Empirical Analysis On The Effects Of Gross Vehicle Weight Of Platoon Leader On Platoon Headway Characteristics: A Case Study In A Developing Country

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Abstract. Vehicle platooning has become a part of traffic flow nowadays, especially on two-lane rural roads. Platoon caused by slow lead vehicle will result in shock wave and instabilities in traffic flow. The situation might become worse when a platoon is being led by heavy vehicles, since the following vehicles have only two choices: to follow or to overtake. This study investigates empirically the effect of platoon leader's gross vehicle weight (GVW) on platoon headway characteristics. The purpose of the investigation is to study the influence of platoon leader on variation of time headway between vehicles. A weigh-in-motion system based traffic data collection was installed at two-lane in sub-urban roads for the purpose of collecting platoon based information. Empirical analysis results show that there is a significant relationship between GVW of platoon headway.
Keywords: platoon, heavy vehicle, vehicle weight, platoon headway

1. INTRODUCTION

The increasing demand of road freight transportation each year brings more heavy vehicles travelling on the roads. Nowadays, the road network facilitates mobility for human on passenger cars, heavy vehicles, two-wheelers and other automobile. Apparently, the existence of heavy vehicles on roads -or the heterogeneity of traffic flow- had caused instability propagation in the same lane (Hoogendoorn et al., 2007), variation in driver behaviour (Sarvi and Ejtemai, 2011), and reduce road capacity (Sarvi and Kuwahara, 2007). However, the incident of road crashes and casualties involves heavy vehicles are quite significant. In Malaysia, the number of road accidents and fatalities are increasing every year and for the year 2008 the total accident increase by 2.7% and road fatality increase by 3.9% from the year before (according to Royal Malaysian Police). Based on accident data obtained from the Malaysian Institute of Road Safety Research (MIROS), the ratio of fatal accident involving heavy vehicle (FAIHV) to total road fatalities is relatively significant as in 2008 the ratio is 25.1%. This means that at least 25.1% of all road fatalities are due to fatal accidents involving heavy vehicles (because by definition a fatal accident is when at least one death occurs in that accident). In addition, vehicle platoons involving heavy vehicles on two-lane roads has also become one of crucial safety issues since it can increase the risk of erratic and aggressive driving behaviour which can lead to dangerous overtaking and rear-end collisions.

Headway is defined as the time elapses between consecutive vehicles and it is considered as one of the safety-related parameters in a traffic study. Driving with short headways on a free flow traffic are always associated with unsafe behaviour and a main contribution of road crashes especially rear-end collision. According to Othman (2004), 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. Safety issue arises particularly on two-lane rural roads regarding vehicle following with small time headway. In this situation, various vehicles on the roads tend to move closely together in a group in some instances and this form of motion is defined as platoon.

According to 4th Edition Highway Capacity Manual (TRB, 2000), platoon is defined as "a group of vehicles or pedestrians travelling together as a group, either voluntarily or involuntarily because of signal control, geometrics, or other factors". To generate platoon-based data, most of previous researches (Athol, 1965; Jiang and Li, 2005) use time headway to separate free-flow moving and impeded vehicles in a platoon. Petigny (1967) found two classes of queuing vehicles: (a) a time headway of the order 1sec to describe vehicles but waiting for a chance to pass, and (b) a time headway of 3.5sec to characterize vehicles that are queuing and are content to do so. In a study on vehicle following interaction, Pahl and Sands (1971) determine that interaction may occur at time headway between 2.5sec and 4.3sec, depending on lane number and traffic flow rate. Al-Kaisy and Karjala (2010) suggest car-following interactions on two-lane rural highways generally cease beyond a headway value of 6sec. The critical headway and interaction headway used in this research is modified based on experts' findings.

As mentioned by Bixel et. al. (1998), the vehicle weight is one of the essential parameters in vehicle design study that can affect vehicle driving, braking and handling performance characteristics. Furthermore, most of the time the vehicle dynamics influence driver behavior in controlling their vehicles (Wong , 1993). Occasionally, heavy vehicles move together in a platoon and sometimes lead a platoon. This creates greater critical safety factor as the disparity in dynamic composition involved different vehicle capacity. This paper focuses on how gross vehicle weight (GVW) of platoon leader affect platoon headway characteristics. Vehicle platoon, especially caused by heavy vehicles gives high impact on traffic flow and drivers' behaviors'. Even though vehicle platoon has been continuously discussed in previous researches over decades, most of the platoon models do not specifically consider the GVW of platoon leader and their interactions with other vehicles in the platoon. The effect of following vehicle GVW has been studied and proven to have significance on the speed characteristics in vehicle following situation (Saifizul et. al., 2011b) and in free flow condition (Saifizul et. al, 2011a).

