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Drivers behaviour on expressways: headway and speed relationships

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Abstract. This paper describes result of a study on driver's car following behaviour on Malaysian high-speed highways. Drivers' car following behaviour can considered as one of the main factors that causes road accidents to occur such as rear end collision between vehicles on highways. The aim of the study was to examine the safe following distance adopted by drivers on expressways at various operating speeds. An automatic traffic recording device attached with pneumatic tubes was used to record traffic movement at three selected expressway segments in Malaysia for six consecutive days. More than one hundred thirty three thousand (133,000) headway and speed data were involved in the analysis. The distance headway and associated speed collected were classified into five vehicle following categories by vehicle type, i.e. all vehicles, car following car, car following heavy goods vehicle (HGV), HGV following HGV, and HGV following car. Linear regression models were used to develop relationship between distance headway and speed. The relationships developed can be regarded as reliable since the R^2-values for each of the relationships is in the range of 0.80 to 0.99 and can be used to estimate a safe following distance perceived by a driver at a given speed. The driver's average response time on an expressway is 3.06 sec which is 1.9 sec longer than those who are driving on a two-lane single-carriageway road. Such a variation in response time indicates that the level of aggressiveness of drivers on a two-lane single-carriageway road are higher than the drivers on an expressway.

1. Introduction

Malaysia is experiencing rapid growth in population, industrialization, economy and motorization resulting demands in increasing number of vehicles which leading to traffic congestion build up from time to time and give higher possibility for one to get involved in road accidents. According to Ministry of Transportation, statistic of road accident for 2016 had been terrifyingly increasing from previous years mainly for land-based transportation from three hundred sixty-three thousands and three hundred nineteen (363,319) in 2007 to five hundred twenty one thousand and four hundred sixty-six (521,466) in 2016 [1].

A scenario of severe traffic congestion that built over time forces the drivers to be impatient and to drive recklessly which tend to violate the speed limit that has been established by the authority and due to this unnecessary behaviour of drivers, road accident statistics for 2016 indicated that up to thirty

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seven point five percent (37.5%) of accidents involving deaths, twenty three point six percent (23.6%) suffered from major injuries and thirty eight point nine percent (38.9%) experienced minor injuries [1].

The occurrence of traffic congestion due to the increasing number of vehicles in roadway can be severe and take up to long hours of static mobile movements and Malaysian drivers are reluctant to be stuck in a traffic congestion for a long period of time which resulting to an impatient behaviour built up within them. A wide range of ages of Malaysian drivers influences different pattern of driving and adverse weather condition alongside with the road geometric aspect may trigger the drivers to have intolerant behaviour during driving.

On a highway when lane-changing or overtaking the leading vehicle is not possible, it will develop a phenomenon of vehicle platooning [2]. This paper describes the result of a study carried out to examine the distance headway and speed relationships which describe the safe following distance as perceived by the impeded vehicles on expressways.

2. Literature review

The rate of road accidents in Malaysia is increasing rapidly over the years and number of deaths recorded by the Transport Statistics Malaysia in 2016 [3] has been a worrisome to the public. There are various factors that can lead to road accidents and most common factors are driving carelessly at entrance or exit, overloading vehicles, wrong parking manner, driving under influence of drug and alcohol, negligent during signalling, dangerous over taking, speeding, violating the rule of traffic light and other offences. In addition, Malaysian Institute of Road Safety Research (MIROS) had carried out a depth road crash investigation and revealed that rear end collisions were the second highest crash configuration with twenty-eight point four percent (28.4%) [3].

These accidents commonly linked with the incorrect judgment of safe following distance made by the drivers with the leading vehicle at particular speed and this occurrence are known as driver's car following behaviour and need to be clearly understood before planning, designing and evaluating stages to ensure a safe and efficient condition of traffic operations on highway facilities. However, Malaysia is still practicing the traditional design of highway and road accident evaluations which does not include the aspect of driver's car following behaviour. Therefore, it is essential to establish the driver's car following model on Malaysian highway design to ensure safe and efficient of new highway facilities and improvements of the existing facilities under various traffic conditions.

