Australasian Transport Research Forum 2011 Proceedings
28 - 30 September 2011, Adelaide, Australia
Publication website: http://www.patrec.org/atrf.aspx

Exploring heavy vehicles car-following behaviour

Dr. Majid SARVI and Omid Ejtemai
Institute of Transport studies, Department of Civil Engineering, Building 60, Monash University 3800, Melbourne, Australia, Tel: +61-3-99059696, Fax: +61-3-99054944,

Majid.Sarvi@eng.monash.edu.au

Abstract

This work investigates the car-following behaviors of heavy vehicles and. Furthermore, a comprehensive comparison between heavy vehicles and passenger cars is presented. Freeways are designed to facilitate the flow of traffic including passenger cars and trucks. The impact of these different vehicle types is not uniform, creating problems in freeway operations and safety particularly under heavy demand with a high proportion of heavy vehicles. There have been very few studies concerned with the traffic behavior and characteristics of heavy vehicles in these situations. This study draws on extensive data collected over a long stretch of freeway using videotaping and surveys at several sites. The collected data were firstly used to study the interaction between heavy vehicles and passenger cars. The results showed a significant difference in the following behavior of heavy vehicles compared to other vehicles.

1. Introduction

Freight transport by road is growing rapidly all around the world. For instance, about 1553 million tones of freight are transported around Australia by road each year and truck traffic is forecast to double over the next 20 years. The volume of domestic freight in USA is projected to increase by 87% between 1998 and 2020. Freight within urban areas makes up a large portion of the total freight movements. Demands of freight and passenger traffic are often considered to be in competition, particularly on designated urban freight routes that use major freeways. The limited road space in urban areas is being called upon to service increasing volumes of both private and commercial traffic. Heavy commercial vehicles are known for their greater impacts on freeways capacity, freeways overall performance, and the delay experience by all vehicles compared to passenger cars. It is this effect of individual vehicle on the surrounding traffic that is most noticeable by the motoring public. The continued efficient movement of freight is a major concern since it can be linked to overall economic efficiency, employment and the affordability of consumer products. It is vital to examine how future main roads will handle the increasing number of heavy commercial vehicles. A higher level of understanding traffic behavior in the growing presence of large vehicles will assist to increase the efficiency of freeway network

Car-following behavior, which describes the processes by which drivers follow each other in the traffic stream, is an essential component in all microscopic simulation models. Several traffic simulation tools have been developed recently, such as AVENUE (2007), PARAMICS (2007), AIMSUN (2006), CORSIM (2003), MITSIM (Yang et al. 2000), VISSIM (2007). Nevertheless, several major problems including computational performance and the accuracy of models in representing the traffic flow has been reported (Skabardonis 1998). The interaction of cars and trucks and its influence on the traffic flow characteristics, as well as the following behavior of trucks (car-following) and its significant contributions to an understanding of traffic flow is a fundamental component of all network micro-simulation models. These interactions and following behaviors are even more significant, since they are directly related to the capacity of freeways, when traffic flow is congested. The difficulties of modeling freeway flow breakdown during congested conditions with the existing simulation models are well acknowledged (Hidas 2004). The traffic flow logic of existing simulation models does not differentiate between the car following behavior of passenger cars and heavy commercial vehicles.

Microscopic simulations may be capable of modeling freeway sections under low to moderate traffic flows when there are insignificant interactions between vehicles. In these situations, most of the available micro-simulation models simply use one of several simplistic assumptions including instantaneous lane changing, optimistic driver behavior under congested conditions, constant acceleration rates, or conventional follow the leader car-following models (Toledo 2007). However, the interactions between the heavy vehicles and the surrounding freeway drivers become even more important when traffic flow is close to the capacity. The complex acceleration characteristics of heavy vehicles drivers and the significant interactions of the heavy vehicles and freeway vehicles in the surrounding lanes are believed to play an important role in modeling freeway sections. The major limitation of existing microscopic simulation models is that they employ a global car following and lane changing model to capture acceleration characteristics of drivers in all driving situations (Panwai. S. and Dia 2005).

