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DRIVER'S CAR FOLLOWING HEADWAY ON SINGLE CARRIAGEWAY ROADS

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Abstract: One of many aspects that are considered to influence road crashes and road traffic handling capacity is the drivers' car following behaviour. This study examines the distance separation between impeded vehicles on single carriageway roads. Data defining headway and speed for more than 8000 vehicles were collected using video cameras to record traffic movement at four sites in Malaysia. The distance headways and associated vehicle speeds were separated into vehicle following category by vehicle type and then into speed classes for vehicle following vehicle: car following car, car following heavy goods vehicle (HGV), HGV following HGV and HGV following car categories. In most cases the lognormal distribution was found to be an appropriate representation of the variation in distance headways for vehicles within a particular speed class. Linear regression models were developed to represent the relationships between distance headway and speed and the predicted variation in population mean distance headway with vehicle speed. In general, Malaysian drivers tend to follow another vehicle closely and platoons appeared to develop rapidly.

Keywords: *Driver Behaviour; Car Following; Headway.*

Abstrak: Antara aspek yang dianggap mempengaruhi kemalangan jalan raya dan kemampuan menampung aliran lalu lintas ialah jarak mengekor pemandu. Artikel ini membincangkan jarak mengekor antara pemandu yang terkekang pergerakannya di atas jalan raya tunggal rural. Data yang menerangkan jarak kepala dan kelajuan bagi lebih daripada 8000 kenderaan telah dicerap menggunakan kamera video untuk merakam pergerakan lalu lintas di empat lokasi di Malaysia. Jarak kepala dan kelajuan kenderaan yang berkait dengannya diasingkan kepada kategori kenderaan mengekor menurut jenis kenderaan dan kemudiannya diasingkan kepada kelas-kelas kelajuan bagi kategori kenderaan mengekor kenderaan: kereta mengekor kereta, kereta mengekor kenderaan perdagangan (HGV), HGV mengekor HGV dan HGV mengekor kereta. Dalam kebanyakan kes taburan data jarak kepala bagi kenderaan dalam kelas kelajuan tertentu berbentuk log–normal. Model-model regresi linear dibina bagi menjelaskan kehubungan di antara jarak kepala dan laju kenderaan. Model seterusnya mewakili ramalan perubahan dalam populasi jarak kepala dan laju. Secara umumnya, kebanyakan pemandu di Malaysia cenderung untuk mengekori kenderaan di hadapannya pada jarak yang rapat. Deretan-deretan kenderaan kelihatan terbentuk dengan cepat.

Kata kunci: *Kelakuan Pemandu; Jarak Mengekor; Jarak Kepala.*

1.0 Introduction

Two aspects that are of the main concerned of road traffic engineers and planners are road safety and road traffic handling capacity. Both analyses are associated with the behaviour of the road users either directly or indirectly. In most cases the analysis of road traffic safety issues is often based on a non-dynamic driver's car following behaviour concept. The driver's car following distance, for instance, is often considered as not related to the speed at which a vehicle travels. On the other hand, the road capacity analysis is based on the American Highway Capacity Manual which is formulated based on American traffic environment (Transportation Research Board (TRB), 1994). Such approaches would lead to an inaccurate evaluation of the problems and hence would result in incorrect planning of improvements. It is, therefore, essential to consider local traffic behaviour in the analysis of road safety and capacity.

Driver's car following behaviour is the process of following drivers attempt to adjust to the behaviour of the leading vehicle. In a situation where the volume of traffic is light or in a free flowing condition, driver's selection of speed is usually constrained by such factors as the road geometry features, lighting, and weather conditions. The attainable speed is only constrained by the driver's desired speed and the performance of a vehicle when negotiating the different road alignment.

In situations where the manoeuvrability of a driver is influenced by the vehicles ahead of him, the driver needs to adjust speed and position to keep a safe following distance at all times (i.e. to avoid rear-end collision with the preceding vehicle). This is termed as driver's car following distance or headway. The phenomena can be observed when a faster vehicle catches up, and cannot immediately overtake, a slower vehicle in a traffic stream. This impeded vehicle is usually, by definition, has a desired speed higher than that of the leader.