2.1. Car following behaviour

Brackstone *et al*. [4] defined car following behaviour as the action of drivers in adjusting safety driving mechanism with the leading vehicle on the same lane under high density. Highway Capacity Manual 1994 [5] states that moving vehicles are considered as impended vehicles when they are being followed by another vehicle with headway of 5 seconds or less. In brief, headway and speed can be regarded as two attributes that play a major role in car following behaviour.

Kathy *et al.* [6] stated that headway is one of crucial parameter in road analysis and short headway times seem to be main reason to car following accidents. According to Evans and Wasielwski [7], 2576 of Michigan drivers received traffic violations or involved in road accidents had extreme short headway which was less than 1 second compared to drivers free from road accidents.

Road visibility plays a major role in estimating safer and more accurate of headway distance to a leading car as described and demonstrated by Evans and Rothery [8]. In conjunction, Evans [9] stated that the high hoods on SUVs causes the passenger cars to have lower road visibility while Herman *et al.* [10] mentioned in his study that smaller cars have bigger inter-vehicle distance than large cars.

Hashim and Johnnie [11] carried out a study to investigate headway characteristic for both rain and non-rain conditions. The author concluded that mean headway decreases between rain and no-rain conditions and decreases further when rainfall intensity increases. Statistically reported that 15.66% reduction in mean headways between no-rain to light rain condition while between no-rain and medium rain condition, the headway reduction is 19.97% and between no-rain and heavy rain condition, the headway reduction is 25.65%.

Studies pertaining to the analysis and modelling of driver's car following behaviour on various types of highway facilities have been reported by numerous researchers over the past decades (e.g. May *et al*. [12]; Gipps [13]; Miyahara [14]; Hunt [15]; Othman [16]; Bevrani, K and Chung, E [17]; Saifizul *et al*. [18]; Suzuki and Nakatsuji [19]; Erwan *et al.* [20]). The studies ranged from an empirical approach to complex mathematical and simulation modelling approaches. Because empirical studies usually concern the analysis of the real data, car following behaviour derived from such studies is referred to, as driver's preferred following distance.

In general, most studies demonstrated that the relationships between headway and speed could be presented by a regression model, i.e.:

$$H = A_0 + A_1V \tag{1}$$

Where; H is the distance headway,
V is the speed of vehicle,
A_0 is representative of vehicle length, and
A_1 is representative of a driver reaction time.

Table 1 provides summary of derived equations by type of car following headway relationships based on empirical studies conducted by Hunt [15], Othman [16] and Erwan *et al.* [20], respectively.

Table 1. Derived Equations of Car Following Behaviour Relationship.

Following type	Hunt [15] (single-carriageway)	Othman [16] (single-carriageway)	Erwan *et al.* [20] (multilane highway)
All vehicles	N/A	$H_{ALL} = 2.98 + 1.16V$	$H_{ALL} = 1.74 + 2.03V$
Car - Car	$H_{CC} = - 4.31 + 2.124V$	$H_{CC} = 1.26 + 1.19V$	$H_{CC} = 1.84 + 1.93V$
Car - HGV	$H_{CH} = 1.156 + 2.052V$	$H_{CH} = 4.04 + 1.12V$	$H_{CH} = 1.43 + 2.12V$
HGV - HGV	$H_{HH} = - 3.997 + 2.79V$	$H_{HH} = 9.33 + 1.21V$	$H_{HH} = 6.96 + 2.94V$
HGV - Car	$H_{HC} = - 8.15 + 2.854V$	$H_{HC} = 5.17 + 1.19V$	$H_{HC} = 2.14 + 0.4V$

2.2. Car following behaviour and accidents

Car following behaviour and habit of decision-making by drivers seem to be essential in understanding on how to avoid rear end crashes. Sato and Akamatsu [21] clarified a rear end collision occurs when headway distance between two vehicles get smaller due to deceleration of frontal vehicle and acceleration of following vehicle.

According to Mohamed Shawky *et al.* [22] the most frequent vehicle crashes to occur is rear end compared to three other types of collision which are side sweep, head-on and right angle collisions. They reported that in Emirates of Abu Dhabi, 17% of total severe crashes are due to rear end collision. A report by Singh [23] also highlighted that one third of road accidents in USA is a rear end collision.

