# CRITICAL GAP ANALYSIS OF MERGING SECTIONS AT KUALA LUMPUR MIDDLE RING ROAD

M. E. Sanik[1*],N. F. L. Rahimi[2], N. B. Hamid[3], A. H. M. Nor[4], J. Prasetijo[5], N. F. Razali[6]

[1,3,4]Department of Civil Engineering, Centre for Diploma Studies, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Johor, Malaysia.
[2,3]Department of Infrastructure and Geomatic Engineering, Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Johor, Malaysia.
[6]Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Johor, Malaysia.

## *ABSTRACT*

*At merging sections, drivers normally slow down and sometimes need to stop while seeking a suitable gap before merging with the mainstream. Thus, there will always be several observed rejected gaps and an accepted gap which can be used to determine the smallest average gap, so-called critical gap. This study was carried out to determine critical gap values at selected merging sections at the Jalan Tun Razak and the DUKE Expressway uses the Maximum Likelihood method. Data were collected by using videotaping method and the gap acceptance data were extracted for analysis. A gap acceptance event at highway merging sections in this study was redefined due to unavailability of stopping vehicles at the ramp junction. Therefore, the gap data were estimated starting from a ramp's vehicle passing the end of gore marking to where it merges with the mainstream. The analysis of the critical gap takes into consideration accepted gaps greater than 5 seconds to avoid forced entry due to lead impedance of successive vehicles on mainstream. The critical gap values obtained in this study, according to vehicle classification were ranged between 4.5 to 5.0 seconds, which are slightly smaller if compared to critical gap values for particularly left turn from minor movement at priority junction of the Arahan Teknik (Jalan) 11/87 and the United States Highway Capacity Manual 2000. The findings shall help to study driving behavior of local drivers, especially at priority control facilities such as merging sections.*

***KEYWORDS:*** *Critical gap; driver behaviour; gap acceptance; maximum likelihood; merging sections*

## 1.0 INTRODUCTION

Kuala Lumpur Middle Ring Road 1 (MRR1) and Kuala Lumpur Middle Ring Road 2 (MRR2) are two well-known highways with the hectic traffic during rush hours. MRR1 consists of Jalan Tun Razak, Lebuhraya Mahameru, Jalan Damansara, Jalan Istana and Jalan Lapangan Terbang, is an urban and municipal main ring in Kuala Lumpur and also known as the Kuala Lumpur - Petaling Jaya Traffic Dispersal Scheme. However, due to demand of increasing traffic, the Department of Works (JKR) has built another ring road

[*] Corresponding Email: erwans@uthm.edu.my

which is also known as MRR2 that connects vicinities near the boundary of Federal Territory of Kuala Lumpur and Selangor (Akmal et al., 2015). These roads were designed with on- and off-ramps as part of their access points. Within these two ramps, on-ramp is more complex since a driver needs to seek for a gap before merging with major traffic (Adnan, 2007).

On-ramp is a short section of road, which allows vehicles to exit a controlled-access highway. When a vehicle enters highways, drivers are no longer travel at the drastically reduced speeds necessary for city driving. Drivers are alerted to increase speeds to that of the highway traffic and use the on-ramp and subsequent merging lanes as a means to flow smoothly into highway traffic (American Safety Council, 2015). At on-ramp or merging section, a driver sometimes must stop and observes a suitable time gap so-called accepted gap. Before that, several rejected gaps may be encountered during this waiting. However, the accepted gap does not represent the average gap that is accepted to all drivers. Therefore, critical gap or the average smallest gap that will be accepted by all homogenous drivers needs to be estimated.

This study was limited to the highway capacity niche area; therefore, the highway safety element was not discussed in this paper. However, the findings can be used to relate drivers' behavior with regard to road safety issue. The Maximum Likelihood method is the preferred technique in estimating critical gap since it was used in measuring values for the United States Highway Capacity Manual (Troutbeck, 2016).

## 2.0 GAP ACCEPTANCE AND CRITICAL GAP

Gap acceptance and critical gap are two different terminologies in traffic capacity study. Gap acceptance is a general term for drivers' behavior in a particular uncontrolled priority facility that requires human justification in seeking gap to maneuver or move to other lanes. Drivers in many developed countries normally adhere priority rules at un-signalized junctions and thus, the gap acceptance analysis can be applied.