On single carriageway roads, vehicle platoons form most rapidly in a situation where traffic flow is high and overtaking opportunities are limited. By definition, a platoon is a group of successive impeded vehicles travelling at a similar speed (Hunt, 1997). As described by Hunt (1997), a vehicle travelling at the driver's desired speed will catch up vehicles travelling at lower speed. In a situation where overtaking is not possible, the driver of the vehicle travelling at higher speed must reduce his/her speed to match the speed of the leading slower vehicle. The distance between the two vehicles will decrease during this period of deceleration. Hunt (1997) defined this range of distance as the zone of influence. When deceleration is complete the vehicles will travel at approximately similar speed. Although in practice the distance will vary as the follower adjusts to changes in speed of the leader, it is assumed that the follower will maintain steady state constant distance headway with the leader. This interaction between drivers in platoons is maintained until the follower overtakes the leader.

Driver's car following behaviour has been studied and modelled by numerous researchers over the past decades (e.g. May et al, 1967; Gipps, 1981; Miyahara, 1994; Othman Che Puan, 1999). The studies and models varied in objectives and 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.:

$$H = A_0 + A_1 V \tag{1}$$

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.

The main objective of the study is to develop empirical relationships between headway and vehicle's speed to describe driver's car–following behaviour on Malaysian typical single–carriageway roads. It should be pointed out that some studies considered such a relationship, as expressed in *equation (1)*, in a quadratic form to include an additional term related to vehicle's ability to brake (e.g. Smeed and Bennet (Lane, 1968)). However this approach was not considered as the term was found statistically insignificance in the formulation of the relationship.

2.0 Methodology

The data that are required for the development of the relationships between distance separations of vehicles and speeds are 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).

2.1 Field data collection procedure

Field studies were carried out to collect and analyse all traffic data pertaining to the development of empirical relationships between headway and speed. Because of limitation in time and resources, the quantity of data collected for this study is a compromise between a reasonable, realistic data collection effort and the need for adequate data for numerical analysis.

In general, the observation sites selected should be representative of rural single carriageway roads and road layout and traffic would provide a high proportion of impeded vehicles. Therefore, the selection of road stretches was based on the following criteria:

(a) road sections with less than 30% overtaking provision,
(b) road sections with sight distances of less than 200 m,
(c) roads carrying a high proportion of long distance trips,
(d) roads with a high traffic volume,
(e) roads with standard width and layout and representing a range of geometric design in terms of alignments,
(f) good access and safety for the enumerators and equipment during the data collection process and good overhead vantage points for video recording purposes,

Field data collections were carried out using video cameras. Othman Che Puan (1999) has described the advantages of using a video recording method for traffic data collection. One particular difficulty with the method is in finding a suitable vantage point with good visibility to acquire the data. This problem was the major factor affecting the type of data obtained for this study.

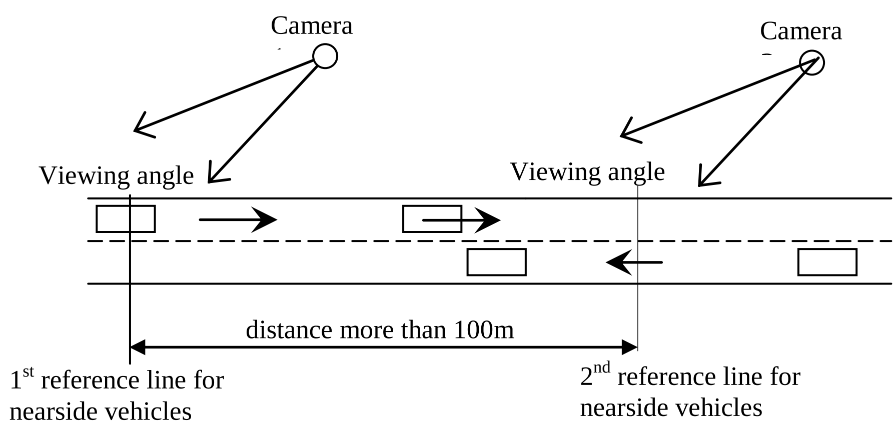

Figure 1: Arrangement of cameras for video recording process.