Few studies in the literature dealt with car-truck interactions (Dijiker et al. 2003, Peeta et al. 2004, Shahabuddin et al. 2001). These researches predominantly utilized the existing micro-simulations and simulators to explore whether the size of a lead vehicle affects the distance at which following vehicles travel. Shahabuddin et al. investigated the influence of differential speeds and accepted gaps on lane changing behavior in the presence or absence of large vehicles in the slow lane. Peeta et al. introduced a discomfort level for passenger cars in the vicinity of trucks to model the behavior of car drivers in the presence of heavy vehicles. Dijker et al. used loop detector data (speed, vehicle lengths, and time and space headways data were collected at one spot) to study the differences in car-following in different traffic regimes. Even if this study in part looked at the following behaviour of heavy vehicles however, due to the nature of the data used (collected through loop detector at one spot) it was not able to provide substantial insights to the dynamic nature of the following behaviour of heavy vehicles over a long stretch of the freeway.

The interaction between cars and heavy vehicles and its effects on the traffic flow characteristics and overall performance of the congested freeway sections utilizing real data over a long stretch of freeways are not considered in the previous studies. Additionally, all these studies were conducted in low to moderate traffic volumes thus, are not suitable to model congested traffic conditions.

In contrast, this work presents the details of the complex interactions of vehicles and presents a thorough methodology that could be used to model truck-following behavior under congested traffic flows. For this purpose, sets of data capturing a wide range of microscopic information were collected using video-recording and image processing techniques. The heavy vehicle's position in comparison to surrounding vehicles (e.g. freeway leader and lag vehicles) was analyzed. Additionally, heavy vehicle speed as well as relative speed, time gap, and space headway between a heavy vehicle and its corresponding leader and lag vehicles were also examined. The findings of this work may serve as initial guidance for modeling truck following behavior. These models could be used in micro-simulation tools to study the truck only lane/s strategy development as well as to study the safety aspect of the heavy vehicle traffic operations.

2. Data

In order to study the truck-following behavior under congested traffic conditions, traffic surveys were performed at two freeway sites in Tokyo and one freeway site in Melbourne. Traffic flow was recorded using several video cameras mounted on the top of the buildings in the vicinity of the sections. The video data were filmed using six cameras which were placed on the high vantage points. Cameras were placed in a consecutive arrangement, allowing a user to track a specific vehicle across that entire section of around 700m. A total of 6 hours of data were recorded at three sites. The tapes were first reviewed and a number of truck-car following identified. Each manoeuvre was analyzed in microscopic detail. The position and speed of each vehicle involved in the following manoeuvre were identified at 0.15 seconds interval using a frame by frame image processing technique. Through this microscopic analysis, time-series data of vehicle position, velocities, and accelerations were stored for 240 vehicles following behavior (120 heavy vehicle following car behavior and 120 car following car and heavy vehicle behavior). Unfortunately, there were not enough truck-following-truck cases in the analyzed videos to be included in this study. From the trajectory data, front and rear spacing, time headway, relative speeds, and accelerations of follower were analyzed. Basically, these variables must be closely related to each other, that is, follower vehicles would not consider only spacing or relative speeds but also the interrelationship among these variables, when they perform following behavior. The detail of microscopic analysis is given in Section 4. In this study heavy commercial vehicles are heavy vehicles with length longer than 10 metres.

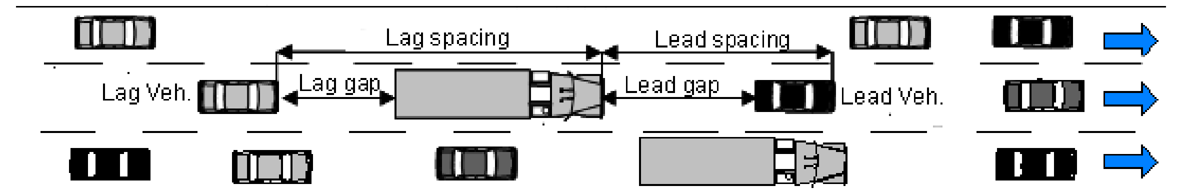
3. Truck-car interaction: A macroscopic view

The key terminologies and variables used in this study to describe the interactions during a heavy vehicle following behavior are shown in Figure 1. Important insights to the impact of vehicle interactions can be obtained by investigating the fundamental traffic flow characteristics such as time and distance headways. Various studies of car-following phenomena indicated that the lane changing are primarily made based on the distance headways between the lead and following vehicles in the target lane. Headway is not only a good measure of degree of congestion, it is also a good measure of safety as close following and lane changing may lead to conflicts and likelihood of crashes.