On the other hand, critical gap is the minimum gap of a driver will accept when a movement is not protected. Moreover, critical gap can be characterized as the threshold by which drivers in a minor stream judge whether to acknowledge the gap (Guo and Lin, 2011). It is influenced significantly by the available sight distance, which is the length of the roadway that is visible ahead of the driver. After all, the minimum gap accepted is influenced by the follow-up time that can be defined as the time interval between departures of two vehicles in a queue accepting the same gap, while sight distance (also known as the length of the roadway) is visible to the driver (Kraft et al., 2000).

Critical gap values are used to estimate movement capacity in assessing, designing and planning road facilities such as un-signalized intersection. Movement capacity is then used to determine the control delay and level of service of certain movement. Since the critical gap could not be observed directly from the field, the gap acceptance data (consist of the accepted gap and the largest rejected gap) are measured and analyzed using the maximum likelihood method (Asmi, 2003). Brilon (1999) and Troutbeck (1992) have evaluated the effectiveness of the Maximum Likelihood method in further studies. In estimating critical gaps for un-signalized intersection, the Maximum Likelihood method currently is treated as the best approach (Brilon, 2016).

In Maximum Likelihood analysis, the first step is to assume a probabilistic distribution for the critical gap (Troutbeck and Brilon, 1997). In most of the cases, this can be assumed to be log-normal. This distribution is skewed to the right and has non-negative values, as would be expected in these circumstances. The distribution is reasonably general and is acceptable for most studies. The likelihood function is defined as the probability that the critical gap distribution lies between the observed distribution of the largest rejected gaps and the accepted gaps as shown by Equation (1) (Troutbeck, 1992).

$$L = \sum_{i=1}^{n} \ln\left[F(y_i) - F(x_i)\right] \quad (1)$$

where,
L = maximum likelihood function
$y_i$ = logarithm of the accepted gap of driver i
$x_i$ = logarithm of the largest rejected gap of driver i
F (…) = cumulative distribution function for normal distribution

By maximizing Equation. (1), mean (μ) and variance ($\sigma^2$) of the gap acceptance distribution are estimated. Thus, the distribution of critical gaps, as well as their mean and variance, can be derived. The case (where the gap acceptance distribution is normally distributed) is related to the critical gap and the mean of the gap acceptance distribution. The relation to estimate the critical gap, $t_c$ is given by Equation. (2) and q is the volume of vehicles in both directions on the major road, which is in vehicles/second (veh/sec) (Sanik, 2007).

$$t_c = \mu - \frac{\sigma^2 q}{2} \quad (2)$$

where,
μ = mean
$\sigma^2$ = variance
q = volume in major road

## 3.0 METHODOLOGY

### 3.1 Location of Study

The framework of this study is as shown in Figure 1. Figures 2 and 3 show the study locations for this study.

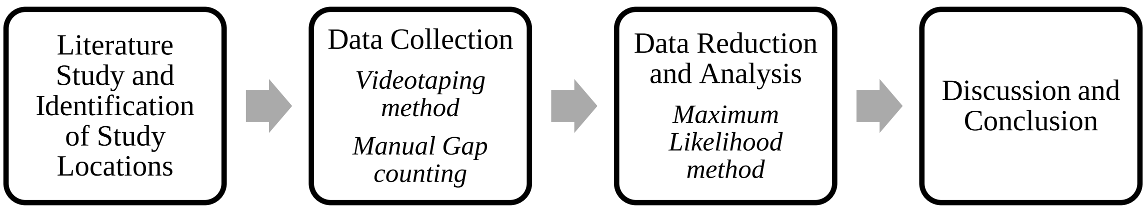



Figure 1. Overall study framework

Figure 2. Merging section at the Jalan Tun Razak, MRR1

Figure 3. Merging section of DUKE expressway - MRR2

### 3.2 Data Collection

Data collection was carried out during daytime, dry weather, off-peak hour period and in stable flow traffic condition. Data were collected during off-peak period in order to avoid forced entry. Forced-entry is defined as a situation where a vehicle on minor street entering the major stream by forced, which may cause the deceleration of vehicles in major street. It usually occurs when the flow in the major street is congested, thus impedes the consistency of the accepted gap. The camcorder was used to record on-ramps traffic flow along the selected Kuala Lumpur Highway. Kuala Lumpur highways were selected due to availability of high-rise building near to study locations. This condition helps to place the camcorder at a high vantage point in order to obtain a sufficient view of the on-ramp junction for analysis purpose.