At each location, two video cameras were mounted unobtrusively by the roadside to record the passage of vehicles. The cameras were located at a distance ranging from 100 m to 200 m apart. The exact location of cameras at each location was influenced by logistics such as vegetation, visibility, etc. On each occasion data were collected only for the nearside vehicles.

An external time device, i.e. a character generator, was attached to each camera to provide a permanent record of stopwatch. The reference points at which the headway data were measured were marked using the road cones. Figure 1 shows the set up of the cameras during video recording process.

On each occasion, traffic data were recorded for three periods of time of day, i.e. from 8.00 am to 10.00 am, 12.00 noon to 2.00 pm, and 4.00 pm to 7.00 pm. These recording periods were considered appropriate for evaluating the required traffic parameters under a range of traffic flows. Four sites were selected as the observed road sections in the study. Table 1 provides the summary of the general characteristics of each section. The maximum speed limit on all road sections is 90 km/h. Except for Site 4, all other road sections carried relatively high traffic volumes during peak hours.

The surveys were carried out during weekdays and under good weather conditions. A total of 8511 vehicles were observed. All roads carried relatively high proportions of HGV during peak hours (i.e. 15 to 20%).

Table 1: The survey sites

Site No.	Location	Average road width (m) (no. of lanes)	Approximate section length - m	Observed stream	Road characteristics upstream (lane marking)*	Road characteristics in section (lane marking)*
1	Kuantan – Pelabuhan Bypass	7.0 (2)	500	Both	Flat, straight (DC)	Flat, straight (SS)
2	Kangkar Pulai – Pontian, Johor	7.0 (2)	300	Both	Flat, straight (SS)	Flat, bendy (DC)
3	Kangkar Pulai – Pontian, Johor	7.0 (2)	250	Both	Flat, straight (SS)	Uphill, straight (DC)
4	Yong Peng – Segamat, Johor	7.0 (2)	500	Both	Flat, straight (SS)	Flat, straight (SS)

*Note: SS – Short single broken line; DC – Double continuous line

2.2 Data abstraction and processing

Each of the videotapes containing the recorded scenes was played back to retrieve the relevant data. For each vehicle, vehicle classification, following headway (measured in term of time), and speed were determined. These were achieved using a computer-based event recorder to extract data defining vehicle arrival time and classification from the video recording of traffic scene at each of two positions of each location. Vehicles were classified as either HGV or car. A bus was recorded as an HGV. Motorcycles were excluded from the analysis.

For vehicle arrival at each detection line, the videotapes were played back in real-time. A vehicle arrival time was recorded by pressing a pre-defined key each time the front of a vehicle reaches a specified reference line. All vehicle arrival time data at two consecutive detection lines were extracted using the same time reference for all directions of traffic. This was an important procedure because all events have to be arranged in a correct order based on the individual occurring times for time headway analysis.

For each data extraction and analysis process, the data were stored on a text-formatted data file and transferred to an Excel spreadsheet file. The data comprised of arrival time and classification at each of the two positions for each measurement. The data for each vehicle were matched and the time headway at each position and vehicle speed between positions were calculated. Time headways were measured as the time between the passages of the fronts of successive vehicles. This is based on the definition given by the TRB (1994) i.e. headway is the time between successive vehicles in a traffic stream, as measured from front bumper to front bumper. This headway measurement method includes the inter-vehicle distance and vehicle length. The speed of each vehicle was computed using the time taken to travel between the two consecutive detection lines.

The headway and speed data were evaluated for the individual vehicles. A preliminary data analysis was carried out using Excel spreadsheets to evaluate the validity of headway and the corresponding speed to identify unrestrained and impeded vehicles in the traffic stream and to evaluate the inconsistencies in the tabulations of the data.