The literature provides conflicting insight into the car and truck following behaviour with counterintuitive cases reported where passenger car drivers maintain shorter gaps behind large vehicles than passenger cars. Using driving simulator and instrumented vehicles there were also evidence suggesting the gap length was shorter when following a simulated passenger car than a van or pickup truck.

A thorough headway analysis was conducted to determine the average headway values and their distributions. Three classes of interactions were analyzed separately for car-following-car, car-following-truck, and truck-following-car. The importance of the current research is that it provides a detail insight to the vehicles interactions and its possible contribution to a reduction in traffic throughput on highways, utilizing a direct observation of vehicle interaction over a long stretch of freeway. Figures 2 and 3 show the relationship between speed and average space and time headways measured through image processing technique at three studied sites. The space headway is measured from the rear bumper of the leader vehicle to the front bumper of the follower vehicle. Results show that cars travel further behind heavy vehicles (in time and space) than when following other cars. Similarly, compared to the car-following-car situation, heavy vehicles adopt longer time and distance headways when following other cars. In other words, the presence of heavy vehicles would increase the headway in the traffic stream, thus reducing the capacity of the lane and the total throughput of the freeway section. Figures 2 and 3 also show that time headways are shorter and space headways are larger at higher speeds for all observed classes of vehicles.

Figure 1. Truck following notation used in this study.



The cumulative distributions of following space headways are shown in Figure 4. The data suggest that car-following-truck headways are generally larger than all other headway categories while truck-following-car headways are larger than car-following-car headways. The values of median following headways are 20, 21 and 28 metres for car-following-car, truck-following-car, and car-following-truck respectively. It is noteworthy that heavy vehicles travel closer to cars than cars follow heavy vehicles. There are few heavy vehicles following below 12 metres while this is around 16 metres for cars following heavy vehicles.

Figure 2. Speed-spacing observed in real traffic.

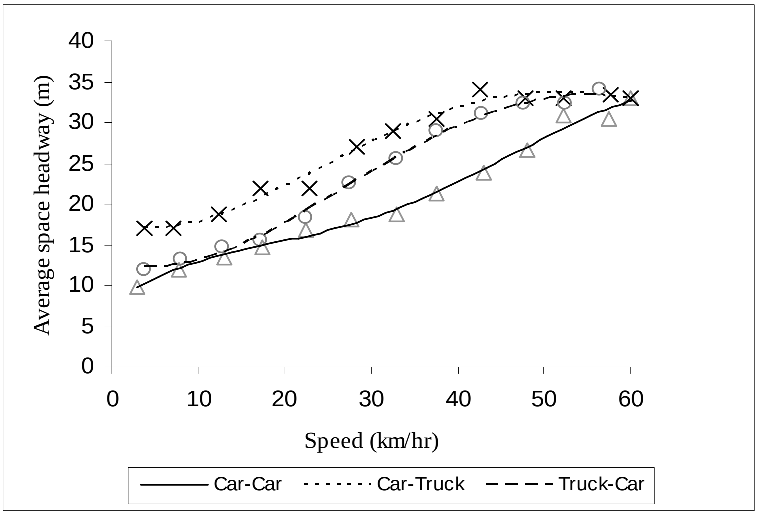


Figure 3. Speed-time headway observed in real traffic.

