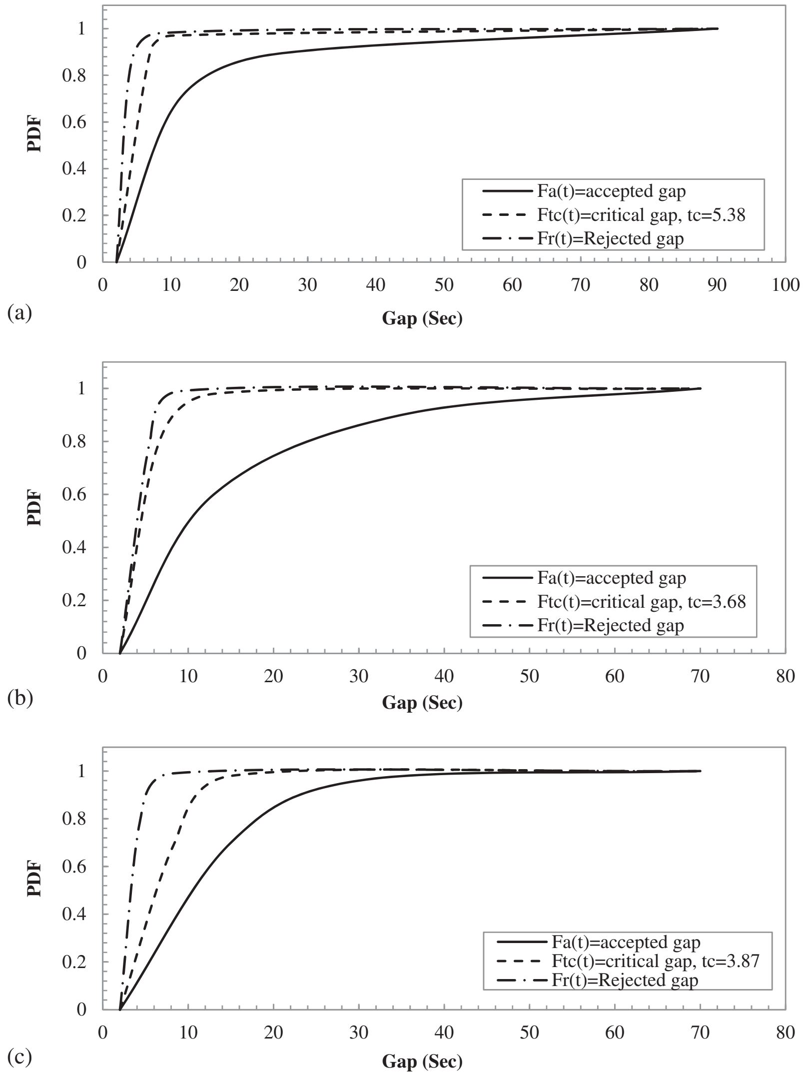

Figure 4. Relationship between the PDF's for the approved gaps, all rejected gaps, as well as critical gap based on the equilibrium technique for (a) right turns, (b) left turns from the minor road and (c) right turn from the major road.

shorter compared to the values of the critical gap based on the equilibrium method with maximum rejected gaps, particularly around 0.70 s for a right turn from a minor road and 0.40 s for the other two movements.

According to the above evaluations, the values of critical gaps were estimated for two situations, namely with the presence and absence of motorcycles. In reference to these computations, the critical gap during the situation without any motorcycles was calculated more than other situations. One of the reasons is that the motorcycles can pass the conflict area in shorter gaps compared to other vehicles. Hence, the value of the critical gap could be decreased in a situation with the presence of motorcycles. Accordingly, the results showed that a critical gap at priority junctions decreases when the total number of motorcycles on the departure line increases even though the differences between both situations are significantly minimum. Therefore, the values of critical gap in some countries such as Malaysia with a vast number of motorcycles tend to be less than other places.