2. DATA COLLECTION AND PREPARATION

Headway data together with all other traffic and vehicular data were collected from the developed weigh-in-motion (WIM) system that operated continuously throughout the year.

Vehicular data captured includes GVW, wheelbase, vehicle class, individual speed, and headway.

The system has been installed at one of the federal roads where the road type is rural single carriageway with standard width, and layout, and geometry is a straight and flat road as shown in Fig. 1. A road section located in country side nearby Ijok, Selangor was selected. Further elaboration of the developed system is presented in Saifizul et al. (2010). Traffic data for one-month period, 24 hours a day are gathered for this study. All the data including every single non-platoon vehicles are used to calculate the 15-minutes flow rate which will be used to study traffic behavior.

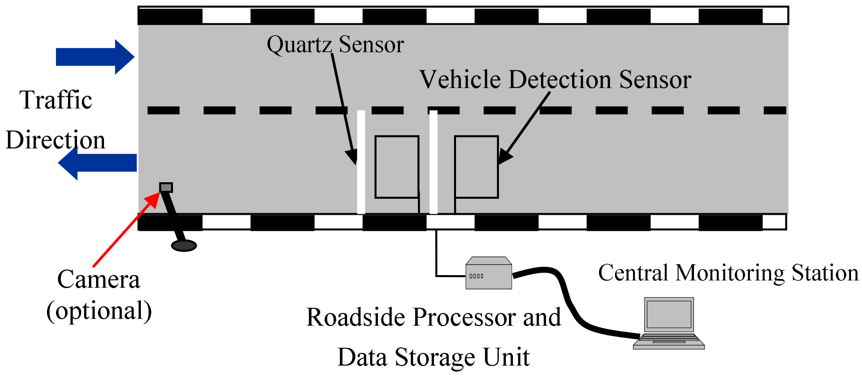


Figure 1. Schematic diagram of WIM system layout

Below are the definitions of terms and variables used in this paper:

Platoon leader : the first vehicle in the platoon.
HV : Heavy Vehicle
C_i : the successive following vehicles within a platoon, where $i = 1,2,3,...,n$.
Var : a set of traffic and vehicular variables captured together in the data set, where Var_C_i *{speed, GVW, Acc, Wheelbase, Headway and Class}*. However, some of the variables are not included since the study only focuses on speed.
Platoon size : the total number of vehicles involved in a platoon, including the platoon leader.
Platoon speed : the average speed of all the vehicles in the platoon.
15-min flow rate : number of vehicle passing through the road section in 15 minutes.

In order to remove the influence of the surroundings and focus on the driver behavior and vehicle performance capability in a vehicle platoon, data were then filtered based on following conditions:-

- A platoon is only considered if it has more than two vehicles. Therefore $C_{i_{min}} = 2$,.he headway between the first vehicle in the platoon (platoon leader) and the vehicle in front is not less than 4 seconds.
- Critical intra-platoon headway (from C_1 to C_n) is less than or equal to 3.5 seconds.

By limiting the number of sample, the data that passed the filtering stage of this study consisted of 17,314 platoon-based data. Then, the platoon-based data are grouped according to platoon leader GVW. In this study, platoon leader is defined as the first vehicle in a platoon. There are three types of vehicle platoon leaders in traffic stream that will be considered as illustrated in Figure 2. The first case is the platoon led by the passenger cars. The second case is the platoon led by heavy vehicle with GVW not more than 20 tonnes, including light trucks such as vans and pickup trucks. The third case is the platoon led by heavy vehicle with GVW more than 20 tonnes. Since the type of following vehicles is not of interest in this study, all types of vehicles is included.