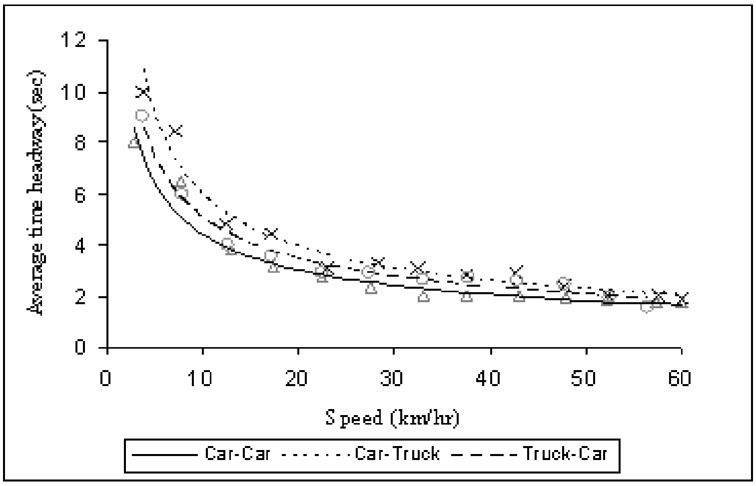


Figure 4. Cumulative following space-headway observed in real traffic.

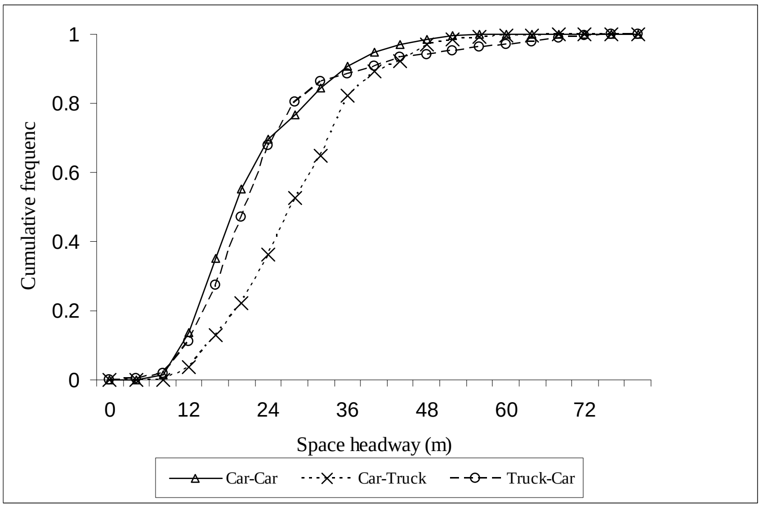
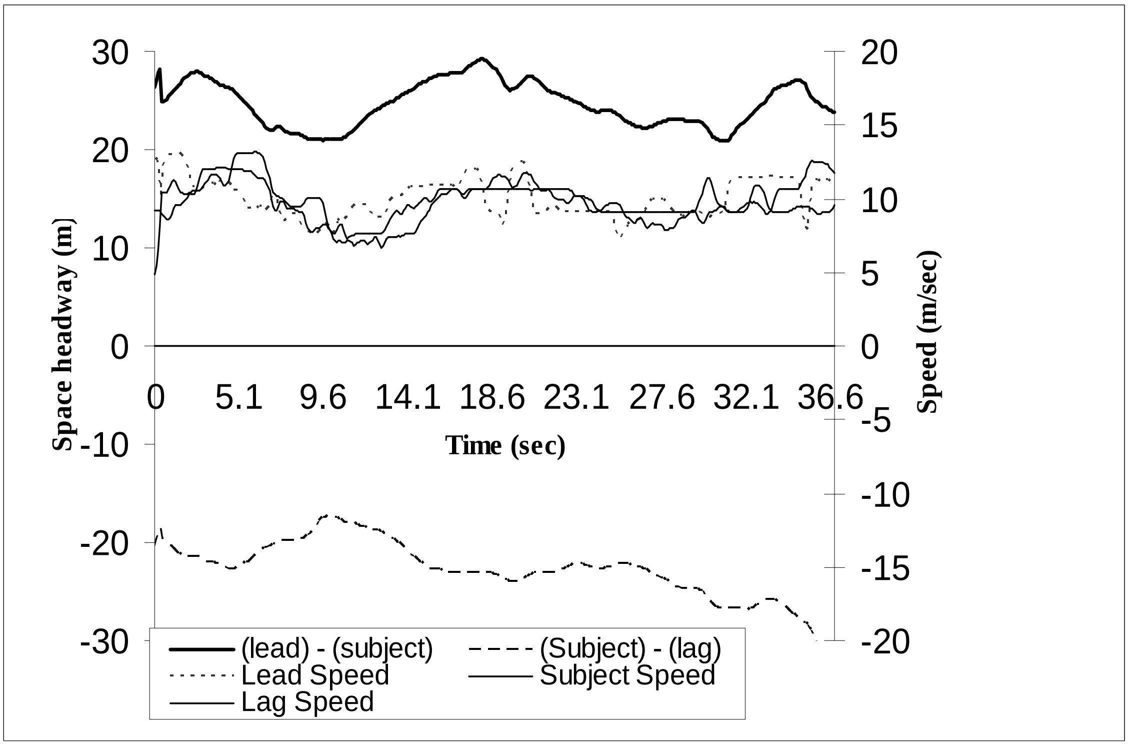