2.3 Data overview

The collected headway and speed data for 8511 vehicles is a mixture of restrained and unrestrained vehicles. It is obvious that the following behaviour of a driver can only be observed in a situation where the follower is impeded by its leader, or the following vehicle has entered the zone of influence. Therefore, the analysis will only consider the headway data for the impeded or restrained vehicles. This requires the headways data for the impeded following vehicles to be separated from the headways for the free flowing or unrestrained vehicles. There is no specific method of identifying vehicles which are impeded by their leader in a traffic stream (Hunt, 1997). However, it is generally accepted that most impeded vehicles are at relatively very small time headways and will travel at a speed relatively similar to their corresponding leader. The Highway Capacity Manual (TRB, 1994) suggests that the headway of 5 seconds or less represents a vehicle which is impeded by its leader. Hunt (1997) used the ratio of speed of follower to the speed of the leader in addition to the maximum time headway cut-off point to differentiate the impeded and unrestrained vehicles. An approach similar to Hunt (1997) was adopted in the study to filter out the impeded vehicles, i.e.:

- time headway of less than or equal to 5 seconds; and
- ratio of speed of follower to speed of leader ranging between 0.9 and 1.02

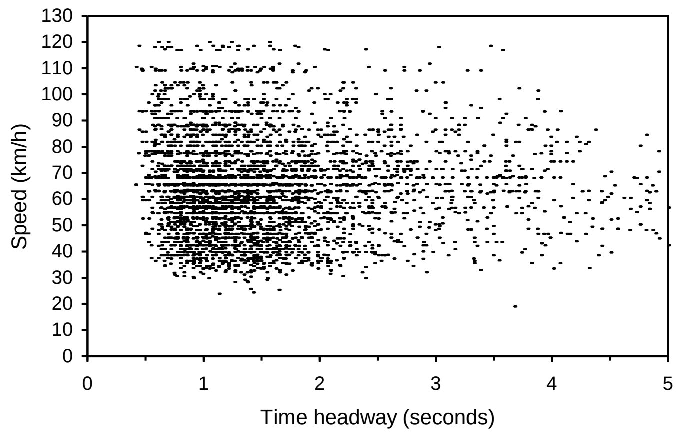

Figure 2: Scatter plot for time headway less than 5 seconds (all vehicles)

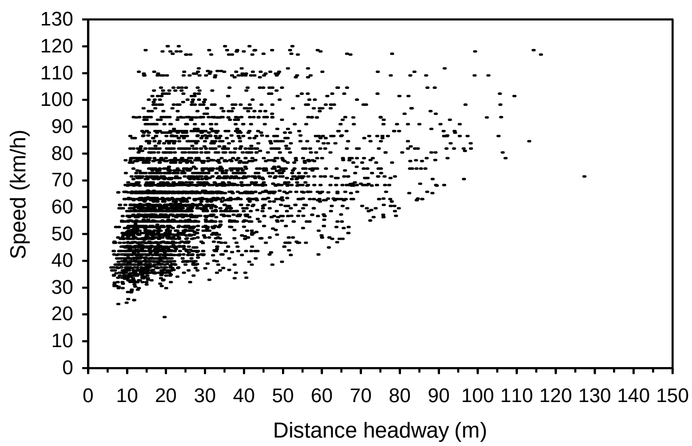

Figure 3: Scatter plot for distance headway less than 130 m (all vehicles)

The impeded vehicle headways were analysed for all types of vehicle and grouped according to the type of vehicles to produce another four sets of headway data. Figure 2 shows scatter plot for the data points in all vehicle data set after filtering out the time headways greater than 5 seconds. The equivalent distance headways were computed using the corresponding speeds and the scatter plot of the distance headway for the impeded vehicles is shown in Figure 3. In terms of distance, the data from this study indicated that the impeded vehicles are at headways not greater than 130 m.

3.0 Data Analysis

The distribution of speeds of all impeded vehicles was plotted (Figure 4). As expected, most impeded vehicles travelled at relatively low speeds. In the analysis the speed class widths were determined to retain reasonable sample frequencies for each class. Within each speed class for each of the vehicle following types, the distance headway data were allocated to the frequency distributions. For each speed class the headway data belongs to it were grouped into headway classes.

