Empirical Evaluation of Lane Changing Following Gap Distance on Expressway

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Abstract: Lane changing (LC) is an essential aspect of driving behaviour on expressways, which impacts on traffic efficiency and safety. Therefore, a wrongful execution of LC, especially the wrong choice following distance before the LC manoeuvre. This could lead to road crashes, mostly in the form of rear-end, sideswipe, or angled crash. This research assesses the characteristics of drivers' following gap distance during LC. The study was performed on a segment along Kuala Lumpur – Seremban expressway. Data were collected along the selected segment using an instrumented test vehicle approach. A passenger car was instrumented with a Video Velocity Box (VBox), which an on-board data acquisition system used for video recording of field traffic events. Hence, VBox attached to the test vehicle was used for recording the following gap distance during LC manoeuvres in the field. After that, the video records were played back on a computer to estimate the gap distance. A total of 174 following incidences were observed in this work. Finding from the study revealed that the following gap distance before LC of the sampled motorists ranges from 4.89 to 81.15 m with a mean and standard deviation of 18.47 and 12.16 m, respectively. Furthermore, out of the 174 sampled drivers, about 86.7% recorded following gap distances in the range of 10 to 30 m, implying that the majority of the motorists accept short gaps while executing LC. It was also found that the space gap is regarded as an essential variable than the time gap because as drivers travel at desired speeds, they tend to be guided by the available space rather than time.

1. Introduction
Lane changing (LC) is referred to as a driving manoeuvre in which a vehicle moves from one lane to another, where both lanes have the same travel direction. LC is one of the most sensible characteristics of driving behaviour, which has mostly impacts on traffic efficiency and safety [1]. Lane changes can occur for different reasons, such as entering the roadway, preparing to exit the road, anticipating other vehicles merging onto the highway, anticipating a slower leading vehicle, a change in the number of lanes available, and many more [2]. When the speed of a leading vehicle in the current lane is lesser and acceptable gaps are available in the target lane, drivers tend to change lanes [3].

Different categories of vehicles perform varying behaviours during lane-changing. For instance, a fast vehicle tends to change lane when hindered by a slower one, even when there is a small adequate distance, but reluctant to change lane when hindered by a fast vehicle unless the driving condition on the other lane is much better than that of the current lane. Slow vehicles are always reluctant to change lane [4]. Generally, the most common type of lane change is a maneuver in which a driver changes lanes to pass a slower lead vehicle to continue the current speed [2]. The choice of lane changing performance may be affected by some factors, including; the emergence of the following vehicle, surrounding traffic impact, and driver's character [5].
The motivations and resulting driving behaviour for the mandatory and discretionary lane change are different. Therefore, a driver is expected to have different decision rules or parameters for the two types of lane change [6]. Thus, modeling the driver's LC decision and implementation process is the most challenging issue due to the complexity and uncertainty of driving behaviours [7]. Traditional lane-changing models consider drivers' choices in two steps; target lane selection and gap acceptance [8].

Separated multilane in all directions on a highway with a high-quality design encourage travel at high speed. Therefore, drivers do change lanes when faced with a slower leading vehicle. Therefore, this process makes traffic accidents and disturbance to other surrounding vehicles. A lane change's crash occurs when drivers attempt to change lanes and strikes or struck by other vehicles in the adjacent lane. However, an erroneous estimate of gap distance (by the following driver) to the leading vehicle and unevaluated adequate time to pass safety are the main reasons for lane changing crashes [9].

Recently, researchers have shown an increased interest in lane changing behaviour and pay more attention to lane changing safety. More recently, concerns have been raised by several relevant researchers who developed models for the determination of safety gap distance. These models depend on many factors, which include drivers' behaviour, relative speed, and so forth. Among these factors, the driver's behaviour is the most important, which directly affects the lane-changing parameters. Despite the models' accuracy, there is entirely different between the European drivers' behaviours and Asian ones; as such, the models specific have been affected by these differences in behaviour. This paper focused on the determination of following gap distance between leading and following vehicles on the multilane highway for safety term and the behavioural of drivers. However, a significant problem with this kind of determination is a variation of drivers' behaviour during the lane changing. Far too little attention has been paid to investigate safety distance during LC maneuvers.