### 3.3 Data Extraction and Reduction Process

Data in the form of time in second were extracted from the recorded video at study locations. Data extraction was carried out manually and usually takes a relatively long time. In order to extract accepted and rejected gaps timing, the video needs to be played, stopped and rewound several times for every waiting vehicle from the ramp. The gap which ignored by the vehicle is considered rejected gap and gap which the vehicle use to enter the major street is counted as accepted gap. Therefore, rationally, there will be one or more rejected gaps and an accepted gap for every waiting vehicle from the ramp. A gap acceptance event at highway merging sections in this study was redefined due to unavailability of stopping vehicles at the ramp junction. Therefore, the gap data were estimated starting from a ramp's vehicle passing the end of gore marking until it merges with the mainstream.

In order to ensure the values of critical gap is being carried out accordingly in this study, the data were checked against the following criteria:

(i) Gaps that were observed to be forced entry were rejected.

(ii) Accepted gaps that are greater than 5 seconds were used in the analysis. The United States Highway Capacity Manual 1994 suggests that headway of 5 seconds or less is normally for a vehicle, which is impeded by its leader (TRB, 1994; Che Puan, 1999). Thus, an accepted gap value of equal or less than 5 seconds may be taken by force.

After extracting raw data of accepted and rejected gaps, data reduction processes were carried out using the following steps:

(i) Identify the largest gap among several rejected gaps to be paired with the accepted gap of every observation.

(ii) Eliminate any pair that is not homogenous, for which the largest rejected gap is greater than it accepted gap values.

(iii) Eliminate any pair for which the accepted gap is equal or less than 5 seconds.

Only then, the screened data were analyzed using the Maximum Likelihood method.

### 3.4 Data Analysis and Tools

Table 1 shows the spreadsheet used in analyzing the screened accepted and rejected gaps data. The table was developed based on calculation using the Maximum Likelihood method. Referring to Table 1, the “Prob.” for accepting gap in the fifth column describes the ratio of each value to the maximum value in the fourth column of “LogNorm.” or log-normal on accepted gap. The probability values are sorted in ascending order under the “Asc. Prob.” in the sixth column. In the seventh column “Asc. Gap”, the accepted gap is sorted in ascending order. The same procedure is applied to the largest rejected gap data. After analysis of the largest rejected gap, the values in the fourteenth column of ascending accepted-rejected gap (Asc. Acc-Rej. Gap) is obtained using Equation. (3) (Asmi, 2003).

$$A = \frac{B - C}{2} - C \qquad (3)$$

where,

A = Ascending accepted-rejected gap.

B = Ascending accepted gap.

C = Ascending rejected gap.

In the cumulative distribution function of accepted gap and the largest rejected gap (See Figure 4 and 5), the value of the largest rejected gap, accepted gap, and mean can be obtained using three lines that are perpendicular to the X-axis and intersect with the horizontal line that crosses the Y-axis at 0.5 (or 50$^{th}$ percentile). Using the values, the standard deviation can be calculated using Equation (4) (Sanik, 2007).

Table 1. Spreadsheet used in Maximum Likelihood analysis.