The relationship among the PDF's for the estimated critical gaps values depending on the equilibrium method for both situations (with and without motorcycles) based on the all rejected gaps and maximum rejected gaps is shown in Figure 7. In this graph, only the PDF's of equilibrium's method is shown since the schematic relationship among the PDF's of the maximum likelihood method and equilibrium's method which are close together are, respectively, shown in Figures 3 and 5.

Meanwhile, the different critical gap values need to be considered despite the close distribution between both situations shown in the graphs. Accordingly, this clearly shows that the values of critical gap using equilibrium method with all the rejected gaps with the presence of motorcycles provide shorter outcomes, respectively, around 0.17 , 0.10 and 0.13 s for right and left turns from a minor road, as well as right-turning manoeuvre from a major road compared to similar method without motorcycles. Similarly, the magnitudes of the critical gap obtained using the equilibrium method

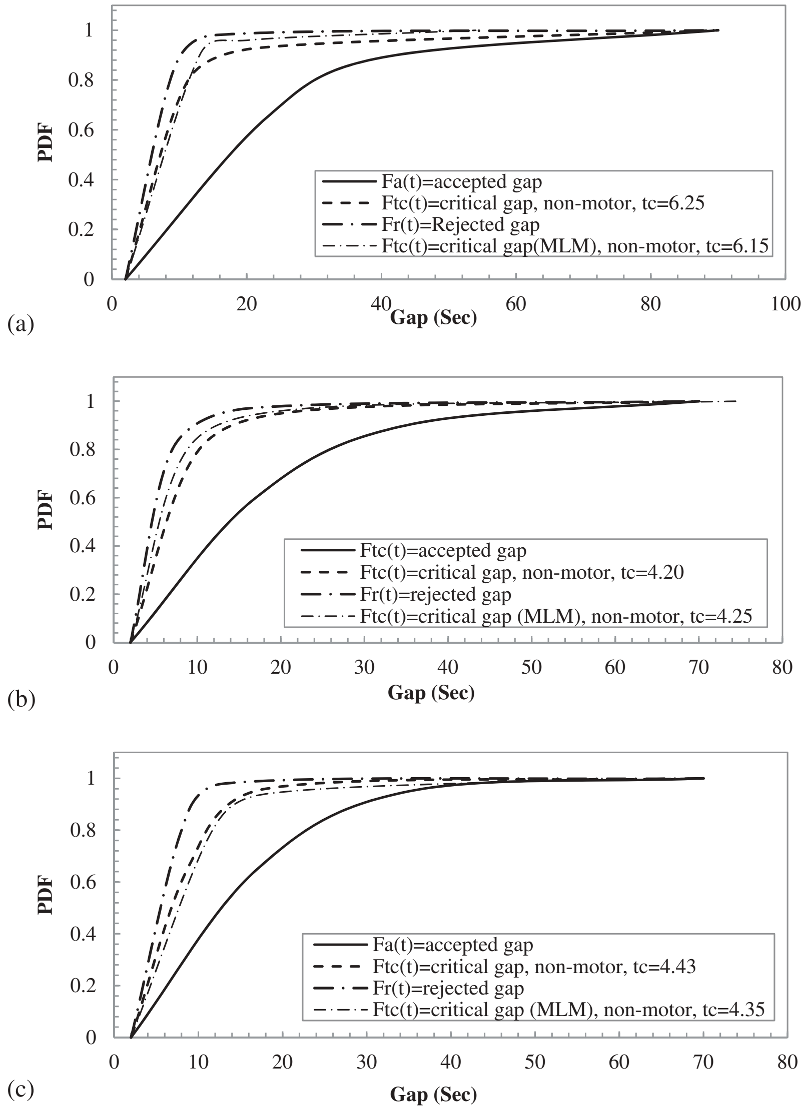

Figure 5. The relationship among the PDF's for the approved gaps, maximum rejected gaps and the calculated critical gaps depending on the Wu's method and maximum likelihood method for non-motorcycle traffic for (a) right turn, (b) left turn from the minor road, and (c) right turn from the major road.

based on the maximum rejected gaps, as well as Troutbeck's methods in a situation with motorcycles were found to produce shorter results compared to the absence of motorcycle with smaller deviations ranging between 0.12 and 0.2 sc for all three movements. These values will be compared with MHCM in the following section.

