MICROSCOPIC EFFECTS OF HEAVY VEHICLES ON CAR-FOLLOWING BEHAVIOR

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ABSTRACT

The proportion of heavy vehicles' in the road traffic stream has been growing rapidly all around the world. This growth is likely to continue. Heavy vehicles (HVs) have different physical and operational characteristics compared to passenger cars (PCs) which may influence the car-following behavior of surrounding traffic. Very few studies have considered the influence of heavy vehicle on the traffic steam. This is remiss since it may significantly influence the traffic flow characteristics in near future due to the increasing volumes of heavy vehicles. This study investigates the influence of heavy vehicle on car-following behavior of drivers at a microscopic level to improve the understanding of traffic behavior of heavy vehicles.

A rich trajectory data set is used in this study to explore the differences in drivers' following behaviour in the four car-following combinations. These combinations include car following car (C-C), car following heavy vehicle (C-H), heavy vehicle following car (H-C), and heavy vehicle following heavy vehicle (H-H).

The driver's reaction time, relative speed-space headway, and subject vehicle acceleration, were analyzed in this study. These analyses showed some fundamental differences during following behaviour when a heavy vehicle is either the subject or preceding vehicle.

This paper serves as initial guidance for heavy vehicle traffic characteristic studies. It highlights a need to develop a car-following model considering the different behavior for different combinations of vehicle class. Further, the results of this work could be of notable interest for researchers attempting to replicate heavy vehicle acceleration behaviour in micro-simulation models.

Keywords: Heavy vehicle, Car following, Truck, Heterogeneous Traffic

INTRODUCTION

Freight movement plays a key role in a nation's economy. Truck transport is the most common mode used to move freight in terms of shipment value and weight (BITRE 2008). The number of heavy vehicles on roads and their percentage in traffic flow has increased over the past decades all around the world and is likely to continue. For instance, the Bureau of Transport and Regional Economics (BTRE 2003) has predicted a growth of 24.7% of the kilometres travelled by all vehicles in Australian metropolitan areas by 2020. The same study predicted that the kilometres travelled by heavy vehicles will increase by 74% between 2003 and 2020. Conway (2005) stated that the proportion of heavy vehicles in Australia could increase to 30% of total vehicles in the morning peak and 20% in the afternoon peak on some freeways. NCHRP (2003) has predicted the volume of domestic freight in USA will increase by 87% between 1998 and 2020. Further, a significant portion of the total freight movements occurs within urban areas (Wright 2006 and Lake et al 2002) which makes the issue more crucial.

Heavy vehicles have different physical and operational characteristics than passenger cars. Their existence can therefore significantly influence the traffic stream characteristics (Daganzo and Laval, 2005). The different behaviour of heavy vehicle and passenger car drivers during lane changing manoeuvres was well-acknowledged in the literature (Aghabayk et al 2011). Further, the different longitudinal driving behavior to a large extent determines the distributions of speeds and densities across lanes which may lead to lane changes. The lane changing maneuvers of drivers may initiate several different types of instabilities in traffic flow because of their influence on the surrounding traffic (Ahn and Cassidy, 2007). The heterogeneity of traffic flow also influences instability propagation in the same lane (Hoogendoorn et al., 2007) as well as the capacity of the road (Sarvi and Kuwahara, 2007).

This study considers four car-following combinations: heavy vehicle following passenger car (H-C), passenger car following heavy vehicle (C-H), passenger car following passenger car (C-C), and heavy vehicle following another heavy vehicle (H-H). It used a real world data set (FHWA 2005) to explore the differences in drivers' car-following behaviour in a heterogeneous traffic stream.

The current study is structured as follow. The data sets used in the study are described in the next section. A detailed data analysis is presented next which consists of the driver's reaction time, relative speed-space headway, and subject vehicle acceleration. The paper is closed by providing some conclusions and further remarks.

DATA SET

The Federal Highway Administration (FHWA) has provided a trajectory data sets for some of the freeways and arterial roads in California (FHWA 2005, 2006). This data was created by Cambridge Systematics Incorporated for the Federal Highway Administration (FHWA) as a part of the Next Generation Simulation (NGSIM) project. The data analysed in this paper was collected from a segment of the Interstate 80 in San Francisco (I-80), California on April 13 2005. Seven video cameras were mounted on the top of a 30 story building (Pacific Park Plaza), located adjacent to the freeway (I-80). The cameras covered about 503 meters of the northbound direction of the freeway. Figure 1 shows a sketch of this site, including the on-ramp at Powell Street and the downstream off-ramp at Ashby Avenue.