Several studies related to car following due to variability of drivers' behaviour have been carried out by using instrumented vehicles. Irene *et al.* [24] carried out an experiment using 31 subjects with variation of age and gender using instrumented vehicle and macroscopic loop detector during both peak hours (AM and PM). The study focused only four scenarios which are with or without congestion and with or without rain. The degree of aggressiveness is based on two criteria listed as below:

i. Number of discretionary lane changes.
ii. Observation of speed when driving under free-flowing and not car following conditions.

Conclusion that can be made from the experiment where driver behaviour can be categorized into three types, i.e.:

i. *Conservative* : Drivers performed up to two lane changes and/or drove at a speed of 2.2m/s higher than speed limit.
ii. *Average* : Drivers performed up to five lane changes and/or drove at a speed of 4.5m/s higher than speed limit.
iii. *Aggressive* : Drivers performed at least six lane changes and/or drove at a speed of 6.7m/s higher than speed limit.

Brackstone *et al.* [4] carried out a study on British freeways and noticed that drivers tend to follow their leading vehicles in shorter headways. Later, the author found out that drivers have variation in headways depend on type of lead vehicle where drivers follow trucks closer than follow passenger cars.

Kim *et al.* [25] improvised their study by equipped instrumented test vehicle with an infrared sensor, GPS-inertial distance measuring instrument (DMI), vehicle computer and a digital video camera. They carried out studied during peak and non-peak hour near Washington, DC for 301 subjects without the subjects knowing they were being experimented. They concluded that each of every driver has their own driving rules and their distance vary over time and space during different conditions.

Dijker *et al.* [26] carried out a study on two Dutch freeways using a loop detector and found that at the same speeds, the headway distance between passenger-cars are larger in congested area compared to non-congested area. According to the authors, discouragement in motivation causes the drivers to have this driving approach to not follow lead vehicle closely and to not overtake their leaders. Therefore, operating speed and appropriate headway distance are crucial parameters that need to be considered and studied for safety purposes.

3. Methodology

The data pertaining to the analysis and development of the relationships between car following headways and speeds is listed below:

- *Headway* – time or distance separation between the fronts of two successive vehicles passing a same point on a roadway.
- *Speed* – rate of travel of an individual vehicle measured in km/h.
- *Vehicle type* – Vehicles are grouped into two major types, i.e. car (a vehicle having not more than two axles or having a total of not more than four wheels) and HGV (a vehicle having more than two axles or more than two wheels on the rear axle).

3.1. Data collection

The traffic data was collected at three (3) segments of high-speed expressway as summarised in Table 2. All studied segments are flat and straight with a maximum speed limit of 110 km/h.

An Automatic Traffic Counter (ATC) connected to pneumatic tubes as shown in Figure 1 and Figure 2, respectively, were used to record traffic data required for the analysis. The equipment used, which is known as the MetroCount, is capable of recording traffic data for long period of time. For this study, the hourly traffic data was collected for six consecutive days.

Table 2. The survey sites.

Site No.	Segment	Lane width (m) (no. of lanes/direction)	Highway segment characteristics
1	E22 – Senai-Desaru Expressway (East Bound) – KM 26.8	7.3(2)	Flat, straight
2	E8 – Lebuhraya Pantai Timur 2 (North Bound) – KM 268.9	7.3(2)	Flat, straight
3	E8 – Lebuhraya Pantai Timur 2 (South Bound) – KM 257.0	7.3(2)	Flat, straight

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Figure 1. ATC device.

Figure 2. Pneumatic tubes laid across the traffic lanes.