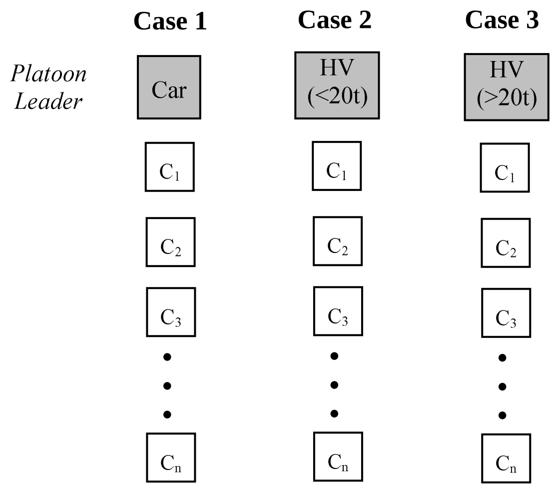


Figure 2. Three cases according to types of platoon leader

3. RESULTS

3.1 Characteristics of sample platoon

According to Jiang et al. (2003), vehicle platoon characteristics on a specific road vary over time because of the fluctuation of traffic flow rate. Thus, both flow rate and GVW are considered in this study to focus on the effect of GVW to the platoon speed and platoon size characteristics at different flow rate. However, analysis is done seperately to exclude their interaction and to focus on the effect of each of them. The selected road section is usually non-congested most of the time, except during peak hours. The total sample for each group which is divided by flow rate are represented in Table 1, where majority of the platoon cases (79.4%) is led by passenger cars, while 13.1% led by heavy vehicle less than 20 tonnes and 7.5% led by heavy vehicle more than 20 tonnes.

Table 1. Number of sample for data analysis.

Platoon Type	15-minutes Traffic Flow Rate (Vehicles)											
	<40	40-50	50-60	60-70	70-80	80-90	90-100	100-110	110-120	120-130	>130	Total
Case 1	722	626	919	1330	2165	2477	1854	1443	983	647	584	13750
Case 2	104	45	96	189	402	513	375	251	132	94	63	2264
Case 3	23	13	25	62	234	335	266	191	77	50	24	1300

Before analyzing the platoon headway characteristics, the platoon size and platoon speed distribution are observed. Figure 3 illustrates the distribution of platoon size by the platoon leaders. A similar pattern observed between the three cases wherein as the platoon size increase, the frequency of occurrence decreases. Figure 4 and Figure 5 shows the average and standard deviation of platoon speed corresponding to three cases of platoons. The average platoon speed demonstrated in Figure 4 explains the evident disparity resulted from different leading vehicle GVW in platoons. It shows that the mean speed for platoon following a passenger car is higher than mean speed for platoon following heavy vehicle less than 20 tonnes, whereas platoon led by heavy vehicle more than 20 tonnes travel has the lowest mean speed.

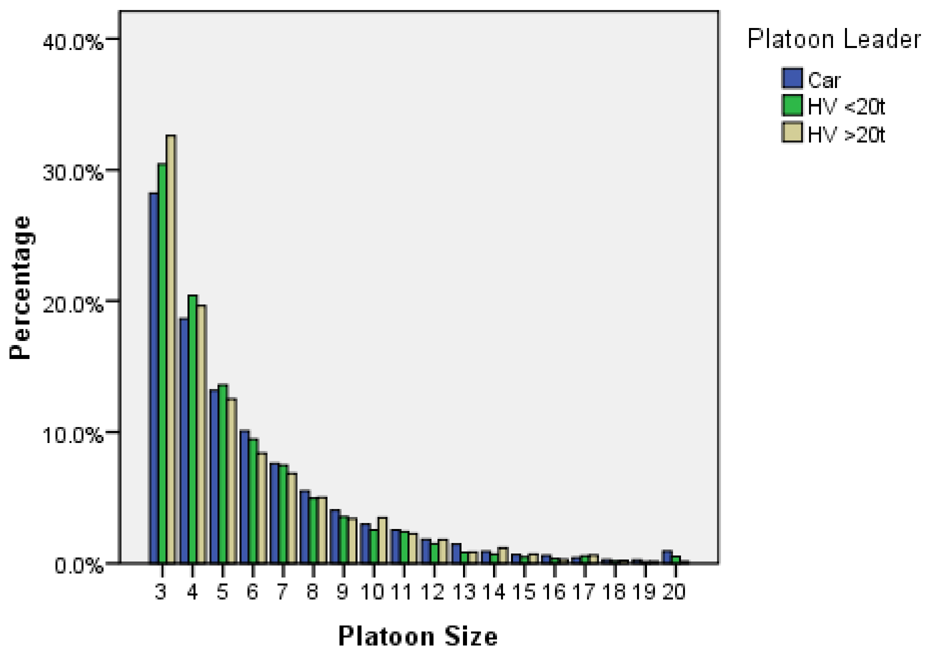


Figure 3. Percentage of platoon size frequency by cases.

