UNDERSTANDING DIFFERENCES BETWEEN CAR AND TRUCK MOVEMENTS ON FREEWAYS USING VEHICLE TRAJECTORY DATA

Umair Durrani, Chris Lee and Hanna Maoh, University of Windsor

Background

Transport Canada in its 2011 report predicts a continued and rapid growth in the freight transportation in Canada over the next several years. The main carriers of freight are heavy vehicles. They have a different set of operational characteristics (acceleration/ deceleration capabilities) and act as a visual obstruction for passenger cars resulting in complex interactions in the heterogeneous traffic which significantly affect the capacity of a roadway.

Apart from the characteristics of vehicles, the behavior of drivers is a key factor in determining the overall performance of a roadway. The distribution of driver behavior is characterized by factors like aggression, perception-reaction capabilities, etc. However, it is very difficult to model these factors as they represent the hidden variable reactions of drivers in different conditions of weather, time of day and traffic congestion (Peeta, Zhang, & Zhou, 2004).

In order to improve the traffic flow and safety, it is fundamental to understand the nature of interaction between cars and trucks and how they affect overall traffic performance. Since late fifties, analysts have tried to understand this relationship and developed models to explain them. Research studies have shown that cars keep more gap (space headways) from trucks than other cars (Peeta, Zhang, & Zhou, 2004) and trucks also maintain wider headways when following a passenger car (Punzo & Tripodi, 2007). The stopping distance as perceived by different drivers lead them to adopt different gaps between their vehicle and leading vehicle (Gowri, Venkatesan, & Sivanandan, 2009; Ravishankar & Mathew, 2011). Aghabayk et. al (2012) used vehicle trajectory dataset of Interstate-80 in US, developed by Cambridge Systems Inc. for Next Generation Simulation (NGSIM) program for the time slot of 4:00 pm to 5:30 pm divided into three 15-minute periods. Analyses was done on space headways, time headways, driver reaction time and following vehicle acceleration for four vehicle following combinations: Heavy vehicle following passenger car (H-C), Car following heavy vehicle (C-H), Car following car (C-C), and Heavy vehicle following heavy vehicle (H-H). The research concluded that the presence of heavy vehicle, its length, power-to-mass ratio of vehicles and sight distances were the factors for different headways, reaction times and acceleration rates applied by vehicles while following others. The headway between H-H was highest and between C-C was lowest with H-C and C-H in between. In addition, the passenger car driver reacted after 1.8 s while following another car and 1/10 of a second more when followed heavy vehicle. On the other hand, heavy vehicle driver reacted after 2 s while following another heavy vehicle and 1/10 of a second less while following a car. Furthermore, it was found that heavy vehicles drove smoothly and applied less acceleration rates compared to passenger cars. However, there has been no implementation of the model in any microscopic traffic simulation. Some analysts have approached the problem of car-truck interaction on freeways by quantifying a *discomfort level* in the car drivers in the presence of trucks. They used fuzzy logic models to incorporate this behavioral factor (Peeta, Zhang, & Zhou, 2004).

Similar studies have shown that lane changing characteristics are also different for cars and trucks (Moridpour, Sarvi, Rose, & Mazloumi, 2012). There are two types of lane changing maneuvers: necessary lane change and discretionary lane change. Moridpour et al. (2012) used US-101 and I-80 datasets of NGSIM to develop a lane-changing model using fuzzy logic modeling and analyzed different scenarios of truck lane use restrictions. Later, the developed model was implemented in VISSIM and calibrated with field data to find the driver behavior parameters that would render close-to-field conditions. According to this research, there are 3 differences in the reasons for lane changing between heavy vehicles and cars. Firstly, the heavy vehicles mostly change the lane to move to slower one whereas cars move to faster lanes. Secondly, heavy vehicle drivers get motivated to change the lane because of a faster moving following vehicle and he doesn't want to obstruct that, while car drivers usually have slower vehicles ahead in the same lane which motivates them to move to a faster lane. And finally, heavy vehicles have slower speeds while cars have faster speed while change of lane (Moridpour et al., 2012). Two models were developed: lane changing to faster lanes and lane changing to slower lanes and only discretionary lane change maneuvers were considered. It was found in VISSIM output that traffic volumes and average speeds as given by new model were more accurate than default VISSIM model. The authors concluded that using the default models was not a valid approach when heterogeneous traffic conditions exist (Moridpour et al., 2012). This study, however, did not develop an exclusive car following model but rather relied on calibration of driver behavior parameters.