A typical plot of the distribution of the distance headway data for all vehicles in speed class 50 – 60 km/h is shown in Figure 5. The distance headway frequency distributions are all positively skewed. As suggested by Daou (1966), the distributions closely followed a lognormal distribution. A lognormal distribution is the distribution of a variate whose logarithm obeys the normal law of probability (Hunt, 1997).

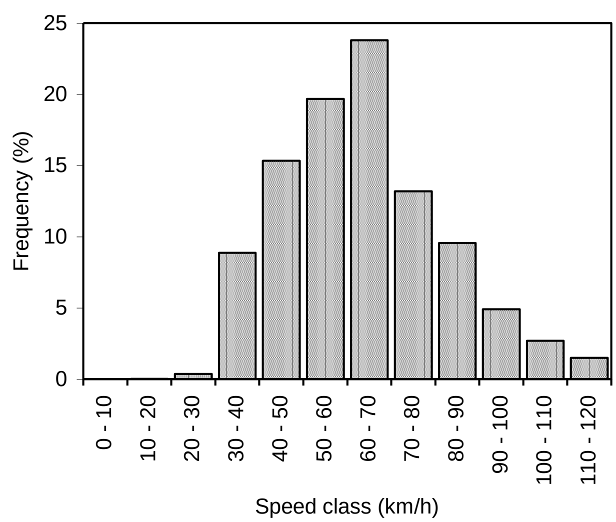

Figure 4: Distribution of speeds for all vehicles

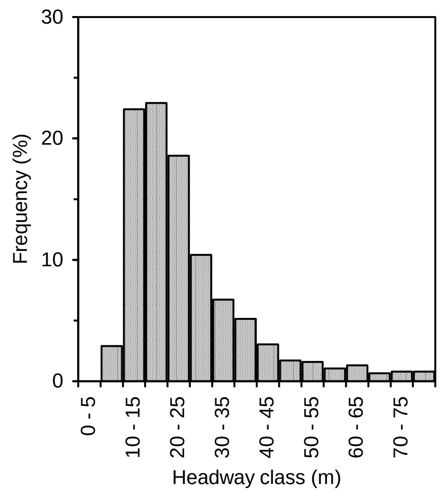

Figure 5: Distance headway for all vehicles in speed class 50 – 60 km/h

3.1 Derivation of Car Following Models

This study derived a median (and hence taken as mean) following distance relationship. The median headway in each speed class was used in view that the arithmetic mean would lead to a biased interpretation of log-normally distributed data. This approach is similar to the approach adopted by Daou (1966). Figure 6 and 7 show the typical relationships between headways and speeds for cases of a vehicle following a vehicle and a car following a car, respectively. Table 2 provides the results of the regression analysis for all types of following vehicles considered.

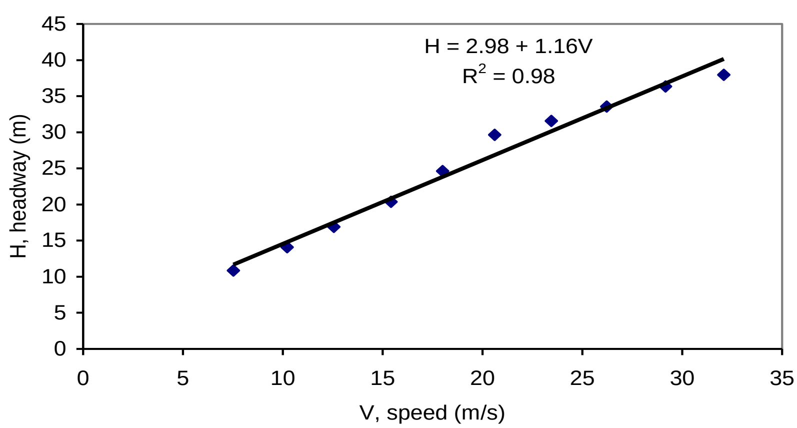

Figure 6: Headway and mean speed for each speed class (all vehicles)