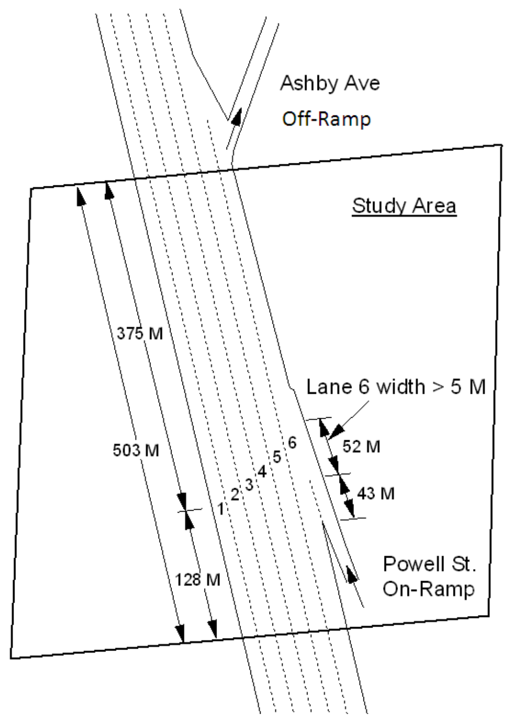

Figure 1 - The study area, Interstate Freeway 80 (I-80), California

Trajectory data sets were derived at the resolution of 1 tenth of second from image processing of the digital video images for three time periods. The time periods include: 4:00-4:15pm (I1), 5:00-5:15pm (I2), and 5:15-5:30pm (I3) all on April 13 2005. Vehicles have been classified using the FHWA vehicle classification (FHWA 2010) into three different types in the NGSIM data sets: motorcycles, automobiles and heavy vehicles. Exhaustive data processing was conducted and detailed data sets of the vehicle class, size (length and width), two-dimension position, velocity, acceleration and deceleration for all vehicles were derived. Each vehicle also has information on the preceding and following vehicle as well as their lane identification.

The position, velocity and acceleration of the vehicles in the NGSIM data sets have some noise. Thiemann et al (2008) reported such variations for all NGSIM data sets. To overcome this variation, positions, velocities and accelerations were smoothed in each 0.5, 1 and 4 seconds, respectively, by applying a moving average method. Table 1 and Table 2 respectively summarise the number of vehicles observed and the traffic flow information at the site during the three observation periods. The approach presented in the highway capacity manual (HCM 2000) was used to determine the level of service (LOS) of the site. It was found that the LOS was “E” and “F”. This means that the freeway is operating at capacity or even has more demand than its capacity which can cause a breakdown in vehicular flow.

Table 1 - Number of vehicles observed at the Interstate 80 site

	I1		I2		I3		Total	
Vehicle Type	**Num.**	**Percent.**	**Num.**	**Percent.**	**Num.**	**Percent.**	**Num.**	**Percent.**
Motorcycle	14	0.7 %	24	1.3 %	17	1.0 %	55	1.0 %
Passenger Car	1942	94.6 %	1742	94.9 %	1724	96.3 %	5408	95.2 %
Heavy Vehicle	96	4.7 %	70	3.8 %	49	2.7 %	215	3.8 %
Sum	2052	100 %	1836	100 %	1790	100 %	5678	100 %

Table 2 - Traffic flow information

Traffic flow information	I1	I2	I3	Total
Flow (veh/hr)	8436	7968	8028	8144
Space mean speed (km/hr)	32.2	28.7	25.2	28.7
Density (veh/km)	262	278	319	283

Microsoft Visual Studio was used to identify vehicle-following combinations. Heavy vehicles were identified first. The leader of each heavy vehicle was identified next. If the leader was also a heavy vehicle this case was considered a “H-H” case. If the leader was a passenger car, this case was considered a “H-C” case. The leader of each passenger car was determined next. If the leader was a heavy vehicle, this case was considered a “C-H” case. The other leaders of this passenger car were also determined. When they were also passenger cars, these cases were considered “C-C” cases. These vehicle pairs generated a considerable number of samples for each combination during car-following process as this process took a few seconds and each second produced 10 samples. Table 3 presents the number of sample size for each vehicle-following combination.