| No | Accepted Gap | | | | | | Largest Rejected Gap | | | | | | Accepted – Rejected Gap | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Gap Value** | **Ln.** | **LogNorm.** | **Prob.** | **Asc. Prob.** | **Asc. Gap** | **Gap Value** | **Ln.** | **LogNorm.** | **Prob.** | **Asc. Prob.** | **Asc. Gap** | **Asc. Gap Value** | **Ln.** | **LogNorm.** | **Prob.** |
| 1 | 11 | 2.40 | 0.73 | 0.74 | 0.07 | 6 | 3 | 1.10 | 0.11 | 0.11 | 0.01 | 2 | 4.00 | 1.39 | 0.03 | 0.03 |
| 2 | 12 | 2.48 | 0.82 | 0.84 | 0.07 | 6 | 6 | 1.79 | 0.82 | 0.83 | 0.01 | 2 | 4.00 | 1.39 | 0.03 | 0.03 |
| 3 | 6 | 1.79 | 0.07 | 0.07 | 0.07 | 6 | 2 | 0.69 | 0.01 | 0.01 | 0.01 | 2 | 4.00 | 1.39 | 0.03 | 0.03 |
| 4 | 7 | 1.95 | 0.17 | 0.18 | 0.07 | 6 | 4 | 1.39 | 0.36 | 0.37 | 0.11 | 3 | 4.50 | 1.50 | 0.08 | 0.08 |
| 5 | 9 | 2.20 | 0.47 | 0.48 | 0.07 | 6 | 3 | 1.10 | 0.11 | 0.11 | 0.11 | 3 | 4.50 | 1.50 | 0.08 | 0.08 |
| 6 | 11 | 2.40 | 0.73 | 0.74 | 0.07 | 6 | 3 | 1.10 | 0.11 | 0.11 | 0.11 | 3 | 4.50 | 1.50 | 0.08 | 0.08 |
| 7 | 12 | 2.48 | 0.82 | 0.84 | 0.18 | 7 | 4 | 1.39 | 0.36 | 0.37 | 0.11 | 3 | 5.00 | 1.61 | 0.14 | 0.14 |
| 8 | 7 | 1.95 | 0.17 | 0.18 | 0.18 | 7 | 4 | 1.39 | 0.36 | 0.37 | 0.11 | 3 | 5.00 | 1.61 | 0.14 | 0.14 |
| 9 | 12 | 2.48 | 0.82 | 0.84 | 0.18 | 7 | 5 | 1.61 | 0.63 | 0.64 | 0.11 | 3 | 5.00 | 1.61 | 0.14 | 0.14 |
| 10 | 7 | 1.95 | 0.17 | 0.18 | 0.18 | 7 | 5 | 1.61 | 0.63 | 0.64 | 0.11 | 3 | 5.00 | 1.61 | 0.14 | 0.14 |
| 11 | 7 | 1.95 | 0.17 | 0.18 | 0.18 | 7 | 2 | 0.69 | 0.01 | 0.01 | 0.11 | 3 | 5.00 | 1.61 | 0.14 | 0.14 |
| 12 | 7 | 1.95 | 0.17 | 0.18 | 0.18 | 7 | 4 | 1.39 | 0.36 | 0.37 | 0.37 | 4 | 5.50 | 1.70 | 0.23 | 0.23 |
| 13 | 7 | 1.95 | 0.17 | 0.18 | 0.18 | 7 | 5 | 1.61 | 0.63 | 0.64 | 0.37 | 4 | 5.50 | 1.70 | 0.23 | 0.23 |