Figure 4 can be presented for different speed limit among various combination of vehicles however, since the date for different combination of vehicles are gathered from similar traffic volume and level of service it is reasonable to assume they have in general a comparable speed. In addition to the presented results, a hypothesis test was carried out to examine whether or not passenger car drivers adopt higher speed in the presence of heavy vehicle as follower. A two sample, one-tailed t test at 5% significance was conducted, when variance were assumed unknown and equal. The F test was carried out to check the equality of variances. From the t test, the t value for the difference in speeds is 2.26 and the table t value is 1.67 thus the null hypothesis is rejected. Therefore, the results indicate that there is enough statistical evidence to claim that passenger car drivers adopt higher speeds in the presence of heavy vehicle as follower.

4. Truck-car interaction: A microscopic view

This section examines the relative speed and spacing between the heavy vehicles and the leader and the lag vehicles traveling in the same lane based on 120 truck-following-car cases studied in this work. In order to study the truck-car following behavior under congested traffic conditions, each following case was analyzed in microscopic detail and the position and speed of each vehicle involved in the truck-car following cases were identified. Fig. 5 shows the positions of the leader and follower vehicles relative to the subject vehicle (i.e. the heavy vehicle in Figure 1), and the calculated speed of the three vehicles during a typical truck-car following. The calculated relative position of the subject vehicle is represented by the X-axis. The distance between the thick lines and the X-axis shows the space headway between the leader and the subject, and the subject and the follower vehicles. This figure clearly shows the detail of a typical truck-car following behavior. Therefore, this representation allows inspecting the interactions between the vehicles involved in the truck-car following in a microscopic scale. The X-axis itself shows the period of time during which these interactions are studies.

Figure 5. Relative vehicle positions and vehicles speed during truck-car following.



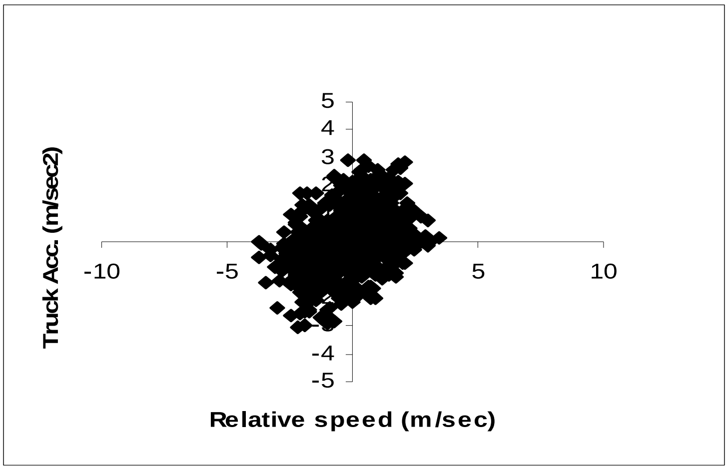
4.1. Relative speed between heavy vehicles and its corresponding freeway leader vehicles