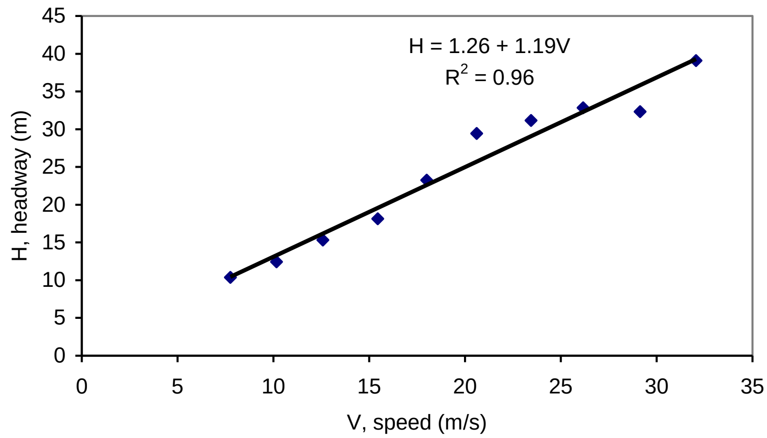

Figure 7: Headway and mean speed for each speed class (car following car)

Table 2: Regression results for each type of following vehicles

		Headway, $H = A_0 + A_1 V$		
Following type	*Sample size*	A_0 ( )	A_1 ( )	R^2
All vehicles	3879	2.98 (3.95)	1.16 (0.19)	0.98
Car – Car	2259	1.26 (5.66)	1.19 (0.28)	0.96
Car – HGV	866	4.04 (1.96)	1.12 (0.11)	0.99
HGV – HGV	278	9.33 (11.19)	1.21 (0.61)	0.85
HGV – Car	430	5.17 (12.96)	1.19 (0.69)	0.81

Note: figure in ( ) is the standard deviation of the corresponding coefficient.

Mathematically, the results of the regression analysis (Table 2) may be written as follow:

$$H_{(all\ vehicles)} = 2.98 + 1.16V \quad (2a)$$
$$H_{(car-car)} = 1.26 + 1.19V \quad (2b)$$
$$H_{(car-HGV)} = 4.04 + 1.12V \quad (2c)$$
$$H_{(HGV-HGV)} = 9.33 + 1.21V \quad (2d)$$
$$H_{(HGV-car)} = 5.17 + 1.19V \quad (2e)$$

In the above equations *H* is measured in metre and *V* is in m/s. In general, the relationships between headway and speed found in this study are conceptually logical. All terms have a positive sign (+ve) which implies that a driver would keep a longer following distance with the leader as the speed increases. The constant could be inferred as the safe buffer distance considered by the follower, although the constants in equations (2a) – (2e) may not represent the average length of the respective leading vehicles plus the distance at zero speed. Such a short distance in the models might have been resulted from the data which might include high percentage of vehicles that are in the process of adjusting their following distance and speed after aborting overtaking manoeuvres. The coefficients, on the hand, appear to agree with a general understanding that an average driver reaction is in a range of 1 to 3 seconds. The good R^2−values (i.e. greater than 0.80) for all models provide a sound basis for the acceptance of the models to represent the behaviour of the drivers on Malaysian single carriageway roads.

3.2 Comparison with Other Car Following Models and Safety Implications

The models of car following distance derived from this study were compared with those developed in the previous studies. Figure 8 shows the plots of the following distance for all vehicles together with those developed by Daou (1966), Smeed and Bennet (Lane, 1968), and the British Highway Code (Macpherson, 1993). The model obtained from this study does not differ much from those of Daou and Smeed and Bennet in terms of characteristics. The Highway Code, however, gives greater vehicle spacing at higher speed as it is based on theoretical safe braking distance under good driving conditions. It could be inferred from the comparison that, in general, most Malaysian drivers on single carriageway roads tend to follow closely their respective leading vehicles. The current models also indicate that most drivers have a relatively shorter reaction time than what is expected. A short reaction time is one of the characteristics of aggressive drivers. This might explain the reason for most Malaysian drivers to adopt a close following behaviour.

The models for the following distance for various types of vehicles were also compared with those developed by Hunt (1997) for British single carriageway roads (Figure 9). These are, again, consistent with what have been described in the preceding paragraph. Although the form of all models appears similar, the current models indicate that the following distances adopted by the local drivers are shorter than those adopted by the British drivers, even at a relatively high speed.