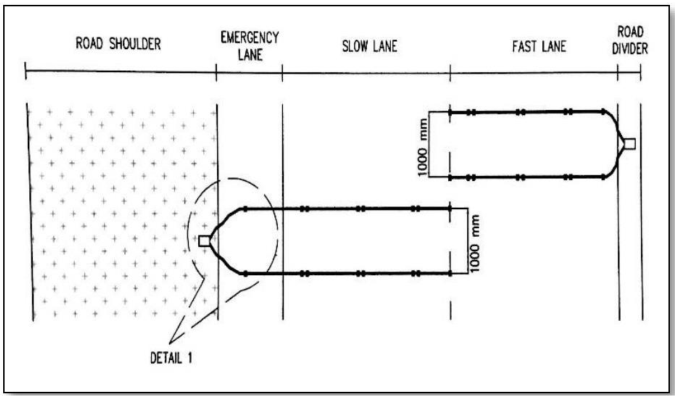

Figure 3. Pneumatic tube's schematic arrangement.

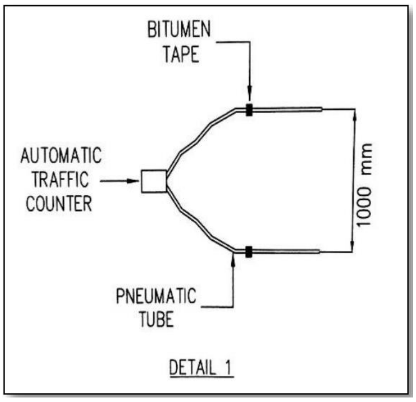

Figure 4. Pneumatic tube's detail arrangement.

The configuration of the equipment installation at the site is shown schematically in Figure 3 and 4. First, two pneumatic tubes were laid adjacently on slow lane with one-meter length and the tubes were stretched before pinned onto the ground to ensure the pressure within the tube was transferrable when in contact with tyres from vehicles. Second, the end of the pneumatic tube was tied into a twisting node and pinned onto the ground using two road nails for each node before bitumen tape was applied. Third, road nails and bitumen tape were applied at several other locations on pneumatic tube as illustrated on Figure 3 to ensure the tube able to stay permanently during data collection process. Figure 4 shows that both of the tubes were connected their ends onto ATC and set data parameter using software's program Metrocount Traffic Executive before locking the ATC into safety box. The equipment was left on site to record traffic data for a week period of time and these recording periods were considered appropriate to evaluate required traffic parameters under a range of traffic flows.

3.2. Data extraction

The required data i.e. traffic volumes, vehicle classifications, headways and speeds were obtained by extraction process from ATC using MetroCount Traffic Executive software. A total of one hundred thirty three thousands and eight hundred fifty-nine (133,859) impeded and unimpeded vehicles were recorded at all surveyed stations for six consecutive days. In order to develop speed–headway relationships based on types of vehicles, the data was grouped into different following types of vehicles, i.e. car following car, car following HGV, HGV following HGV, HGV following car, and all

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vehicles. Buses were recorded as HGV while motorcycles were excluded from the analysis. Distance headways were computed based on the time headways extracted from the recordings using the following Equation 2.

$$\text{Distance Headway (m)} = \text{Time Headway (s)} \times \text{Speed (m/s)} \quad (2)$$

For each type of following vehicles, the headway data was grouped based on speed classes 20-30 km/h, 30-40km/h, 40-50km/h, 50-60km/h, 60-70km/h, 70-80km/h, 80-90km/h, 90-100km/h, 100-110km/h, 110-120km/h, etc.

4. Results and discussion

4.1. Drivers' desired speed

Figure 5 shows the distribution of speed of all vehicles passing the traffic census points on the expressways for the recording period. As can be seen from the figure, about 35% of the vehicles were recorded to travel at speeds higher than 110 km/h. About 30% of the drivers were found to travel at or near the posted speed limit, i.e. 110 km/h. Since the data recording exercises and equipment were not visible to the drivers, the speed collected can be considered as the drivers' desired speed on the particular highway segment under the prevailing traffic and weather conditions. The data implies that speed limit is not that important to some of the drivers.