Table 3 - Number of samples for vehicle-following combinations

	I – 1	I - 2	I – 3	Total
Case	**Sample size**	**Sample size**	**Sample size**	**Sample size**
H-C	45255	50281	42011	137547
C-H	47692	51418	46613	145723
C-C	62465	56840	53322	172627
H-H	8722	4808	2142	15672

Figure 2 illustrates a typical example of the vehicle trajectories used in this study. The outcomes of the initial car-following behaviour analysis indicated that drivers show different following behaviour based on their vehicle and their front vehicle types. It was found that the headways vary in front of heavy vehicles (HVs) and passenger cars (PCs). Further, passenger cars tend to keep larger headways while following a heavy vehicle compared to that of following another passenger car. This led the authors to investigate the microscopic behaviour of drivers in different car-following combinations in details. The results of these investigations are presented below.

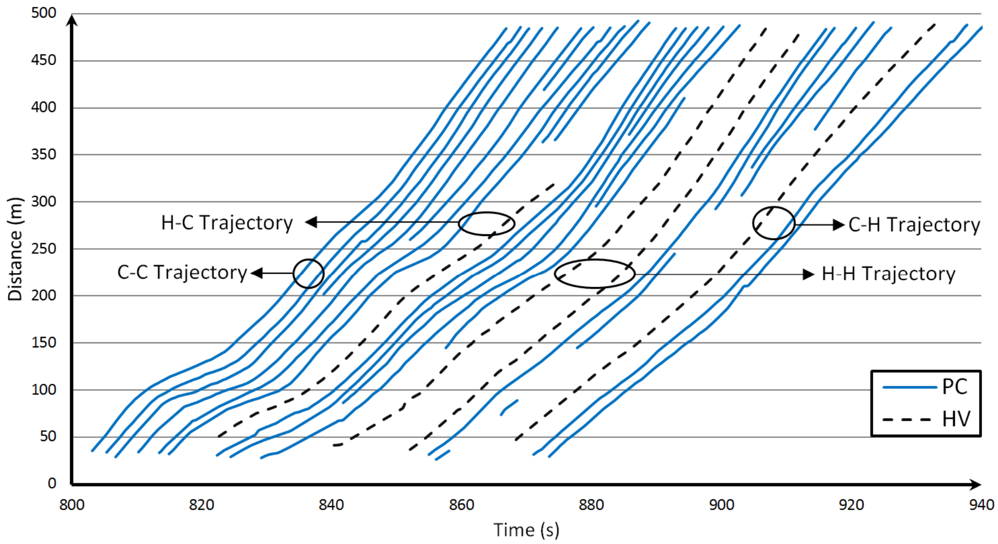

Figure 2 - A typical vehicle trajectories used in this study

DATA ANALYSIS

Reaction Time Analysis

The reaction time describes the period between the occurrence or appearance of a stimulus such as a speed difference, and the driver's reaction. In the car following process,

- the reaction can be the acceleration or deceleration of the subject (follower) vehicle and
- the stimulus can be define as the speed difference between the subject vehicle and its leader.

This section investigates the driver's reaction time for the four vehicle-following cases. The vehicle-following cases are "H-H", "H-C", "C-H" and "C-C" as explained above.

The reaction time of drivers was determined by using Equation 1. Indeed, the subject vehicle driver reacts after T seconds according to the relative speed between the subject vehicle and its leader.

$$a_n(t) \;\alpha\; \Delta v(t-T) \tag{1}$$

Where $\mathrm{a_n(t)}$ is the subject (follower) vehicle acceleration at time t,

$\Delta\mathrm{v}$ is the relative speed between the subject vehicle and its leader, and

T is the driver's reaction time.

Different values of T were tested between 0.1 second and 2.5 seconds. The strongest correlation between the subject vehicle acceleration, $\mathrm{a_n(t)}$, and the relative speed, Δv, was considered the reaction time.

Table 4 and Figure 3 show the correlation values for the "H-H" case. In Table 4 values are also provided for each of the three time periods: 4:00-4:15pm (I1), 5:00-5:15pm (I2), and 5:15-5:30pm (I3). Since the correlation is highest at 2 seconds, it can be concluded that the reaction time of a heavy vehicle driver is 2 seconds when following another heavy vehicle.