With the advent of simulation software, it became easier to test the models without doing huge and expensive field tests. The provision of vehicle trajectory datasets by Federal Highway Administration (FHWA), U.S DOT under its Next Generation Simulation (NGSIM) project and modeling efforts, several models were developed to represent the vehicle following and lane changing processes in car-truck mixed traffic.

VISSIM is a stochastic, time-step, microsimulation modelling software that uses a psycho-physical car following model to simulate the driver behavior (PTV Vision, 2012). The term psycho-physical is used for these models because they consider both the psychological (perception-reaction thresholds, unintentional car-following, etc) and physical behaviors (acceleration rates, etc) in the model. The modeling process assumed both spacing and relative velocity (difference between velocities of a vehicle and its preceding vehicle) to be decision factors for drivers for the application of acceleration/ deceleration. Whenever a certain threshold of relative speed and/or spacing (action points) is exceeded, considering the visual angle subtended by the lead vehicle, the subject driver is supposed to respond by braking or speeding (Michaels, 1963 and Lee & Jones, 1967). Wiedemann (1974) was the first to combine different thresholds and developed four different driving regimes: free flow, approaching, following and decelerating (Wiedemann & Reiter, 1974). VISSIM uses the Wiedemann 99 model as the car-following logic to simulate the behavioral interaction among vehicles on freeways. This model uses ten car-following parameters which control different aspects of vehicle acceleration, safety distances, etc. The lane change parameters are comprised of lane change distance i.e. the distance from a routing decision to begin attempting the lane change, acceleration and deceleration characteristics of vehicles in car following regime and the measure of cooperation between vehicles in lane changing maneuver and in the destination lane. Some of the car following parameters also control the lane change behavior in VISSIM so it is important to effectively modify both models to accurately match the observed conditions.

This study focuses on the analysis of the observed data on different locations of US-101 dataset provided by NGSIM. The goal of this paper is to present the difference in truck and car following behavior in terms of speeds, headway and spacing with the recommendations on modification of driving behavior parameters in VISSIM to represent observed conditions.

Study Area and Data set

Next Generation Simulation (NGSIM) project is an initiative taken by FHWA, US DOT to develop driver behavioral algorithms in order to enhance the current microscopic simulation modelling. NGSIM website provides detailed vehicle trajectory data sets for a few arterial roads and freeways in California. The data analyzed in this study was collected from a segment of southbound US-101, also known as Hollywood Freeway, in Los Angeles, CA on June 15, 2005. Eight synchronized video cameras mounted at the top of an adjacent 36-story building recorded the traffic moving over different sections of approximately 640m-long study area. The freeway consists of five lanes in the mainline along with an auxiliary lane between the on-ramp at Ventura Boulevard and off-ramp at Cahuenga Boulevard (Figure 1**Error! Reference source not found.**). The lane numbering starts from the left-most lane and lane # 6 is the auxiliary lane.

Trajectory data were extracted at the resolution of 0.1 seconds resulting in precise lane positions and locations of vehicles relative to other vehicles. The data sets were divided into three 15-minute time periods: 7:50-8:05 am (t1), 8:05-8:20 am (t2) and 8:20-8:35 am (t3).

The first data set represents the build-up of congestion and the other two represent congested conditions on the freeway.