| 14 | 9 | 2.20 | 0.47 | 0.48 | 0.18 | 7 | 7 | 1.95 | 0.92 | 0.93 | 0.37 | 4 | 5.50 | 1.70 | 0.23 | 0.23 |
| 15 | 7 | 1.95 | 0.17 | 0.18 | 0.18 | 7 | 4 | 1.39 | 0.36 | 0.37 | 0.37 | 4 | 5.50 | 1.70 | 0.23 | 0.23 |
| 16 | 9 | 2.20 | 0.47 | 0.48 | 0.18 | 7 | 7 | 1.95 | 0.92 | 0.93 | 0.37 | 4 | 5.50 | 1.70 | 0.23 | 0.23 |
| 17 | 10 | 2.30 | 0.61 | 0.62 | 0.18 | 7 | 5 | 1.61 | 0.63 | 0.64 | 0.37 | 4 | 5.50 | 1.70 | 0.23 | 0.23 |
| 18 | 15 | 2.71 | 0.95 | 0.97 | 0.18 | 7 | 7 | 1.95 | 0.92 | 0.93 | 0.37 | 4 | 5.50 | 1.70 | 0.23 | 0.23 |
| 19 | 6 | 1.79 | 0.07 | 0.07 | 0.32 | 8 | 5 | 1.61 | 0.63 | 0.64 | 0.37 | 4 | 6.00 | 1.79 | 0.33 | 0.33 |
| 20 | 10 | 2.30 | 0.61 | 0.62 | 0.32 | 8 | 4 | 1.39 | 0.36 | 0.37 | 0.37 | 4 | 6.00 | 1.79 | 0.33 | 0.33 |
| 21 | 8 | 2.08 | 0.31 | 0.32 | 0.32 | 8 | 4 | 1.39 | 0.36 | 0.37 | 0.37 | 4 | 6.00 | 1.79 | 0.33 | 0.33 |
| 22 | 6 | 1.79 | 0.07 | 0.07 | 0.32 | 8 | 5 | 1.61 | 0.63 | 0.64 | 0.37 | 4 | 6.00 | 1.79 | 0.33 | 0.33 |
| 23 | 16 | 2.77 | 0.97 | 0.99 | 0.32 | 8 | 4 | 1.39 | 0.36 | 0.37 | 0.37 | 4 | 6.00 | 1.79 | 0.33 | 0.33 |
| 24 | 17 | 2.83 | 0.98 | 1.00 | 0.32 | 8 | 4 | 1.39 | 0.36 | 0.37 | 0.37 | 4 | 6.00 | 1.79 | 0.33 | 0.33 |
| 25 | 7 | 1.95 | 0.17 | 0.18 | 0.32 | 8 | 5 | 1.61 | 0.63 | 0.64 | 0.37 | 4 | 6.00 | 1.79 | 0.33 | 0.33 |
| 26 | 12 | 2.48 | 0.82 | 0.84 | 0.48 | 9 | 5 | 1.61 | 0.63 | 0.64 | 0.37 | 4 | 6.50 | 1.87 | 0.43 | 0.43 |
| 27 | 12 | 2.48 | 0.82 | 0.84 | 0.48 | 9 | 4 | 1.39 | 0.36 | 0.37 | 0.37 | 4 | 6.50 | 1.87 | 0.43 | 0.43 |
| 28 | 7 | 1.95 | 0.17 | 0.18 | 0.48 | 9 | 4 | 1.39 | 0.36 | 0.37 | 0.64 | 5 | 7.00 | 1.95 | 0.53 | 0.54 |
| 29 | 12 | 2.48 | 0.82 | 0.84 | 0.48 | 9 | 3 | 1.10 | 0.11 | 0.11 | 0.64 | 5 | 7.00 | 1.95 | 0.53 | 0.54 |
| 30 | 8 | 2.08 | 0.31 | 0.32 | 0.48 | 9 | 5 | 1.61 | 0.63 | 0.64 | 0.64 | 5 | 7.00 | 1.95 | 0.53 | 0.54 |