Table 4 - Correlations in the “H-H” case

Time	I1	I2	I3	Total
0.5	0.360	0.504	0.379	0.395
1.0	0.430	0.596	0.419	0.465
1.5	0.532	0.693	0.489	0.559
1.6	0.554	0.710	0.500	0.577
1.7	0.571	0.723	0.509	0.592
1.8	0.584	0.732	0.514	0.602
1.9	0.591	0.737	0.515	0.607
2.0	0.593	0.737	0.513	0.608
2.1	0.590	0.732	0.506	0.605
2.2	0.583	0.723	0.497	0.597
2.5	0.535	0.680	0.451	0.551

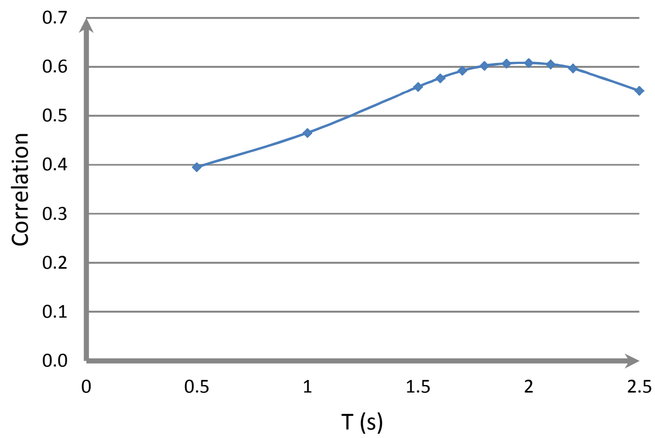

Figure 3 - Correlation between Acceleration and Relative velocity in the “H-H” case

Similar to what was explained for the “H-H” case, Tables 5 to 7 and Figures 4 to 6 are presented for the other cases. As can be seen different reaction times can be derived for each case. The reaction times for the “H-C”, “C-H” and “C-C” cases are respectively 1.9, 1.9 and 1.8 seconds. Table 8 summarises the reaction times for all vehicle-following combinations.

Table 5 - Correlations in the “H-C” case

Time	I1	I2	I3	Total
0.5	0.373	0.451	0.416	0.414
1.0	0.426	0.508	0.466	0.468
1.5	0.489	0.571	0.517	0.527
1.6	0.500	0.582	0.526	0.538
1.7	0.508	0.591	0.533	0.546
1.8	0.513	0.596	0.537	0.551
1.9	0.514	0.598	0.538	0.552
2.0	0.511	0.596	0.535	0.550
2.1	0.505	0.591	0.529	0.544
2.2	0.495	0.582	0.519	0.534
2.5	0.449	0.541	0.473	0.490

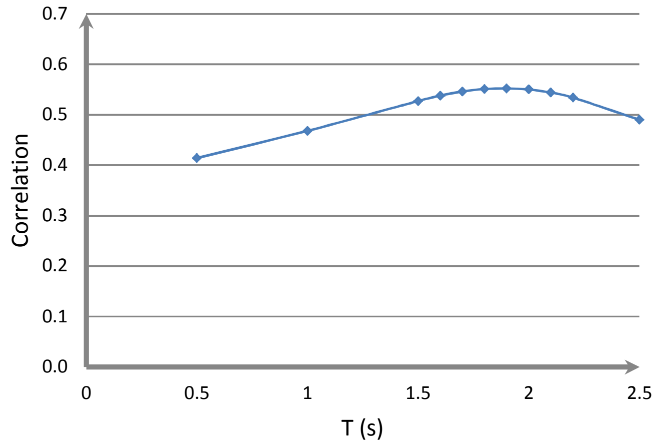

Figure 4 - Correlation between Acceleration and Relative velocity in the “H-C” case

Table 6 - Correlations in the “C-H” case

Time	I1	I2	I3	Total
0.5	0.341	0.429	0.442	0.402
1.0	0.413	0.501	0.516	0.474
1.5	0.496	0.581	0.593	0.554
1.6	0.511	0.595	0.606	0.568
1.7	0.521	0.606	0.615	0.578
1.8	0.527	0.612	0.619	0.584
1.9	0.529	0.614	0.619	0.585
2.0	0.525	0.611	0.614	0.581
2.1	0.518	0.603	0.605	0.573
2.2	0.506	0.591	0.592	0.561
2.5	0.448	0.532	0.531	0.502