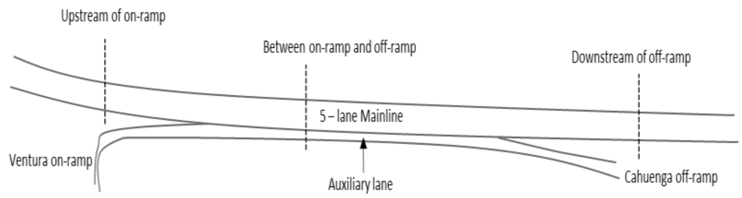

Figure 1 Study Area

The observed vehicles have been classified into automobiles, motorcycles and heavy vehicles (trucks & buses) using FHWA classification system. In addition to positions, each vehicle in the data sets has information about the preceding and following vehicles, speeds, accelerations/ decelerations, time and space headways, vehicle dimensions and lane identification.

According to Thiemann et al. (2008), there is some noise in the vehicle velocity data in all NGSIM data sets. The probability density function of vehicle velocities was plotted and was found to have spikes. This means that drivers always accelerated or decelerated to exact same velocities, which is unrealistic. Symmetric exponential moving average was applied in each second of velocity data to remove the data noise. All later analyses were performed using the smoothed data sets.

Data Analyses

Lane-by-lane analysis

Average spot speeds and vehicle counts were observed over 15-minute period for the three locations - upstream of the on-ramp, between the ramps and downstream of the off-ramp (Figure 1). It was found from all trajectory data sets (transition period and congested conditions) that both cars and heavy vehicles' speeds were lowest at the locations upstream of the on-ramp. The speeds gradually increase towards the downstream sections to about 30 mph on freeway downstream of off-ramp. Table 1 shows the volume and average speed of cars by lane and Table 2 shows the same for trucks (and buses) for the built-up of congestion period (t1). The volume of trucks was very low in all time periods (≈ 2.6 %) and for the first two time periods (t1 and t2) no trucks were observed in lane # 2. Figure 2 and Figure 3 show the average speeds by lane for cars and trucks respectively for the third time period (t3) representing congestion. As before, the speeds of cars increased significantly in the downstream section in all lanes compared to upstream of the on-ramp location. This trend was similar in heavy vehicles, however, they had quite different speeds across the lanes. Trucks moved with higher speeds in left-most (1) and right most (5) lanes and had lower speeds in lanes in between.

Table 1 Average Speed of Cars by Lane (7:50 – 8:05 am)

	Upstream of on-ramp		**Between on-ramp and off-ramp**		**Downstream of off-ramp**	
Lane #	**Vol**	**Speed (mph)**	**Vol**	**Speed (mph)**	**Vol**	**Speed (mph)**
1	366	20.44	372	22.43	375	30.93
2	420	21.65	419	24.58	436	33.82
3	393	22.48	397	24.86	412	32.86
4	378	23.71	377	26.25	395	33.64
5	395	25.00	367	28.43	395	34.29
6 (Auxiliary lane)			154	35.59		

Table 2 Average Speed of Trucks by Lane (7:50 – 8:05 am)

	Upstream		**Between ramps**		**Downstream**	
Lane #	**Vol**	**Speed (mph)**	**Vol**	**Speed (mph)**	**Vol**	**Speed (mph)**
1	1	30.29	1	21.42	1	28.97
3	15	23.56	15	25.52	12	34.34
4	23	23.3	22	27.65	20	33.86
5	14	23.55	12	24.86	19	34.27
6 (Auxiliary lane)			3	31.23		