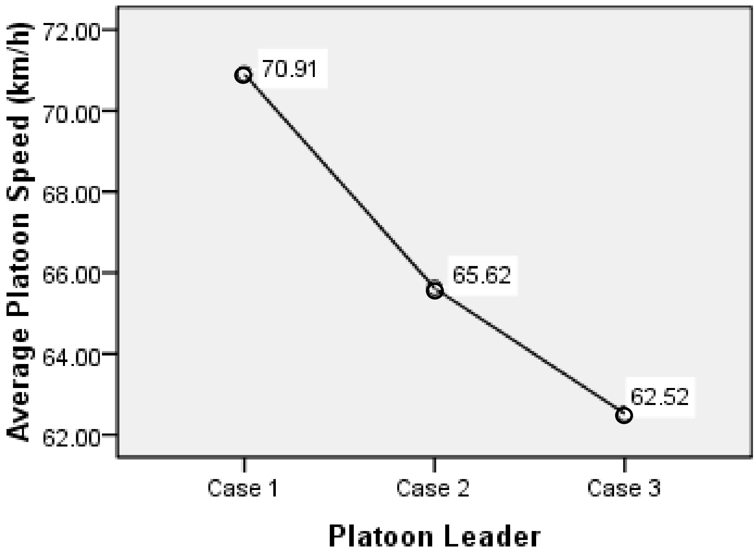


Figure 4. Average platoon speed according to three cases.

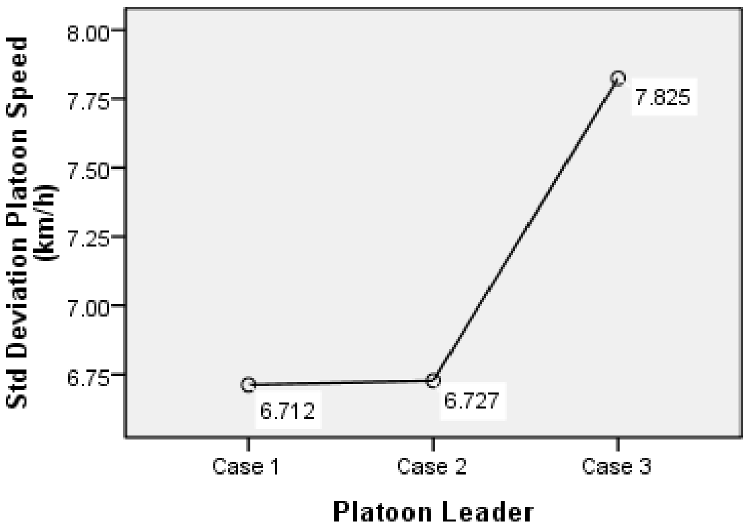
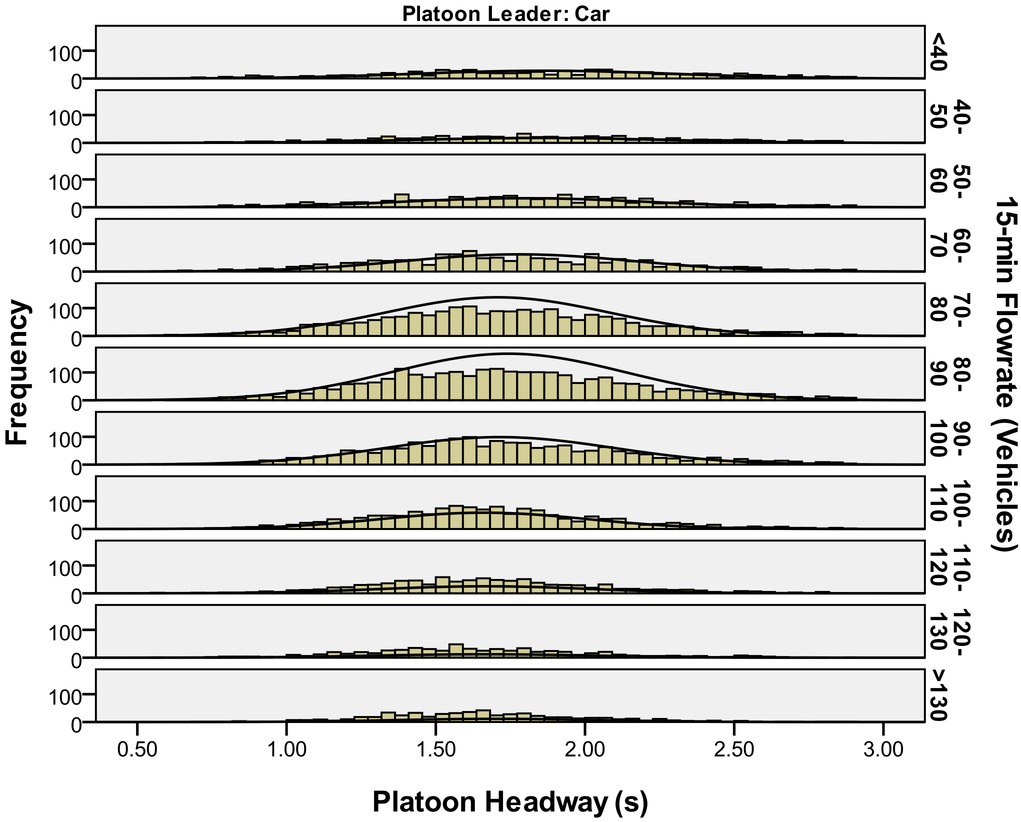