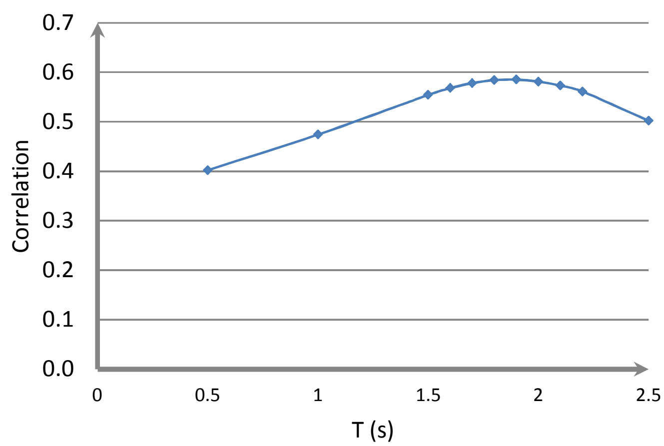

Figure 5 - Correlation between Acceleration and Relative velocity in the “C-H” case

Table 7 - Correlations in the “C-C” case

Time	I1	I2	I3	Total
0.5	0.403	0.432	0.461	0.426
1.0	0.461	0.499	0.520	0.488
1.5	0.523	0.567	0.577	0.550
1.6	0.534	0.578	0.586	0.560
1.7	0.541	0.587	0.592	0.567
1.8	0.544	0.592	0.594	0.571
1.9	0.543	0.593	0.591	0.570
2.0	0.539	0.590	0.584	0.566
2.1	0.532	0.582	0.573	0.558
2.2	0.520	0.571	0.557	0.545
2.5	0.469	0.519	0.491	0.490

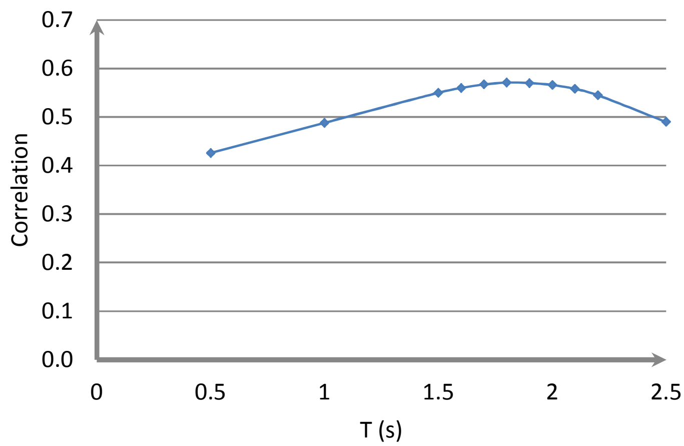

Figure 6 - Correlation between Acceleration and Relative velocity in the “C-C” case

Table 8 - Reaction times in different vehicle-following combinations

Case	H-H	H-C	C-H	C-C
Reaction time	2.0 (s)	1.9 (s)	1.9 (s)	1.8 (s)

Relative Speed-Space Headway Analysis

The relation between relative speed and space headway between two successive vehicles involving in a following process was considered in this section. The relative speed was defined as the speed of the lead vehicle minus the speed of the following/subject vehicle. The space headway was defined as the distance between the front to front bumpers of the two vehicles. Figure 7 shows the relation of relative speed and space among the four car-following combinations. The graphs have been plotted using the same scale to accommodate visual comparison. The vertical axis shows the relative speed (Δv) and the horizontal axis shows the space headway (Δx) between the two vehicles.

The Figure shows that the range of Δv is much narrower in the “H-H” case compared to the other cases. The range is 11.5 m/s for the H-H case. This is less than half of the corresponding values for the other combinations. If the range is ranked from the smallest to the largest values, the result will be “H-H”, “C-H”, “C-C”, and “H-C”. This rank could be explained by the different behaviour of passenger car and heavy vehicle drivers. To explain this phenomenon, the relative speed definition should be recalled to highlight that the speed of the leader and consequently the leading vehicle behaviour could influence Δv. When a heavy vehicle driver is following another heavy vehicle, the Δv range is the least since the both drivers drive in a non-oscillation manner resulting in less speed variations among the two successive vehicles and cause small range in Δv. This might be associated to the fact that heavy vehicle drivers are trained and professional drivers and are able to drive in a much smoother manner. The next case is the "C-H" because the passenger car driver is following a heavy vehicle and although a passenger car driver tends to drive more aggressively/responsively compared to a heavy vehicle, the behaviour was limited by the lead heavy vehicle driver behaviour. Thus a large range cannot be seen compared to the remaining combinations. The finding indicates that the range is smaller when the lead vehicle is a heavy vehicle. However, the largest value of the Δv range is associated to the "H-C" case since the lead vehicle speed changes more often however, the heavy vehicle driver as the follower, does not react to the change in speed in the same rate as a passenger car driver.