Lane changing is referred to as a driving maneuver that vehicle moves from one lane to another lane wherever each lane has a similar direction of travel. LC behaviours had been actively studied for a minimum of five decades [10]. It is one of the fundamental activities in freeway driving. Drivers change lanes based on different reasons, among which could be to gain speed or get into the target lane in anticipation of following turning vehicle downstream. An LC that is not executed in a safe manner could lead to a rear-end, sideswipe, or angled crash [11]. Commonly, a vehicle changes lane in order to achieve a specified destination, which is regarded as a fundamental characteristic of multilane roads.

A gap distance is regarded as space or time interval that a subject vehicle requires to merge safely between two vehicles. Gap acceptance is that the minimum gap needed to complete lane changing safely. Gap acceptance is additionally an essential part of most lane changing models. Within the case of a merge into an adjacent lane, if the driver will settle for both lead gap and lag gap, the gap is accepted, and therefore the lane change can be accomplished [2]. On multilane highways, when a fast-moving vehicle approaches a slow-moving lead vehicle, the driver explores for gaps of adequate space prior to the execution of lane change. Consideration of gap as adequate enough is commonly associated with behaviour of drivers in the traffic stream. It was demonstrated that aggressive drivers seem to accept smaller gaps than non-aggressive ones [12].

A review of the existing literature on lane changing execution gap distance showed that there are limited studies regarding drivers' behaviour during LC maneuver. Specifically, there are rare such studies relating to Malaysian drivers' behaviour during LC, especially using an instrumented vehicle, which allowed for the record of related traffic events during the data sampling. In an attempt to explore the subject relating to Malaysian traffic condition, this paper investigates the following gap distance on Malaysian expressway. This could provide information on Malaysian drivers' behaviour relating following gap distance on multilane highways.

Various studies were conducted on following gap distance on multilane highways, ranging from the estimation of the parameter through empirical and simulation approaches to its modelling. Few among these studies [5,11, 13–18] worked on the estimation of the following gap distance as amid which some of them focused on its modelling. As mentioned earlier lack of adequate information on following gap distance regarding Malaysian drivers, particularly relating to their behaviour is what compelled the need for the current study.
2. Methodology

2.1. Study area
As well known, lane changing (LC) manoeuvre is associated with expressways; this research used a representative segment along Kuala Lumpur – Seremban expressway, Malaysia. Figure 1 shows the location of the study site used as extracted from Google map. The expressway comprises of three lanes in each traffic direction (having a lane width of 3.70 m for each) along which the posted speed is mostly 110 km/h. This segment was chosen as it is particularly in good condition with sizable traffic volume because it links many parts of Malaysia to the capital city. Likewise, the traffic volume on the road consists of varying vehicles categories with reasonable incidences of LC manoeuvres due to the presence of on- and off-ramps within the chosen study segment. This would allow for observing considerable samples of LC incidences adequate for analysis to arrive at logical conclusions.

![Figure 1. Study site location.](image)

2.2. Estimation of following gap distance
To estimate the following gap distance, many approaches can be employed. A common approach is as shown in figure 2, which is based on [19]. In figure 2, vehicle $F$ is the one in need to perform a lane change. Whereas, vehicles $T$ (an instrumented vehicle during this study) and $C$ are the leading and following vehicles (within the same lane with vehicle $F$), respectively. Likewise, vehicles $B$ and $A$ are the leading and following vehicles in the target lane, respectively. Vehicle $F$ switches to the target lane between vehicles $A$ and $B$ from its initial lane, between vehicles $T$ and $C$.

![Figure 2. Lane changing manoeuvre scenario.](image)
After vehicle $F$ arrives at the target lane, it can subsequently adjust its speed to ensure safety with vehicle $B$. Likewise, vehicle $A$ adjusts its speed accordingly to achieve safety with vehicle $F$ [19], as depicted in figure 3.

**Figure 3.** Schematic diagram for acceleration lane change stages.

Regarding figure 2, $S_{FT}(0)$ denotes the distance between vehicles $F$ and $T$ at the start moment of lane changing; $S_{FT}(t)$ is the distance between vehicle $F$ and vehicle $T$ at any moment of lane changing.

To determine the distance between vehicles $F$ and $T$, there is a need to establish the longitudinal acceleration of vehicle $F$: In the process of vehicle $F$ accelerating to change lane, the vehicle moves at a constant positive acceleration. This acceleration of vehicle $F$ is computed using equation (1).

$$a_F = \frac{V_e - V_o}{t}, \quad t \in [t_o, t_a]$$

(1)

Where $V_e$ is the desired speed of vehicle $F$, $V_o$ is the initial speed of vehicle $F$, $t_o$ is the start moment of the accelerated lane change, and $t_a$ is the end moment of the accelerated lane change.