*Note: Ln = Natural Log; LogNorm = Log-Normal distribution; Prob. = Probability; Asc. Prob. = Ascending Probability; Asc. Gap = Ascending Gap Value*

$$D = \frac{E - F}{2} \tag{4}$$

where,
D = Standard Deviation.
E = Accepted gap (at 50$^{th}$ percentile).
F = Rejected gap (at 50$^{th}$ percentile).

## 4.0 RESULTS AND DISCUSSION

Figures 4 and 5 show the cumulative distribution function of the accepted and the largest rejected gaps for passenger car at Jalan Tun Razak, MRR1 and DUKE Expressway – MMR2 merging sections, respectively.

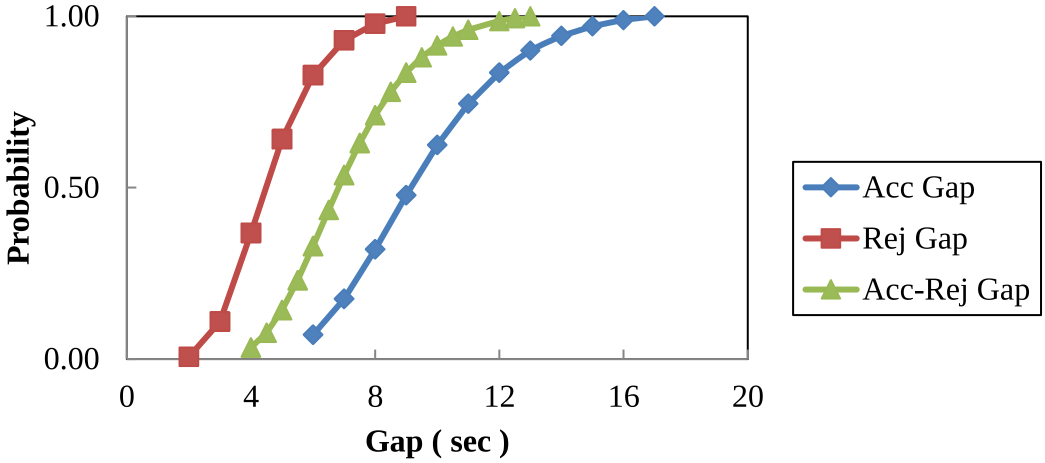



Figure 4. Cumulative distribution function of accepted and largest rejected gaps for passenger car at Jalan Tun Razak, MRR1 merging section.

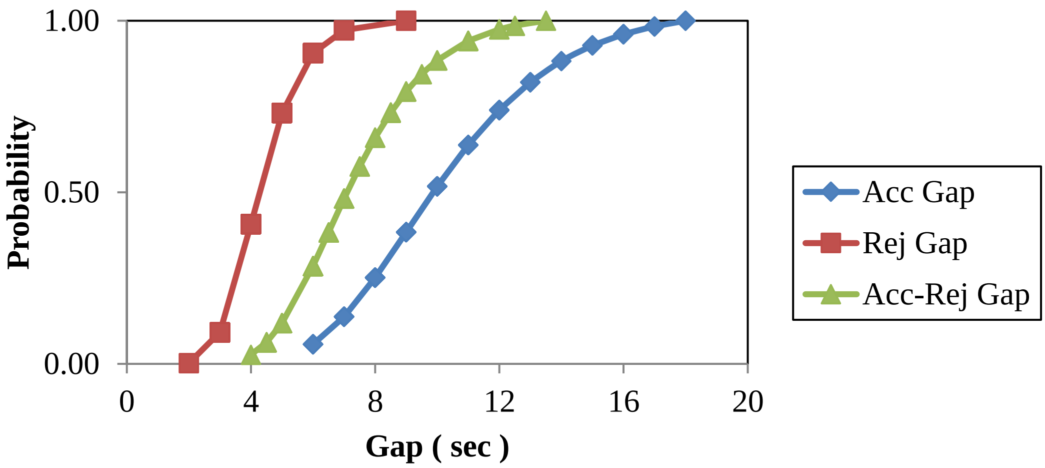



Figure 5. Cumulative distribution function of accepted and the largest rejected gaps for passenger car at DUKE - MRR2 merging section.

Referring to Figures 4 and 5, the largest rejected gap, accepted gap, mean and calculated standard deviation values were obtained as shown in Table 2.

Table 2. Values of gap acceptance parameters obtained from the cumulative distribution functions.

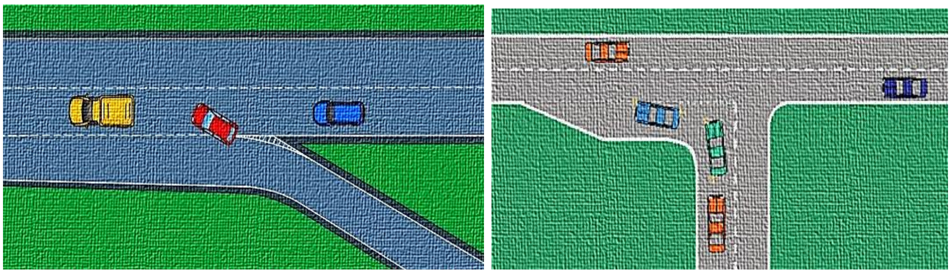
| **Study Location** | **Largest Rejected Gap** | **Accepted Gap** | **Mean (μ)** | **Standard Deviation (σ)** |
|---|---|---|---|---|
| Jalan Tun Razak, MRR1 | 4.5 sec | 9.1 sec | 6.8 sec | 2.3 sec |
| DUKE Expressway – MRR2 | 4.3 sec | 9.8 sec | 7.0 sec | 2.8 sec |
| Differences | 0.2 sec | 0.7 sec | 0.2 sec | 0.5 sec |