As a theoretical fact, the shorter critical gap tends to influence the analysis of the delay at priority junctions which leads to the increase of accident risk. On the other hand, an analysis of the priority junctions with higher critical gap can result in the overestimation of delay for each movement. Consequently, it can be implied that the critical gap in both situations in mentioned countries is better to be estimated despite the small differentiation between two conditions, namely with and without motorcycles.

5. Comparison with HCM and MHCM

The value of critical gap for every three movements within the two situations, namely with and without motorcycle was calculated by MHCM in order to consider the effect of a motorcycle on the critical gap at priority junctions. In reference to this manual, the values of a critical gap for right- and left-turning manoeuvre from a minor road as well as a right-turning movement from the major road can be estimated using Equation (3). Moreover, the magnitude of the critical gap should be calibrated in the site study in order to achieve a practical value. Therefore, the critical gap values that utilised the HCM 2000 and HCM 2010 were modified using the parameters $t_{c,M}$ and $P_{M,x}$. The adjustment parameter will ensure that the calculated critical gap will be based on the Malaysian traffic condition (MHCM 2011). The values for the base critical gap ($t_{c,base}$) as well as the adjustment

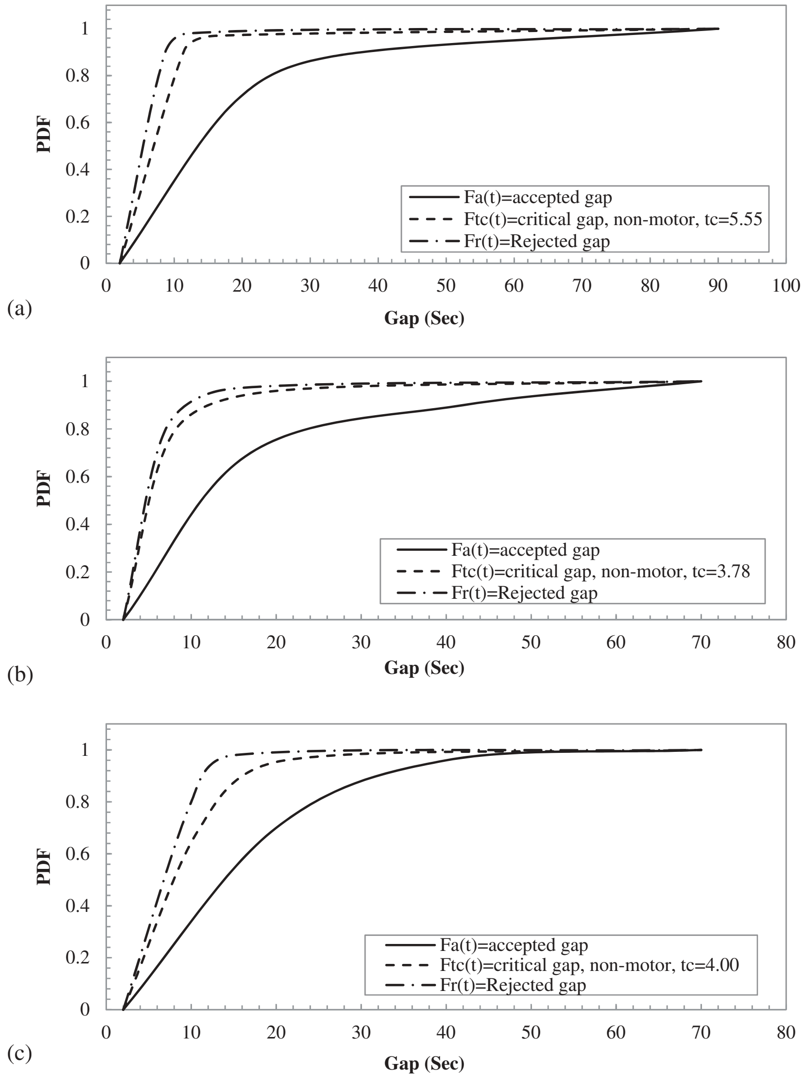

Figure 6. The relationship among the PDF's for the approved and all rejected gaps and the calculated critical gaps depending on the Wu's method for non-motorcycle traffic for (a) right turn, (b) left turn from the minor road and (c) right turn from the major road.