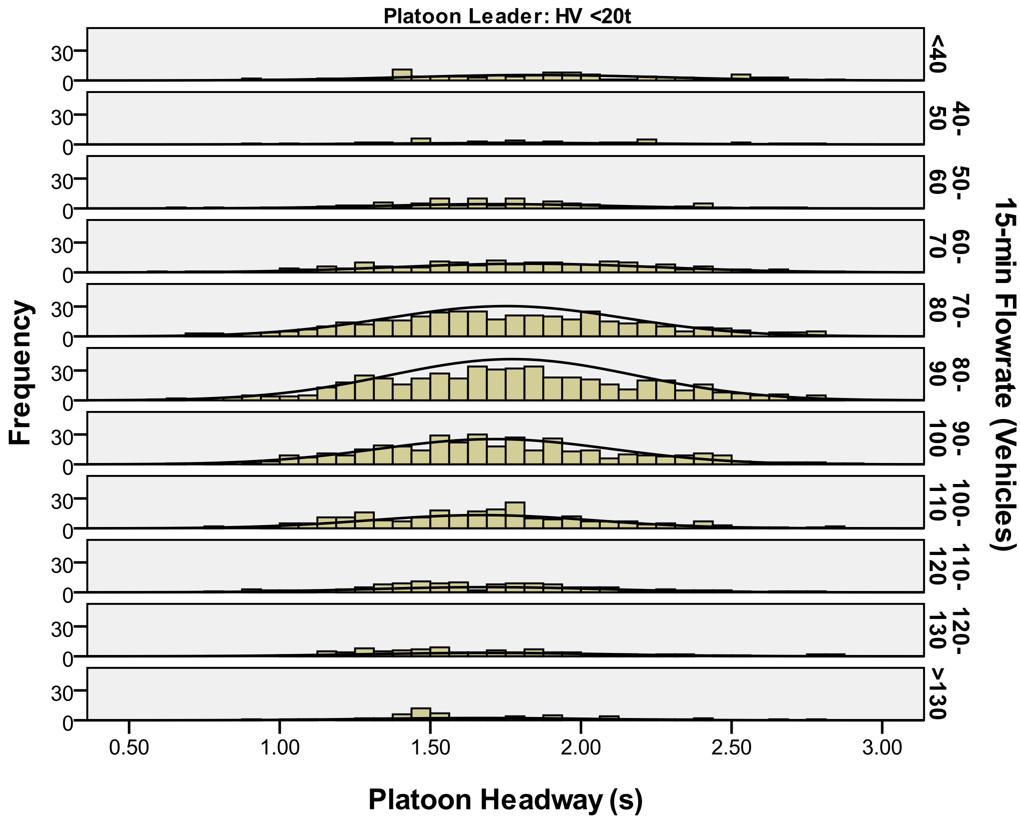
Figure 5. Standard deviation of platoon speed according to three cases.