Referring to Table 2, the largest rejected gap, accepted gap, mean and standard deviation between both study locations have only slight difference in values range from 0.2 to 0.7 seconds. This may be due to homogenous and similar driving behavior by drivers particularly in Kuala Lumpur. Although the comparison is only between two locations, yet, the drivers need to behave equally in making decision at any merging sections. These values were then used to determine critical gap using Equation. (2). Based on manual counting, the volume in major or mainstream roadway at Jalan Tun Razak, MRR1 and DUKE expressway – MRR2 study locations were 0.832 and 0.643 vehicles per second, respectively. Thus, the critical gap can be determined and are as shown in Table 3.

Table 3. The obtained critical gap values of both study locations with regard to vehicles classification.

| **Location of Merging Section** | **Vehicles Classification** | **Critical Gap (sec)** |
|---|---|---|
| Jalan Tun Razak, MRR1 | Passenger Car | 4.6 |
| DUKE Expressway - MRR2 | Passenger Car | 4.5 |
| Both locations | Heavy Vehicle | 5.0 |

Referring to Table 3, both study locations obtain the critical values with a difference in 0.1 second. Data of heavy vehicle were also used to determine critical gap using a similar analysis as a passenger car. Due to limited heavy vehicle data, observations at both locations were combined and the obtained critical gap is 5.0 seconds. Logically, heavy vehicles need additional time to move, especially when they already stopped at the acceleration lane. The movement at merging section may be equated or assumed similar to the movement of the left turning from minor road at priority or un-signalized intersection. Figure 6 shows the similarity between these movements.



(a) (b)

Figure 6. The similarity of movement at
(a) merging section and (b) left turn from minor at priority junction.

Therefore, comparison between critical gap values obtained in this study and available in the U.S. HCM 2000 and the Arahan Teknik (Jalan) 11/87 were made, as shown in Table 4.

Table 4. Comparison of critical values of merging section and left turn from minor movement at priority junction.

| **Study/Manual** | **Average $t_c$ of on-ramp/ Left turn from Minor** |
|---|---|
| This study (2016) | 4.6* |
| U.S. HCM 2000 (TRB, 2000) | 6.9 |
| Arahan Teknik (Jalan) 11/87 (JKR, 1987) | 5.0 |

* Average values at both study locations

Referring to Table 4, the critical gap value obtained in this study is found to be smaller than the values available in the Malaysian and American guidelines (Jabatan Kerja Raya, 1987: American Safety Council, ASC, 2015). Although this study emphasized on similarity of movement, yet, as previously mentioned in the preceding section, there were some difficulties in identifying local drivers who completely stopped in acceleration lane and waited for a suitable gap before merging with mainstream traffic. Thus, in this research work, most drivers were assumed to move slowly rather than stopping before merging and due to this, the critical gap is smaller.

## 5.0 CONCLUSION

In conclusion, the critical gap values for on-ramp or merging section at selected study locations were successfully determined. The challenging part of this study was to observe gap acceptance event at merging section. The conventional gap decision activity was redefined due to unavailability of stopping vehicles at the ramp junction. Therefore, the gap data were estimated starting from a ramp's vehicle passing the end of gore marking until it merges with the mainstream. Although there were no stopping vehicles, but still drivers need to seek for a suitable gap while slowing down their vehicles. The critical gap values obtained in this study were 4.6 and 4.5 seconds at Jalan Tun Razak, MRR1 and DUKE Expressway – MRR2, respectively. These values shall be considered small since drivers tend to seek gap less than 5 seconds while following vehicle is still impeded by its lead vehicle at major road. The combination of heavy vehicle data at both locations produces a critical value of 5.0 seconds. These values may represent the behaviour of drivers in the vicinity of study locations. Thus, the findings should be considered in planning and designing new merging sections.

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