parameter ($t_{c,M}$) for priority junction with multilane or single-lane are shown in Tables 2 and 3.

$$t_{c,x} = t_{c,base} - t_{c,M} P_{M,x} \tag{3}$$

where

$t_{c,M}$ = adjustment parameter for motorcycles referring Table3,

$t_{c,base}$ = base critical gap referring Table2,

$t_{c,x}$ = critical gap for movement x (s),

$P_{M,x}$ = Proportion of motorcycles for movements x.

Regarding Equation (2), the two scenarios involving the absence and presence of motorcycles based on the MHCM (2011) was computed. Next, a comparative estimation of the critical gap was conducted whereby the results clearly showed the differentiation between two situations at each movement. Accordingly, the value of critical gaps based on 13% and 10% of motorcycles on the right and left turn from a minor road as well as 14% of motorcycles for right-turning manoeuvre from the major road were estimated to be 4.16 , 3.27 and 3.66 s, respectively. As suggested by MHCM's method, the values of the critical gap without motorcycles were estimated by assuming that the proportion of motorcycles for movements x was zero. The magnitude of the critical gap based on the mentioned situation was estimated to be around 4.20 , 3.30 and 3.70 s for left and right turns from a minor road, as well as right-turning manoeuvre from a major road. In this case, the values of the critical gap using MHCM's model with motorcycles was found to produce shorter outcomes with deviations smaller than 0.40 s compared to the situation without a motorcycle. Hence, the above analysis clearly shows that the value of critical gap decreases if the proportion of motorcycle for each movement at priority junction increases. Accordingly, it is better to estimate the critical gap in both situations during an analysis of junction in mentioned countries despite the small differentiation between two conditions.

6. Conclusion

Capacity evaluation of priority junction is mainly dependent on the evaluation of critical gap value and gap acceptance theory. The current research was carried