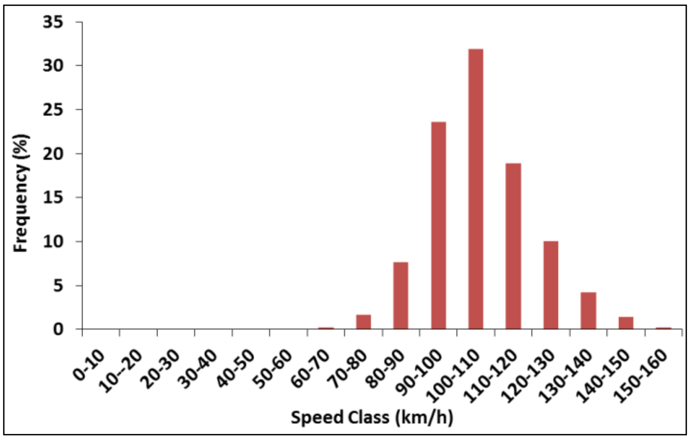

Figure 5. Speed distribution for all vehicles on high-speed highways.

4.2. Headway distribution

Figure 6 shows a typical distribution of distance headways of vehicles traveling at the speed class of 90-100km/h for all vehicles. The data shows that some drivers do adopted a close car-following behaviour where under impeded situation they were still following the leading vehicles as close as 10-15m at speeds ranging from 90-100km/h. This behaviour explains the reason why platooning can build up at faster rate on motorways.

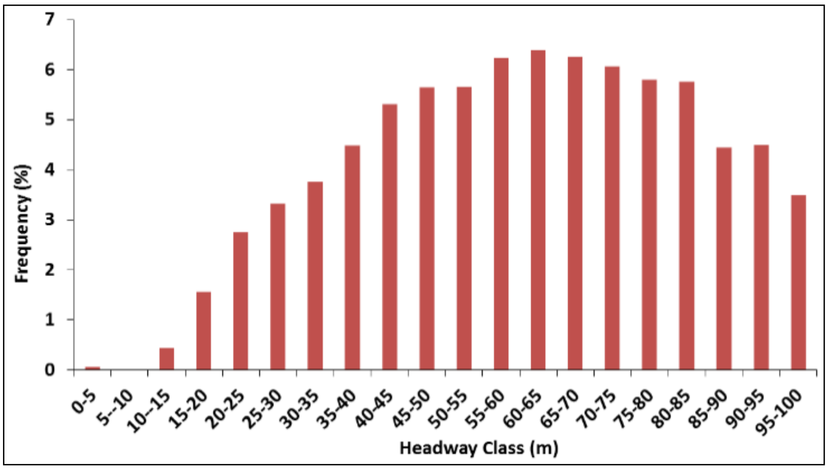

Figure 6. Distance headway for all vehicles.

4.3. Speed–headway relationships

This study derived the regression models of speed-headway relationships based on the median value of the following distance for each speed class. Figure 7 shows the typical relationship between headways and speeds for case of vehicle following vehicle. Table 3 provides summary of regression analysis for all types considered in the analysis. The values in Table 3 are fitted into Equation 1 to form the speed-headway relationships for the corresponding types of following vehicles as shown in Equation 3-7.

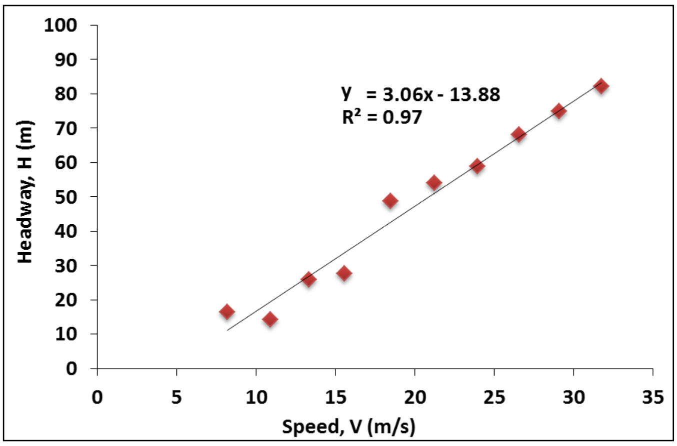

Figure 7. The relationship between headway and speed for all vehicles.

Table 3. Regression result for each type of following vehicles.