3.2 Analysis of platoon headway characteristics

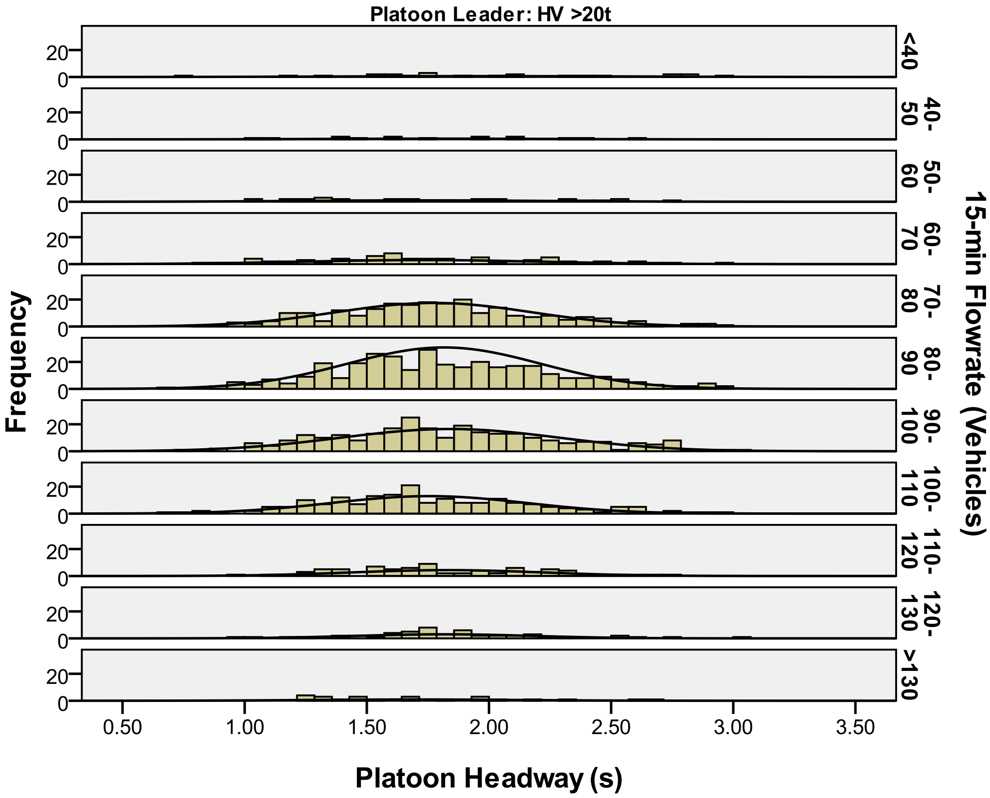
The analysis of data has been done for platoon headway characteristics. Normality test has been performed for each group of platoon headway data by observing their Skewness and Kurtosis; Case 1 (S= 0.258, K=-0.161), Case 2 (S= 0.238, K=-0.281), Case 3 (S=0.330, K= -0.203). Normality test performed on 33 groups of data shows that all groups follow normal distribution. Figure 6 shows the histogram for all groups of data by 15-min flow rate.


Platoon Leader: Car
Frequency
100
0
<40
40-50
50-60
60-70
70-80
80-90
90-100
100-110
110-120
120-130
>130
15-min Flowrate (Vehicles)
0.50
1.00
1.50
2.00
2.50
3.00
Platoon Headway (s)

(a)


Platoon Leader: HV <20t
Frequency
30
0
<40
40-50
50-60
60-70
70-80
80-90
90-100
100-110
110-120
120-130
>130
15-min Flowrate (Vehicles)
0.50
1.00
1.50
2.00
2.50
3.00
Platoon Headway (s)

(b)



(c)

Figure 6. Frequency of platoon headway by flow rate for three groups of platoon leader cases. (a) Case 1 (b) Case 2 (c) Case 3

Two-way analysis of variance was performed to observe the effect of platoon leader GVW and flow rate on the variable. Table 2 shows the result of two-way ANOVA test performed on platoon size. The result shows that flow rate, F(10, 17281)= 5.430, p<.001 and GVW of platoon leader, F(2, 17281)= 12.571, p<.001 significantly affect platoon headway characteristics. On the other hand, the interaction of the two independent variables are not significant.