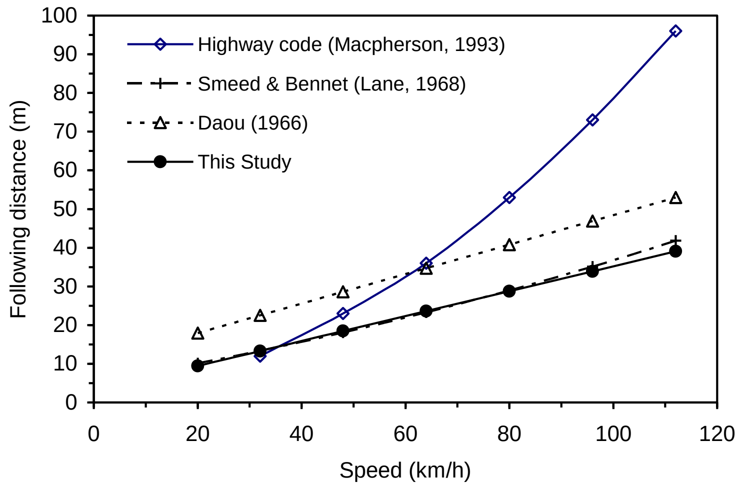

Figure 8: Comparison of following distance (all vehicles)

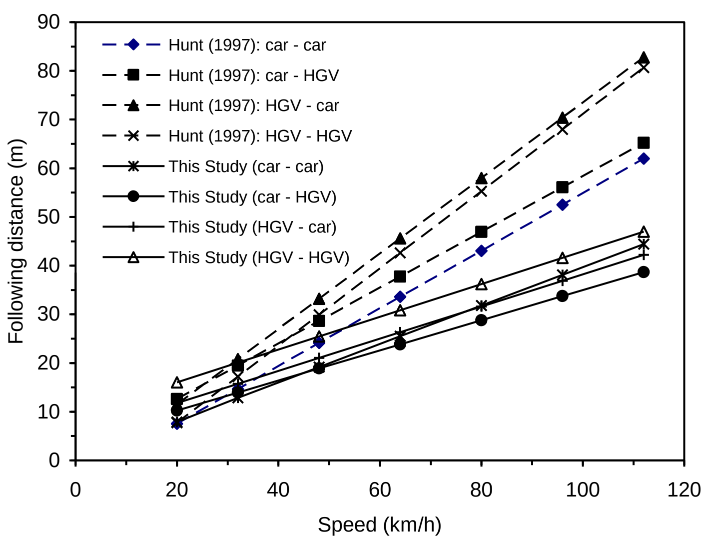

Figure 9: Comparison of following distance by vehicle types

The above interpretations are consistent with the typical characteristics of traffic flow on Malaysian roads where vehicles are observed to travel in platoons. Such behaviour would lead to a multiple rear-end-collision when the follower failed to adjust his/her speed and distance with the sudden braking by the leading vehicle.

5.0 Concluding Remarks

The analysis has provided linear functions describing the variation in distance headway for restrained or impeded vehicles on single carriageway roads. The relationship between distance headway and speed for all vehicles is similar to that of Smeed and Bennet (Lane, 1968) for vehicle's speed less than 120 km/h.

The study provides some important aspects of traffic data and the driver's behaviour on single carriageway roads. These are:

- Headway data are log normally distributed which is in agreement with the expectation.
- Most of the drivers appeared to adopt a close-following driving style. This implies that most drivers always seek opportunities to overtake the leading vehicles.
- Such a close-following distance characteristic leads to the rapid formation of vehicle platoons particularly in high traffic flows, and hence causing the road section to reach its capacity at a faster rate.
- The risk of road crashes is high on a single carriageway road because of close-following distance adopted by most drivers.

In general, the models describe some important characteristics of Malaysian drivers on single carriageway roads. The models also show level of aggressiveness of Malaysian drivers. Further study is essential to include headway data defining driver behaviour on hilly and bendy road sections.

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