For the insurance of safety between vehicles $F$ and $T$, while $F$ is making an accelerated lane change, the displacement of vehicle $F$ at any time $t$ is determined based on equation (2).

$$S_F = V_o t + \left( a_F t^2 \right), \quad t \in \left[ t_o, t_a \right]$$

(2)

The displacement of vehicle $T$ at any time $t$ can be computed as in equation (3).

$$S_T = V_T t, \quad t \in \left[ t_o, t_a \right]$$

(3)

Where $V_T$ denotes the speed of vehicle $T$. Therefore, the distance between vehicle $F$ and $T$ at any moment in $[t_o, t_a]$ is given by equation (4).

$$S_{FT}(t) = S_T - S_F + S_{FT}(0), \quad t \in \left[ t_o, t_a \right]$$

(4)

In order to ensure that vehicle $F$ does not make a collision with vehicle $T$ in the time period $[t_o, t_a]$, the condition $S_{FT}(t) \geq 0$ should be satisfied. There must have existed a moment that is $t_0[t_o, t_a]$, making the value of $S_{FT}(t)$ to attain maximum value. By satisfying the condition $S_{FT}(t) \geq 0$, means that vehicle $F$ would not make a collision with vehicle $T$ in the time period $[t_o, t_a]$ [19].

Gap acceptance within the current study refers to the minimum size of the gap (seconds) in traffic flow that drivers are willing to accept while changing lanes which depends on driver's parameters like aggressiveness, urgency, and impatience [15].
2.3. Data collection and processing

As stated in the preceding section, data for this study were collected on segment situated along Kuala Lumpur – Seremban, Malaysia expressway. Data for the study were sampled during the daylight period under different traffic conditions. The data on LC following gap distance were collected using an instrumented vehicle. A passenger car instrumented with a Video Velocity Box (VBox) was used for the data sampling. A VBox is an on-board data acquisition system used for traffic event parameters measurements, such as the speed of the instrumented vehicle, acceleration, and lap timing, among other things. It comprises many components, including; VBox video recorder, 10Hz GPS data logger (with an external antenna), two video cameras (used for recording desired direction events), SD card, and a microphone. For the purpose of this study, the VBox camera was used for the recording of LC events as the instrumented vehicle traverses the road study segment. There are many versions of the VBox system. However, the version of the system used in this work is RLVBVBD10LT, which records the traffic events and logged the recorded data onto the SD card inserted into the VBox system at 10 Hz [20].

During the data collection, the instrumented vehicle was driven over the defined study section length of 50.2 km for about 35 minutes (depending on the traffic situation, which the duration could be higher or lower). As stated earlier, the selected segment has three traffic lanes along which the posted speed is 110 km/h with a considerable number of on- and off-ramps with recurrent lane changing manoeuvres. To collect the relevant data, the instrumented vehicle was driven on the selected segment with VBox system's video camera being fixed on the vehicle's rear windscreen to capture the following vehicles' LC events. The VBox video camera with a resolution of 720 x 576 pixels was mounted on the vehicle in such a way that it covered the entire trajectory of vehicles involved in LC manoeuvre. This allows for capturing and noting of all relevant events including the LC manoeuvres, the speed of the instrumented vehicle, the speed of the following vehicle, follower LC duration time, and the following gap distance for both before and after the manoeuvre [21]. These parameters were also observed in this study as reported and discussed in the later section of this paper.

It should be noted that the video camera on the instrumented vehicle was fixed in the hidden location from the view of other motorists in order not to influence their driving behaviour. For each test trip of the instrumented vehicle, over the defined segment, the traffic events within the road were recorded by the video camera. As the video recording process continues, the GPS data logger registered the position and speed of the instrumented vehicle at any moment. The driving style of the instrumented test vehicle was made in a manner that its speed along the segment is consistent depending on the traffic condition [22].

During the field data sampling, 188 lane changing manoeuvres were observed out of which 14 LC incidences were performed at on- and off-ramp sections with others performed in succession. These 14 LC manoeuvres were excluded from the sample used in the analysis. Thus, only 174 LC manoeuvres were utilized for the data analysis. This process is consistent with the approach by [6]. It was demonstrated that the non-inclusion of vehicles making multiple LCs in the analysis is to avoid possible mandatory LC manoeuvres [6].