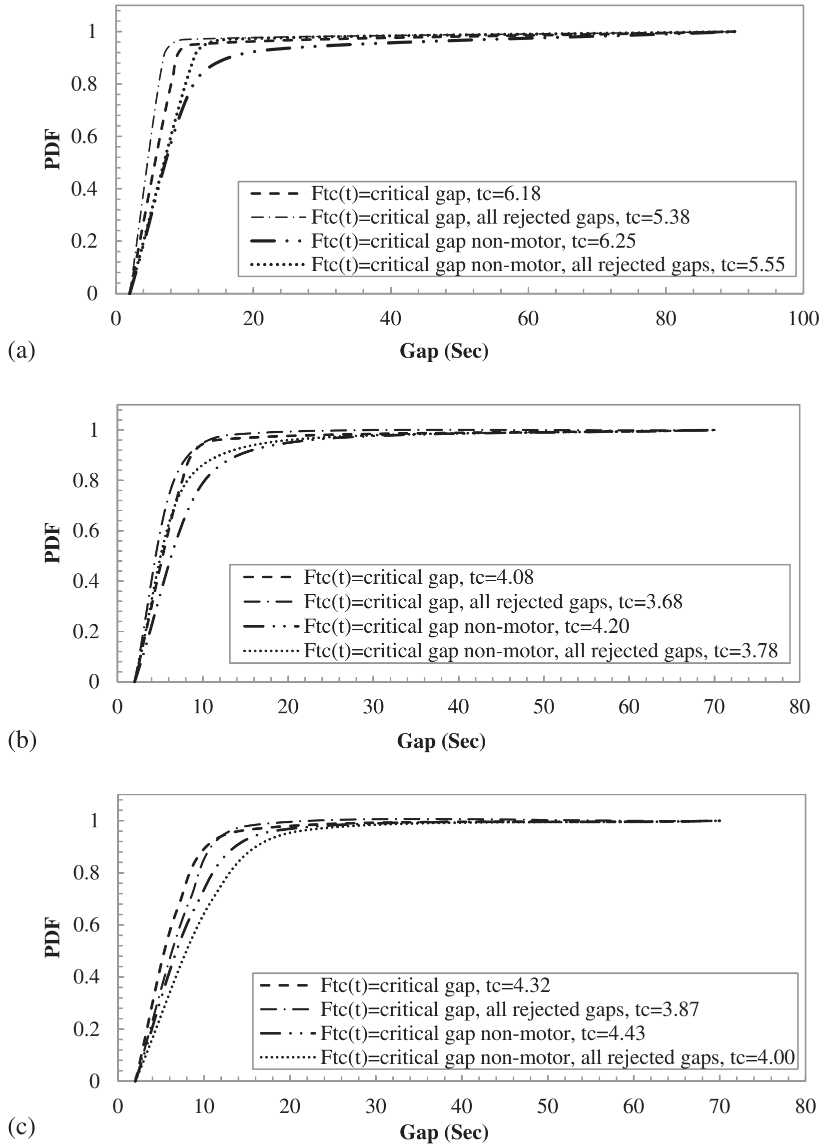

Figure 7. The relationship among the PDF's for the calculated critical gaps depending on the Wu's method with maximum rejected gaps and all rejected gaps during all vehicles and non-motorcycle situation for (a) right turn, (b) left turn from the minor road and (c) right turn from the major road.

Table 2. The base critical gap for priority junctions.

	Base critical gap (t_c), second	
Vehicle manoeuvre	Single lane	Multilane
Right turn from the major street	3.50	3.70
Left turn from the minor street	3.20	3.30
Right turn from the minor street	4.0	4.20

*Adapted from MHCM (2011).

Table 3. The adjustment factor for motorcycle.

$t_{c,M}$	
Single lane	Multilane
0.424	0.252

*Adapted from MHCM (2011).

out for the purpose of determining the effect of a motorcycle on critical gap at priority junctions. In the present study, the magnitudes of the critical gap were estimated by employing the equilibrium method, maximum likelihood method and Malaysia Highway Capacity Manual (MHCM) for two situations, namely with and without motorcycles. Accordingly, data were gathered with the help of video cameras from 9:00 am until 6:00 pm from two multilane priority junctions during normal working days in order to present the performance of the methodology for critical gap evaluation at priority junction. Moreover, the total data gathering for the present study was carried out during daylight time period without rainy weather condition in order to prevent the impact of adverse weather and environmental situations including rain and darkness. Meanwhile, all gap acceptances throughout the main road blockage and pedestrian blockage were removed. According to the equilibrium method, the values of the critical gap using all rejected gaps with motorcycles produced shorter results of around 0.17 s compared to similar method without motorcycles. Meanwhile, the magnitudes of the critical gap using the same method with the maximum rejected gap with motorcycles provided shorter outcomes with deviations smaller than 0.12 s for all three movements. Specifically, this procedure was conducted for maximum likelihood method and MHCM whereby the values of the critical gap with motorcycles computed shorter results of around 0.04 s for MHCM and 0.20 s for maximum likelihood method compared to a situation without motorcycles. More importantly, the result indicated that the value of critical gap for all three movements in a situation of non-motorcycles was greater than the condition with motorcycles at priority junction. As a theoretical fact, shorter critical gap tends to influence the analysis of the delay at priority junctions which may lead to the increase of accident risk. Additionally, analysis of the priority junctions with higher critical gap can result in the over-estimation of delay for each movement. Consequently, it can be implied that the critical gap during an analysis of priority junctions in both situations in countries such as Malaysia and some other Asian countries with many motorcycles should be estimated despite the small differentiation between the two conditions, namely with and without motorcycles.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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