Table 2. Two-way ANOVA for platoon headway.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	50.798[a]	32	1.587	8.789	.000
Intercept	9177.529	1	9177.529	50814.036	.000
PlatoonCase	4.541	2	2.270	12.571	.000
FlowRateNum	9.807	10	.981	5.430	.000
PlatoonCase * FlowRateNum	2.056	20	.103	.569	.936
Error	3121.123	17281	.181		
Total	55390.027	17314			
Corrected Total	3171.921	17313			

a. R Squared = .016 (Adjusted R Squared = .014), dependent variable: platoon headway (s)

The line plots of average and standard deviation of platoon speed corresponding to flow rate are demonstrated in Figure 7 and Figure 8. Figure 7 shows the average platoon headway for Case 3 platoon (platoon leader: HV more than 20 tonnes) is notably higher than the other two groups. Whereas not much difference of platoon headway is observed between Case 1 and Case 2 in average. The standard deviation for the three groups are shown in Figure 8, with range between 0.51 to 0.67 seconds.

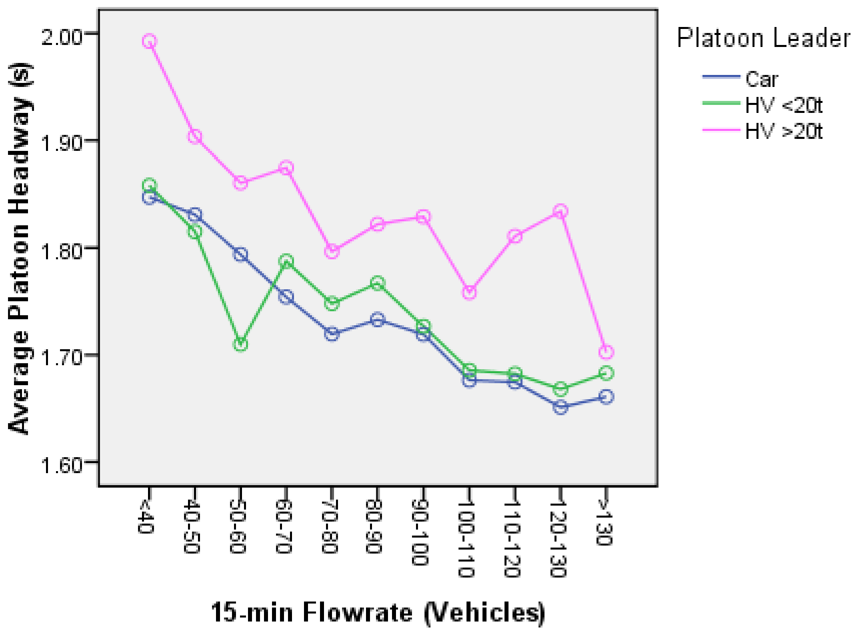


Figure 7. Average platoon headway corresponds to flow rate

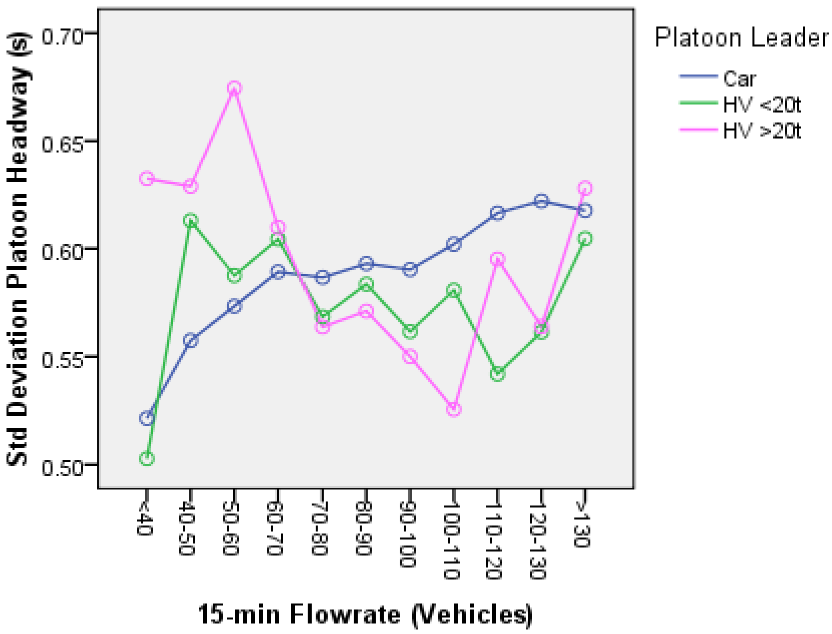


Figure 8. Standard deviation of platoon headway corresponds to flow rate

4. DISCUSSION

This study was designed to investigate the following vehicle driver behavior within platoons for different types of platoon leader. The results discovers that time headway is significantly influenced by both flow rate and type of platoon leader. The average platoon headway for Case 3 are higher than Case 1 and Case 2, while the average platoon headway for both Case 1 and Case 2 follows similar pattern. Briefly, platoons led by heavy vehicle more than 20 tonnes possess higher average headway than platoon led by lighter vehicle.

Based on the results, the presence of heavy vehicle as a platoon leader slows down the platoon speed, increases speed variation, reducing road capacity, thus increases delays of vehicle traveling time. This is expected due to the dynamic limitation of heavy vehicle related to acceleration and braking function. Consequently, platoon drivers will decrease their speed to adjust to the speed of front vehicles and keeping longer time headway.

The result from this study is consistent with the past research (Sarvi and Ejtemai, 2011) where HV has been identified to have operating capabilities that inferior to those of PC, thus requiring longer headways. However, the effect of leading vehicle weight on platoon headway has not been addressed in past research. This may be due to limited measurement capabilities or lack of sufficient data.

There are two possible factors which influence the headway characteristics difference on Case 3 platoons involving both physical and psychological factors. First, the large size of heavy trucks limits drivers' vision which includes vehicles travel behind the truck, and further back in a platoon. Since the drivers' view is obstructed by large size of front vehicle, the drivers' view of the condition and geometry of roads ahead are also restricted. Therefore, they need safe