Figure 6 shows the data between the heavy vehicle acceleration and its relative speed for heavy vehicles and freeway leader vehicles (Lead vehicle in Figure 1). The relative speed measured with respect to the freeway leader vehicles is defined as follows:

Relative Speed (Vfleadtruck) = freeway lead vehicle speed-heavy vehicle speed

Relative speed is one of the most important variables that affect the truck-car following behavior.
Based on Figure 6 when the speed of a heavy vehicle is lower than its freeway leader vehicle traveling in the same lane, a positive relative speed, the truck driver will accelerate and tries to minimize relative spacing. However, if the speed of a heavy vehicle is higher than its freeway leader vehicles (with a negative relative speed) it doesn't need to accelerate and consequently decelerates in order to avoid collision. The statistical test results presented in Table 1 indicate a significant result was obtained and a relationship is present (in other words, there is a significant relationship between the relative speed and the heavy vehicle acceleration).

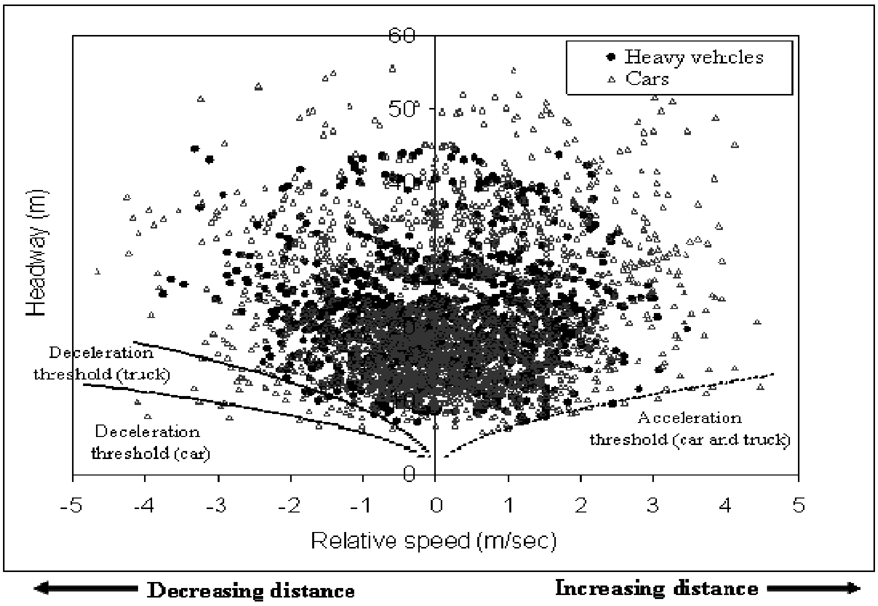
Figure 6. Heavy vehicle acceleration rate vs. relative speed for heavy vehicles and freeway leader vehicles.



4.2. Spacing between heavy vehicles and its corresponding freeway leader vehicles

Many studies used the relative distance and relative speed to establish a model for cars longitudinal movement (Todoseiv 1961). In order to investigate the heavy vehicles longitudinal movement in the truck-car following process the relative distance and relative speed of heavy vehicles and cars (measured with respect to the leader) are presented in Figure 7. Results suggest a significant difference in the following behavior of heavy vehicles compared to passenger cars. It is evident that in the decreasing distance regime (negative relative speed) for a given relative distance, heavy vehicle drivers keep a smaller relative speed compared to car drivers. In other words, in the car-following process, heavy vehicle drivers try to maintain longer distance headway to the vehicle in front compared to passenger cars. This is due to the lower acceleration-deceleration performance of heavy vehicles and partially due to the fact that most of the heavy vehicle drivers are professional drivers with relatively high driving skill who can subtly follow the front vehicle with less speed and distance oscillation from the front vehicle. Additionally, the majority of heavy vehicles do not travel with a relative speed higher than 2 m/sec (less than 5% having relative speed higher than 2 m/sec) while this is around 3m/sec (less than 7% having relative speed higher than 3 m/sec)   for passenger cars. The deceleration and acceleration thresholds when follower drivers notice that they are traveling faster or slower than the leading vehicles and start to decelerate or accelerate are presented in Figure 7 based on the observed data. By comparison, Figure 7 identifies that the deceleration threshold of heavy vehicles is located above the deceleration threshold of passenger cars while the acceleration threshold is identical for heavy vehicles and passenger cars.