Furthermore, only cars involved in LC manoeuvres were considered in this research. Heavy vehicles (such as trucks, buses, etc.), as well as motorcycles, were excluded as they are completely characterized by different LC manoeuvres behaviour. Heavy vehicles being associated with low speed commonly utilized the outer most lane; hence, their LC behaviour is certainly different from those of cars. Similarly, the fraction of motorcycles on intercity expressways are usually trivial relative to that found on urban highways. For instance, in this study, both the heavy vehicles and motorcycles constitute only 3.5 percent of the traffic stream. All data collection processes were made using the instrumented vehicle with the aid of video camera fixed to the VBox system and attached to the test vehicle's rear windsreen, which was used for the video recording of the road's traffic events.

In the current study, the following gap distance was estimated as the longitudinal spacing between the rear bumper of the instrumented test vehicle and the front bumper of the immediate vehicle
following the former. It worthy at this point to mention that before the commencement of the field data collection, the VBox camera was calibrated for the estimation of the following gap distance.

2.4. Calibration of VBox camera for estimation of following gap distance

As stated in the preceding section, prior to the beginning of the data collection, the VBox camera was calibrated for the estimation of the following gap distance. The calibration of the VBox camera was conducted at a standstill position using two vehicles; one as a test car (as well as the lead vehicle) and the other as the potential following vehicle. In the course of the calibration process, the test car instrumented with a VBox system for continuous recording of the event was stationed at one point and kept constant over the observation period, whereas the potential following vehicle was positioned behind the test vehicle such that they duo was reasonably aligned in the same course. They were positioned at an initial spacing of 2.5 m front (of follower)-to-rear (of test vehicle), followed by 5.0 m, and then varied in an increment of 5.0 m up to a maximum spacing of 35.0 m. The positions of the following vehicle were denoted as P1, P2, P3 and P8 corresponding to the Spacing of 2.5m, 5m, 10m, 15m, …, and 35m, respectively. This process was performed with a view to estimate the following gap distance based on the changes in the front width of the potential following vehicle in relation to the varied spacing between the two vehicles. Because the front width of the following vehicle decreases with an increase in the spacing and vice versa. This approach was used for the estimation of vehicles following headways and established as a satisfactory [23]. Figure 4 depicts the arrangement of the test car and the immediate following vehicle during the calibration process.

![Figure 4. Setup of test and following vehicles during calibration of VBox Camera.](image)

The entire process involved in the calibration were recorded onto the VBox, which were later uploaded and played back on a laptop computer with 15 inches screen at a resolution of 1366 x 768 for the extraction of the relevant traffic data. The data extraction was done by automatic screenshot software capable of image capturing at an interval of 0.5 seconds. During the playback of the recorded events, the front width of the following vehicle ($w$ (mm)) was measured for each of the following vehicle's position with the aid of a pair of dividers. The width size is then transferred to a ruler using an AutoCAD software to deduce the size in millimeters (mm). The regular size is then recorded against the corresponding ground spacing or distance headway ($hd$ (m)) between the vehicles. Table 1 presents the sample data as extracted from the calibration video record.
Table 1. Sample data of observed spacing and displayed front width of following vehicle for calibration of VBox camera.

| $h_d$ (m) | 2.5  | 5.0  | 10.0 | 15.0 | 20.0 | 25.0 | 30.0 | 35.0 |
|-----------|------|------|------|------|------|------|------|------|
| $w_b$ (mm) | 30.342 | 18.882 | 10.531 | 7.275 | 5.453 | 4.435 | 3.835 | 3.309 |

* Spacing between test and following vehicles.
* Displayed front width of the following vehicle.

Subsequently, the following gap distance ($G$) was estimated by subtracting the length of the test vehicle from the distance headway ($h_d$). This corresponds to the Spacing between the rear bumper of the test vehicle and the front bumper of the following vehicle. Thus, the following gap distance is determined based on equation (5).

$$G = h_d - L$$  \hspace{1cm} (5)

Where, $G$ is the following gap distance, $h_d$ is the distance headway, and $L$ is the length of the test vehicle. From the two variables, $G$ (m) and $w_b$ (mm), a relationship was developed for the estimation of following gap distance from video scene display based on the front width of the following vehicle.

In developing the calibrated relationships, a negative power function was found to fit the data most, that depends on the value of (R-square 0.70). The general form of the relationship is given by equation (6).

$$G = aw^{-b}$$  \hspace{1cm} (6)

Where, $G$ is the following gap distance between the leading and following vehicles, $w$ is the front width of the following vehicle in video scene record during playback, and ‘$a$’ and ‘$b$’ are coefficients.