Following type	Sample Size	Headway, $H = A_o + A_1V$ A_o	A_1	R^2
All vehicles	19319	-13.88	3.06	0.97
Car – Car	15289	-13.67	2.94	0.97
Car – HGV	852	-6.53	3.15	0.90
HGV – HGV	220	-1.72	2.79	0.91
HGV – Car	689	0.47	2.88	0.98

$$H_{(All\ vehicle)} = -13.88 + 3.06V \quad (3)$$
$$H_{(car-car)} = -13.67 + 2.94V \quad (4)$$
$$H_{(car-HGV)} = -6.53 + 3.15V \quad (5)$$
$$H_{(HGV-HGV)} = -1.72 + 2.79V \quad (6)$$
$$H_{(HGV-car)} = 0.47 + 2.88V \quad (7)$$

The data shows that the average response time of a driver on an expressway is in the range of 2.79-3.15sec. The mathematical relationships between headway and speed as shown in Equations 3-7 can be considered reliable to describe the drivers' car following behaviour on expressways since R^2-value for each of the models is high, i.e. greater than 0.8.

4.4. Drivers' following headways on different types of highways
Figure 8 shows the variation of speed and headway relationships or car following models for three different types of highway facilities, i.e. expressway, multilane highway and two-lane single-carriageway road. The speed and headway relationship describing the car following behaviour of drivers on multilane highways was based on the work reported by Erwan *et al*. [20] while for the two-lane single-carriageway roads, the relationship is based on the author's previous work reported in year 2004 [16].

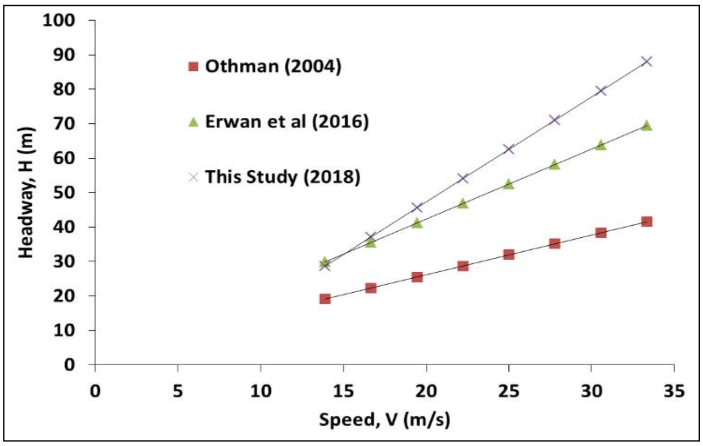

Figure 8. Comparison of Following Distance (all vehicles).

The relationships shown in Figure 8 imply that the drivers seemed to adopt longer following headways when driving on an expressway than that on a multilane highway and a two-lane single-carriageway road. This is most likely due to the fact that the opportunity to pass or to overtake slow moving vehicles on an expressway and multilane highway is more than the opportunity available when driving on a two-lane single-carriageway road. Close car following situations are seldom occurred on expressways when traffic volumes are below capacity.

In terms of drivers' aggressiveness, it can be deduced from the models for all vehicles given in Table 1 and Equation 3 from this study. The data shows that drivers on an expressway are less aggressive than those on a multilane highway and on a two-lane single-carriageway road. This is exhibited by different response times on expressway, multilane highway and two-lane single-carriageway road, i.e. 3.06 sec, 2.03 sec [20] and 1.16 sec [16], respectively. The longer the response time the lesser aggressive the driver is.

5. Concluding remarks

This study developed linear functions of speed and distance headway relationships to describe the drivers' car following behaviour on expressways. The study provides some important aspects of safe following distance as perceived by drivers on various types of highway facilities. These are:

- Under stable traffic flow conditions, drivers on an expressway adopt longer safe following distance than the distance they adopted when they are on a two-lane single-carriageway road. This could be due to the fact that the opportunity to overtake or to pass slow moving vehicles on an expressway is better than those on the two-lane single-carriageway road where drivers appeared to adopt a close-following distance and always seek opportunities to overtake the leading vehicles.
- Drivers' response time varies from 1.16 sec on a two-lane single-carriageway road to 3.06 sec on an expressway. Such a variation in response time shows that the level of aggressiveness of Malaysian drivers is also influenced by the types of highway facilities they used.

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