Figure 7. Observed space headway as a function of relative speed.



Several previous studies assumed that the space headway (relative distance measured with respect to the leader) has a significant effect on the acceleration of the follower vehicle (Helly 1959, Parker 1996, 34). Several models were developed assuming that drivers try to attain some desired relative speed and space headway. In order to examine the impact of space headway on truck-car-following behavior the relation between space headway and heavy vehicles acceleration were examined. The distribution of the space headway of heavy vehicles (while involved in car-following) is shown in Figure 8.

Figure 8. Heavy vehicles acceleration rate vs. spacing between the freeway leader vehicles and heavy vehicles.

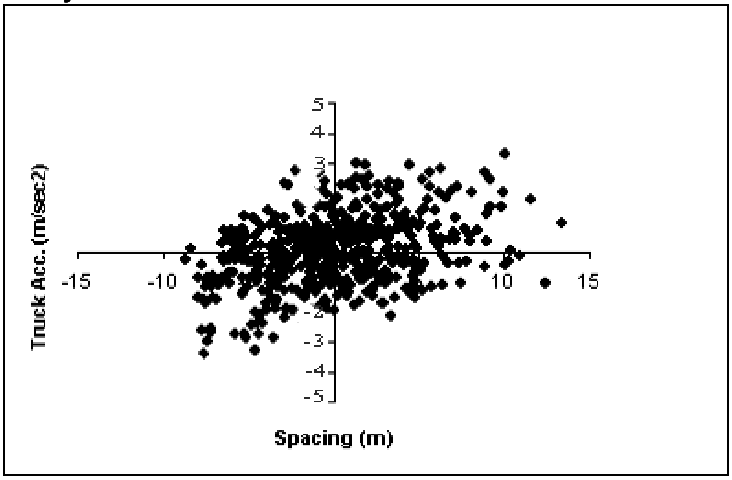


Figure 8 shows the relationship between the heavy vehicle acceleration and its spacing for freeway leader vehicles and heavy vehicles (Lead vehicle in Figure 1). The spacing (the direct distance between the front bumper of the heavy vehicle and the front bumper of the lead vehicle) measured with respect to the heavy vehicles is defined as follows:

Spacing (Sfleadtruck) = (Spacing between the freeway lead vehicle and heavy vehicle) - (Desired spacing as a function of speed)

Figure 8 represents a spring action of spacing in which the follower accelerates is drawn ahead when the spacing is larger than the desired value. In other words, if the heavy vehicle driver feels unsatisfied with his spacing, too long or too short, this will inspire him to drive faster or slower to keep or recover the comfortable spacing desired. In this study the desired spacing is referred to as the “spacing”, which is a function of the speed and is obtained by fitting a parabolic curve to the observed speed of heavy vehicles and the space between the heavy vehicle and its corresponding freeway leader vehicles. The statistical test results shown in Table 1 confirm the existence of a relationship. In a comparative sense the slope of the presented trend between relative speed and heavy vehicle acceleration in Figure 7 is sharper than the slope of the trend between the spacing and the acceleration presented in Figure 8.

Table 1. Summary results of relationship significance tests.

Parameter	**Calculated *t* statistic**	**Critical p value (5% significance level)**	**conclusion**
	slope		
Relative speed between freeway leader and heavy vehicle	6.23	8.22E-10	Highly significant
Spacing between freeway leader and heavy vehicle	3.31	6E-04	Highly significant

5. Concusions

This study investigated the effects of heavy commercial vehicles on the capacity and overall performance of congested freeway sections. Additionally, the following behaviors of heavy commercial vehicles and its comparison with passenger cars were explored. Comprehensive microscopic observations at three sites collected over a long stretch of freeway provided a sound and robust database for performing traffic characteristics analysis of heavy vehicle in terms of the interaction between heavy commercial vehicles and other class of vehicles.