Hence, after fitting the data to the negative power function, the resulting VBox camera calibration model for the estimation of following gap distance based on front width of a potential following vehicle (car) is given by equation (7).

$$G = 1332.4704w^{-1.0310}$$  \hspace{1cm} (7)

The calibrated VBox camera relationship or model was subsequently applied for field estimation of following gap distance. In other words, the model was applied for measurement of gap distance from the field recorded traffic events (while being played back in a computer) relating to lane changing as evaluated in this study.

3. Results and discussions

As mentioned in the preceding section, a total number of 174 LC manoeuvre incidences were observed in this research. It was also mentioned earlier that following gap distance was estimated for two scenarios in this study. That is gap distance was estimated before and after lane changing (LC). Table 2 presents the statics summary of the results obtained regarding respective speeds of the test and following vehicles, and those of following gap distance for before and after LC.

From table 2, it can be deduced that the following gap distance values range from 4.89 to 81.15 m with an average of 18.47 m. This finding suggests a typical level of aggressive behaviour of drivers, particularly when the average gap distance of 18.47 m is related to the average following speed of 25.91 m/s, similar to that of [2] and [24]. Aggressive driving behaviour has been identified as a contributing factor to road crashes [2]. The following gap distance results obtained in this study were relatively similar to those obtained previously [19]. In other words, these two estimations of the following gap distance give the same results. Further analysis of the results is shown in figure 5, which illustrates the variation of the following gap distance with frequency.
### Table 2. Summary of results statistics.

| Parameters                                  | Parameters' Statistics |
|---------------------------------------------|------------------------|
| Speed of test vehicle (m/s)                 | Minimum | Maximum | Average  | Std. Deviation |
| Speed of following vehicle (m/s)            | 18.75   | 29.12   | 24.34    | 2.15           |
| Following Gap distance before LC (m)        | 16.21   | 42.90   | 26.04    | 3.60           |
| Following Gap distance after LC (m)         | 4.89    | 81.15   | 18.47    | 12.16          |

**Figure 5.** Variation of following gap distance with frequency.

In figure 5, it is clearly shown that most of the drivers' gap distances range from 10 to 30 m, which corresponds to about 86.7% of the total sampled following gap distances. This shows that the majority of the drivers accept short gap distance based on high speed of drivers in executing their lane changing maneuvers, which is usually associated with aggressiveness driving behaviour. Acceptance of such short net gaps results in a smaller net gap between the leading and following vehicles. However, few incidences with longer gap distances were also recorded, which suggest that there were little or no interaction between the leading and following vehicles.

### 4. Conclusions

This study examined the characteristics following gap distance during lane changing (LC) manoeuvre on an expressway segments along Kuala Lumpur – Seremban expressway in Malaysia with the aid of an instrumented vehicle technique. From the study carried out and the results obtained, it was discovered that the following gap distance before lane changing of the sampled drivers ranged from 4.89 to 81.15 m with mean and standard deviation values of 18.47 and 12.16 m, respectively. Likewise, the following gap distance after lane changing of the sampled drivers ranged from 5.04 to 73.38 m with mean and standard deviation values of 14.11 and 9.50 m, respectively. Further, out of the total of 174 sampled motorists, approximate of 86.7% recorded following gap distances in the range of 10 to 30 m, implying that the majority of the drivers accept short gaps while executing lane changing. It was also found that space gap is a essential variable than the time gap, because as drivers travel at their desired speeds, they tend to be guided by space rather than time [25].
5. References

[1] Kao Y 1991 An empirical investigation of macroscopic lane-changing characteristics on uncongested multilane freeways, *Transportation Research Part A: General* 25(6) 375–389

[2] Sanik M E, Hamid N B, Mat Nor A H, Prasettijo J, Che Ani M S and Mustakim F 2016 Drivers lane changing behavior at urban intersection by using Gap Acceptance approach, *ARPN Jour. of Eng. and App. Sci.* 11(24) 14070–14074

[3] Wei H, Meyer E, Lee J and Feng C 2000 Characterizing and modeling observed lane-changing behavior: lane-vehicle-based microscopic simulation on urban street network, *Transp. Res. Rec.* 1710(1) 104–113

[4] Liu P, Kurt A, Redmill K and Ozguner U 2016 Classification of highway lane change behavior to detect dangerous cut-in maneuvers *Transportation Research Board 95th Annual Meeting*, 16-5124