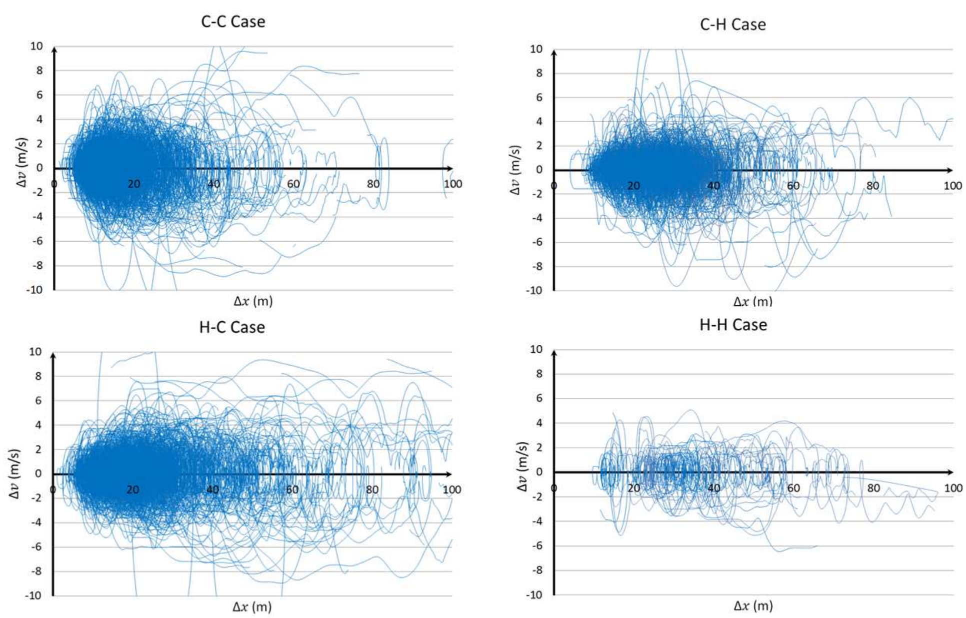

Figure 7- Relative speed-space graphs

The range of Δv could mostly be affected by instant responses and so can explain the immediate behaviour. The standard deviation of Δv can be also considered to explain the different behaviour of heavy vehicle and passenger car drivers during car-following process. However, the standard deviations may not be very different due to the congested traffic and steady state conditions used in this study. The findings show that the standard deviation of Δv is less when the leader is a heavy vehicle compared to passenger car. However the passenger car driver can adapt the speed faster than heavy vehicle driver as following another vehicle. This means that when the general process of car-following is considered, the "C-H" case will have the least variation and the "H-C" case will have the most variation in Δv among the other combinations (1.2m/s versus 1.6 m/s).

The variation of Δx is considerably smaller when the following vehicle is a passenger car rather than a heavy vehicle. The standard deviations of Δx for the "C-C", "C-H", "H-C", and

“H-H” cases are 9.3, 9.4, 16.5, and 14.7 meter respectively. This indicates that a passenger car driver is more responsive to the stimulus compared to a heavy vehicle driver and maintains the front gap as soon as possible.

Another support for the aforementioned conclusion may be obtained through considering a threshold of 30 meters for the Δx axis (Δx =30). The data shows that 93% of the space headways are less than 30 metres in the “C-C” case while this is only 39% in the “H-H” case. Further to have the same percentage of the “C-C” case (93%) in the “H-H” case, this threshold should move to 60 metres.

Acceleration Analysis

Heavy vehicle have a lower power to mass ratio than passenger cars (Ramsay 1998). They also have better sight distance than passenger cars due to the higher driver sitting positions. Because of these reasons it is expected that heavy vehicle apply lower acceleration than passenger cars. The results of acceleration analysis are presented in this section. In this section not only heavy vehicles and passenger cars are analysed as a following vehicles but also the impact of the leader type is explored. The same four vehicle-following combinations are considered.

The acceleration of the following vehicle was categorised with 0.1 m/s2 intervals. The range of acceleration across all vehicles was between -2 m/s2 and +2 m/s2. The number of observations in each acceleration category was calculated as a proportion of the total number of observations.

Figure 8 shows the proportion of observations in each acceleration group for in the “H-H” case. As expected, due to the central limit theorem, the acceleration distribution follows a normal distribution. The mean and the standard deviation of this distribution were 0 and 0.283 m/s2 respectively.