Results suggested that passenger cars travel further behind heavy vehicles (in time and space) than when following other passenger cars. Similarly, compared to the car-following-car situation, heavy vehicles adopt longer time and distance headways when following other vehicles. The presence of heavy vehicles would increase the headway in the traffic stream, thus reducing the capacity of the lane and the total throughput of the freeway section. It has been shown that time headways are shorter and space headways are larger at higher speeds for all observed classes of vehicles. The cumulative distributions of following space headways showed that the values of median following headways are 20, 21, and 28 metres for car-following-car, truck-following-car, and car-following-truck respectively. It is noteworthy that heavy vehicles travel closer to passenger cars than cars follow heavy vehicles. This could be of relevant implication to the accurate calculation of Passenger Car Equivalents (PCEs) factors. Through a hypothesis test it was shown that there is enough statistical evidence to claim that passenger car drivers adopt higher speeds in the presence of heavy vehicle as follower.

Through image processing technique the following behavior of 120 heavy vehicles were analyzed to provide a thorough understanding of heavy vehicles following behavior process. Results showed a significant difference in the following behavior of heavy vehicles compared to other vehicles. It was evident that in the decreasing distance regime for a given relative distance, heavy vehicle drivers keep a smaller relative speed compared to passenger car drivers.

Due to the limited number of study sites used in this study the conclusions drawn from this work are tentative. However, the results of this study could serve as initial guidance for modeling freeway heavy commercial vehicles following process. Further, the results of this work could be of notable interest for researchers attempting to replicate heavy vehicle acceleration behavior in micro-simulation models. The effects of heavy vehicles on the car-following behavior of passenger cars are also very important in order to constitute a complete picture of driver interaction behavior under congested traffic conditions. This will be considered and investigated in the next phase of this research project.

References

Avenue User Manual, V4, Tokyo, Japan (2007).

AIMSUN user manual, V5.1.3 (2006).

Advanced CORSIM training manual, SEH No. A-MNDOT0318.00, (2003).

Duncan, G.I., "PARAMICS wide area microscopic simulation of ATT and traffic management". In: 28th ISATA Conference, Stuttgart, Germany (1995).

E. P., Todoseiv., " The action point model of the driver-vehicle-system, The Ohio State University Report 202, A3 (1963).

M. T. Parker, "The effect of heavy goods vehicles and following behaviour on capacity at motorway roadwork sites," Traffic Eng. Control, vol. 37, no. 9, pp. 524–531, (1996)

M., Shahb Uddin and S., Ardekani. "An observational study of lane changing on basic freeway segment" Transportation Research Board 81st Annual Meeting (2001)

P, Hidas. "A functional evaluation of microsimulation models", CAITER conference, Melbourne, Australia (2004)

Panwai. S. and Dia, H., "Comparative evaluation of microscopic car-following behavior". IEEE Transaction on intelligent transportation systems, Vol. 6, No.3, 314-325 (2005).

Skabardonis, A., May, A. "Simulation models for freeway corridors: state-of-the art and research needs". Transportation Research Board 77th annual meeting, Washington, DC (1998).

S., Peeta, W., Zhou and p., Zhang. "Modeling and mitigation of car-truck interactions on freeways", Transportation Research Record No. 1899, p. 117-126, (2004).

T., Toledo and Z., David "Modeling the Duration of Lane Changes" Transportation Research Board 86th Annual Meeting (2007).

T., Dijker, P., Bovy, and R., Vermijs. "Car-Following Under Congested Conditions, Empirical Findings", Transportation Research Record No. 1644, p. 20-28, (1998).

VISSIM User Manual Version 5, PTV AG, Karlsruhe, Germany, (2007).

W. Helly, "Simulation of bottlenecks in single lane traffic flow," in Symp. Theory Traffic Flow, Research Laboratories, General Motors, New York, pp. 207–238 (1959).

Yang, Q., Koutsopoulos, H.N. , and Ben-Akiva, M. "A Simulation Laboratory for Evaluating Dynamic Traffic Management Systems". Transportation Research Record, No. 1710, pp 122-130 (2000).