[5] Cao X, Kim I and Young W 2016 A study of mandatory lane-changing execution behaviour model considering conflicts *Australasian Transport Research Forum* (Melbourne)

[6] Balal E, Cheu R L and Gyan-sarkodie T 2014 Analysis of discretionary lane changing parameters on freeways, *Int. Jour. of Transp. Sci. and Technol.* 3(3) 277–296

[7] He H, Susret R, Menéndez M and Ge Q 2015 Modelling lane changing behavior at freeway weaving sections *4th Sym. of Europ. Assoc. for Res. in Transp. (hEART). 2015 List Abstr.*, (Lyngby)

[8] Sun D and Elefteriadou L 2011 Lane-changing behavior on urban streets: A focus group-based study, *Appl. Ergon.* 42(5) 682–691

[9] Fitch G M, Lee S E, Klauer S, Hankey J, Sudweeks J and Dingus T 2009 *Analysis of Lane-Change Crashes and Near-Crashes* Final Report DOT HS 811 147 (U.S.A: National Highway Traffic Safety Administration) pp. 1–88

[10] Zhao D, Peng H, Nobukawa K, Bao S, LeBlanc D J and Pan C S 2014 Analysis of mandatory and discretionary lane change behaviors for heavy trucks *14th Int. Symp. Adv. Veh. Control, Mlc*, 1–6

[11] Vechione M, Balal E and Cheu R L 2018 Comparisons of mandatory and discretionary lane changing behavior on freeways, *Int. Jour. of Transp. Sci. and Technol.* 7(2) 124-136

[12] Shoraka M 2016 *Development of Simulation Model for Assessing the Performance of Weaving Section on Interchanges* PhD Thesis (Malaysia: Universiti Teknologi Malaysia) pp 1-301

[13] Bhan G H and Ph D 2009 Estimating driver mandatory lane change behavior on a multi-lane freeway estimating driver mandatory lane change behavior on a multi-lane freeway *Proc. of 88th Annual. Meet. Transp. Res. Board*, 573 (Washington D.C.)

[14] Choudhury C F, Ramanujam V and Ben-akiva M E 2009 Modeling acceleration decisions for freeway merges, *Transp. Res. Rec.* 2124(1) 45–57

[15] Gurupackiam S and Jones Jr S L 2012 Empirical study of accepted gap and lane change duration within arterial traffic under recurrent and non-recurrent congestion, *Int. Jour. for Traff. and Transp. Eng.* 2(4) 306–322

[16] Hidas P 2002 Modelling lane changing and merging in microscopic traffic simulation, *Transp. Res. Part C: Emerg. Technol.* 10(5–6) 351–371

[17] Zhang L, Chen C, Zhang J, Fang S, You J and Guo J 2018 Modeling Lane-Changing Behavior in Freeway Off-Ramp Areas from the Shanghai Naturalistic Driving Study,” *Jour. of Adv. Transp. 2018* Article ID 8645709

[18] Wu J, McDonald M and Chatterjee K 2007 A detailed evaluation of ramp metering impacts on driver behaviour, *Transp. Res. Part F: Traff. Psych. and Behav.* 10(1) 61–75

[19] Xiaoru W and Hongxu Y 2013 A lane change model with the consideration of car following behavior, *Procedia - Soc. Behav. Sci.* 96 no. Cipt 2354–2361

[20] RACELOGIC 2009 *Video VBOX Lite Hardware and Software Manual* www.racelogic.co.uk 1, (United Kingdom) pp 1–87

[21] Hegeman G, Haskoningdhv R and Hegeman G 2008 *Assisted Overtaking : An Assessment of Overtaking on Two-Lane Rural Roads* PhD Thesis (The Netherlands: The Netherlands TRAIL Research School) pp 1-265
[22] Llorca C, Moreno A T and Garcia A 2016 Modelling vehicles acceleration during overtaking manoeuvres, *IET Intel. Transp. Sys.* **10**(3) 206–215

[23] Ibrahim M N, Puan O C and Mustaffar M 2019 Measurement of percent time spent following on two-lane highways: An exploration of spot and space-based methodologies *IOP Conference Series: Mat. Sci. and Eng.* **527**(1) 12069

[24] Puan O C 2004 Driver’s car following headway on single carriageway roads, *Jurnal Kej. Awam* **16**(2) 15–27

[25] Hwang S Y and Park C H 2005 Modeling of the gap acceptance behavior at a merging section of urban freeway, *Proc. East. Asia Soc. Tansp. Stud.* **5** 1641–1656