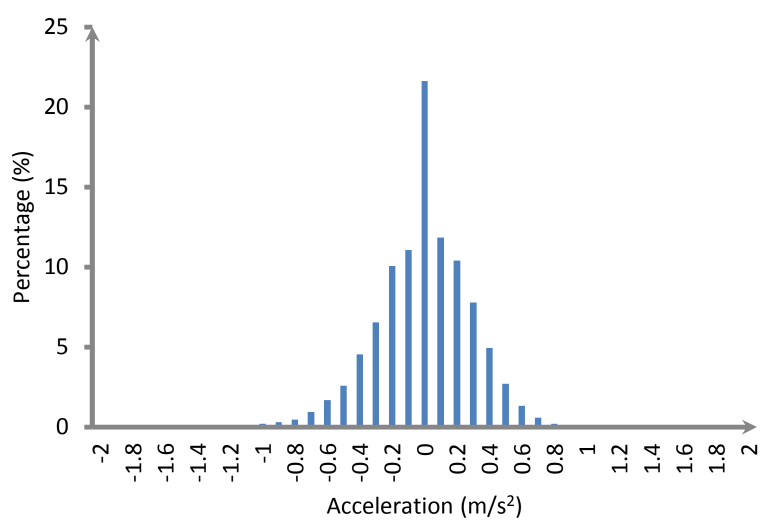

Figure 8 - Following vehicle acceleration in the “H-H” case

Figures 9 to 11 show the acceleration of the following vehicles for “H-C”, “C-H” and “C-C” cases respectively. The following vehicle accelerations in all cases are normally distributed with the mean of zero but with different standard deviations. The values are summarised in Table 9. The results indicate that the density function of the “H-H” case is the most concentrated one among the others. The standard deviation of this case is equal to 0.283 m/s2. This means that a heavy vehicle driver applies the lowest range of acceleration when following another heavy vehicle among the other combinations. According to the findings, the “H-C” case would be the second most clustered distribution with the standard distribution of 0.316 m/s2.

The flatness results from the data being less concentrated around its mean, due to large variations within observations. The most flat distribution would belong to the “C-C” case. The standard deviation of the accelerations used by the following vehicle is 0.376 for this case. The “C-H” case has the second most dispersed distribution amongst the combinations with the standard deviation of 0.335 m/s2.

The results show that the variation of accelerations is higher among the passenger car compare to heavy vehicles. This indicates that heavy vehicle drivers follow the preceding vehicle more sustainable than passenger car drivers. However, the type of the preceding vehicle also affects the acceleration rates of the following vehicle. When the leader is a heavy vehicle, the acceleration rate of the follower is lower.