headway so that they have sufficient time to react appropriately when unintentional situation occurs. Secondly, the behaviour of following drivers within a platoon when seeing a heavy truck leading the platoon ahead also affects the platoon headway characteristics. This is due to their understanding of the operation capabilities of heavy trucks related to acceleration and braking function. Most of the drivers notice that the heavier the load they carry, the longer the headway they need in order to have adequate stopping distance and to avoid rear-end collision. In addition, large trucks often have several blind spots due to parts of vehicle/load, and this includes behindhand the truck unless they are using mirror or on-board camera system. Although there are some drivers attempt to find the opportunity to overtake, empirical results show that they tend to keep further distance away from front vehicle in case of any emergency caused by the lead vehicles' actions.

The findings of this empirical study serve as initial guide and fundamental for road safety and driver behaviour researches. Heavy vehicles had been proved to cause a large impact on traffic flow, because of its large size and different operational capabilities (in terms of acceleration, deceleration, maneuver etc.). Therefore it will result in psychological and physical action effects on following vehicle drivers. It is believed that this study also benefits road safety policy. To overcome the problem caused by the platoon trap behind a heavy vehicle, improvements has to be made on road geometric design for safety purpose. First, the traffic flow for different direction needs to be seperated at accident prone area. In addition, an extra lane should be designed for overtaking, especially on steep road where most of heavy vehicles are moving at low pace. Another method includes sign installation to instruct heavy vehicle to drive at left-most lane,as in Malaysia case, except for those who tend to overtake. Through this method, vehicles with high speed have more opportunities to overtake the slow vehicles with better road traffic safety.

5. CONCLUSION

The research findings presented in this paper investigated platoon headway characteristics based on GVW of platoon leader. Real data set was collected on two-lane rural road by using developed WIM based traffic data collection system. The conclusion is drawn based on limited variables of interest in this study; the important findings are:

1. GVW of platoon leader is significantly influencing platoon headway characteristics.
2. The study confirmed that flow rate affects platoon headway distribution pattern.
3. It is proven that platoons led by heavy vehicles more than 20 tonnes posses larger platoon headway in average, compared to those being led by passenger cars and lighter truck.
4. The study provides an initial guide for further research on heavy vehicle influence on vehicle platoon, especially in road safety and driver behaviour researches.

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