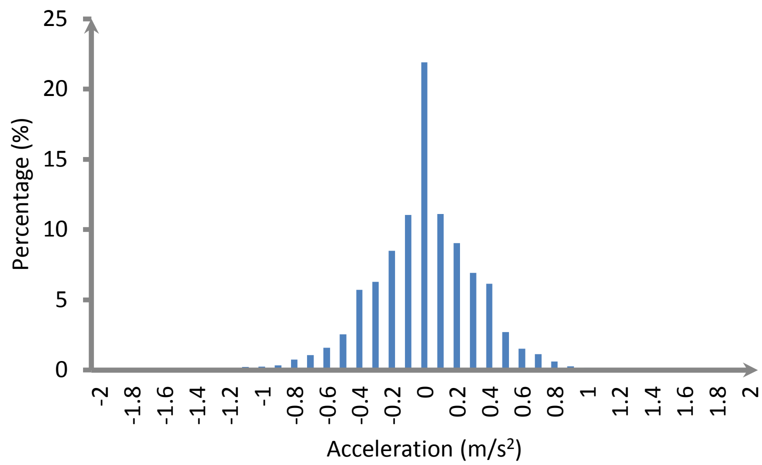

Figure 9 - Following vehicle acceleration in the “H-C” case

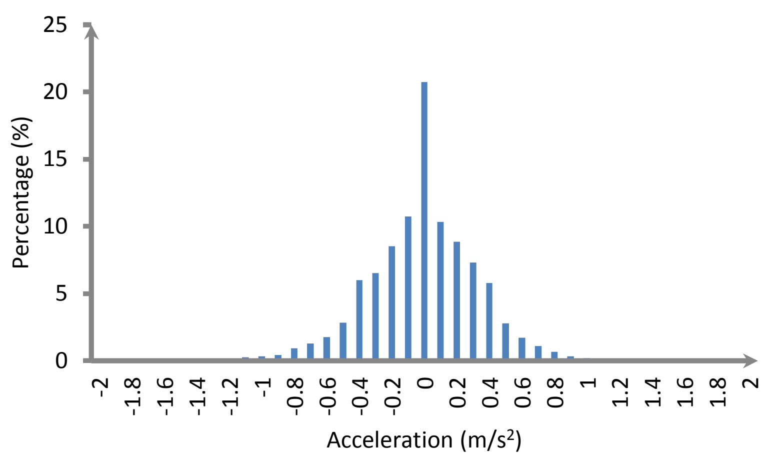

Figure 10 - Following vehicle acceleration in the “C-H” case

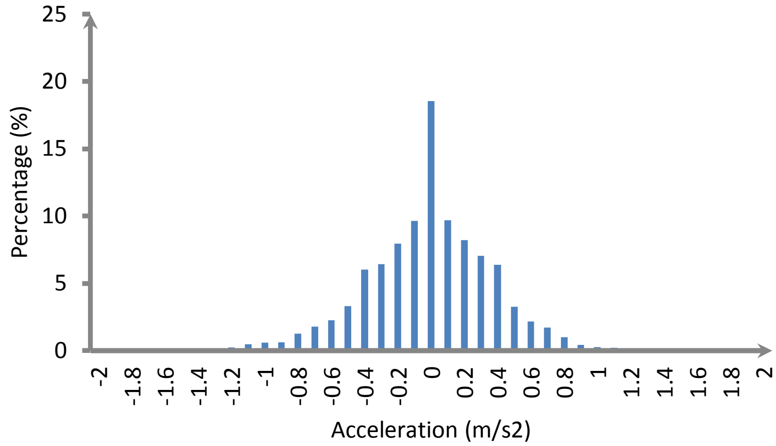

Figure 11 - Following vehicle acceleration in the “C-C” case

Table 9 - Acceleration means and standard deviations

Case	H-H	H-C	C-H	C-C
Mean	0	0	0	0
Standard Deviation	0.283	0.316	0.335	0.376

Any two successive distributions were tested by Two-sample Kolmogorov–Smirnov test in order to show they are statistically different (Table 10). The null hypothesis was that the distributions are the same and thus the alternative hypothesis indicated the difference. The test was conducted with 95% level of confidence and the results have been summarized in Table 10. Results showed that the null hypothesis should be rejected (K-S value >1.36). This indicates that the acceleration distributions are statistically different.

TABLE 10: Two-sample Kolmogorov–Smirnov test results

Hypothesis Case	Kolmogorov–Smirnov Values
H-H vs H-C	3.3
H-C vs C-H	4.7
C-H vs C-C	7.5

CONCLUSION

This paper used a real world data set to investigate the different car-following behaviour of divers in congested traffic condition. Four types of combinations were considered according to the classes of the subject vehicle and its leading vehicle. These include heavy vehicle following heavy vehicle (H-H), heavy vehicle following passenger car (H-C), passenger car following heavy vehicle (C-H) and passenger car following passenger car (C-C). The driver’s reaction time, relative speed-space headway, and subject vehicle acceleration during the following behavior were analyzed in this study. The results showed the fundamental difference amongst the combinations.

It was found that a heavy vehicle driver reacts to an action after 2 seconds when following another heavy vehicle. The reaction time would be 1/10 of second less if the driver follows a passenger car. A passenger car driver reacts to an action after 1.8 seconds when following another passenger car. This reaction time increases 1/10 of second when the passenger car driver follows a heavy vehicle.

The relative speed-space headway analysis was conducted to provide a comparison amongst the above-mentioned combinations in three aspects. The range and standard deviation of relative speed between the subject vehicle and its leader in each combination were compared. Further, the variation of space headway in front of the subject vehicle was carried out for different combinations. The results showed major difference amongst the combinations. For instance, the range of relative speed in the "H-H" case was around 50% lower than the values for the other vehicle combinations.

It was found that the accelerations applied by the subject vehicle drivers in all combinations are normally distributed but differ in terms of probability distribution functions. A heavy vehicle driver applied a lower acceleration and followed a leading vehicle smoother than a passenger car driver. It was found that the acceleration sequence from the "H-H" case to the "C-C" case is "H-H", "H-C", "C-H" and "C-C".

This study reported the microscopic differences among the four aforementioned car following combinations which could highlight the necessity of development of a model in which these dissimilarities could be addressed. The model could be in the interest of the traffic planer in order to replicate the traffic phenomena more accurate and reliable.

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