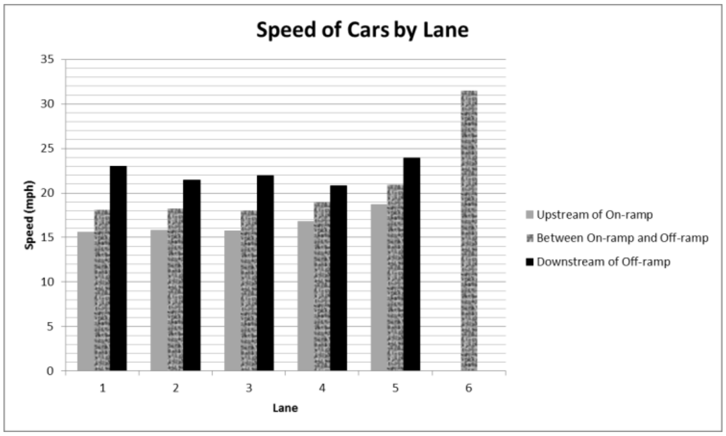

Figure 2 Average Speed of Cars by Lane (8:20 - 8:35 am)

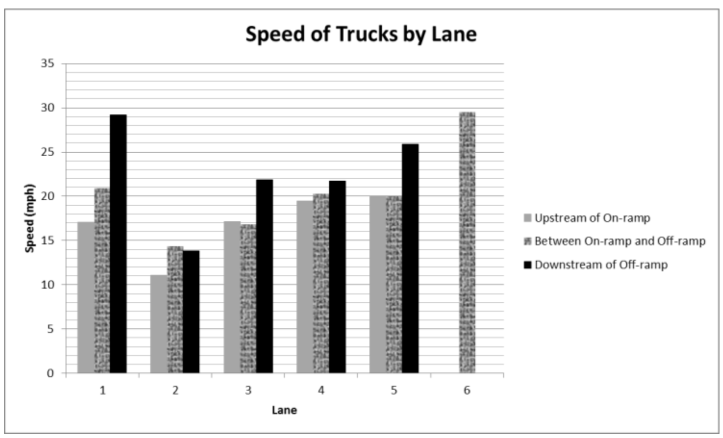

Figure 3 Average Speed of Trucks by Lane (8:20 - 8:35 am)

Spacing and Headway Analyses

To investigate the interaction among different combinations of vehicles, the trajectory data were divided into the following four combinations: car following car (cc), car following truck (ct), truck following car (tc) and truck following truck (tt). For every pair of vehicles, the speed of subject vehicle was divided into intervals of 5 km/hr. The averages of spacing and headway were computed in each 5-km/hr interval and plotted against the median of each interval. These plots were created for all three time periods. The number of pairs of each vehicle following combination and sample size of spacing or headway is given in Table 3.

Table 3 Vehicle Pairs and Sample Size

	7:50 - 8:05 am		**8:05 - 8:20 am**		**8:20 - 8:35 am**	
Case	**# of Pairs**	**Sample size**	**# of Pairs**	**Sample size**	**# of Pairs**	**Sample size**
cc	2060	968155	1937	1209363	1842	1322475
ct	118	20985	75	25142	65	28537
tc	53	20978	43	23983	40	27745
tt	7	1276	1	350	1	179

Analysis of Spacing

The spacing (or space headway) is defined as the distance in meters between the front end of subject vehicle and front end of the preceding vehicle. Figure 4 shows the spacing in meters between different vehicle combinations for all time periods. In general, cars kept smaller spacing when they followed cars, and trucks kept higher spacing when they followed trucks. This could be attributed to the size of the vehicles which make drivers less or more cautious of their proximity to preceding vehicle. However, there is a large variation in spacing in tt case which is closely observed by plotting the spacing for three time periods (Figure 5). This variation might have occurred because of the level of congestion at different time periods which influenced the truck driver behavior significantly. During the first time period, t1, conditions were not congested and drivers tend to keep shorter spacing but later the speeds reduced and drivers tend to have more spacing at t2 and significant reduction in spacing at highly congested conditions, t3

At lower speeds the spacing in ct case was higher than spacing in tc case but after the subject vehicle's speed of 30 km/hr trucks kept more spacing behind cars compared to the spacing between cars (subject) and trucks (preceding) as shown in figure 4.

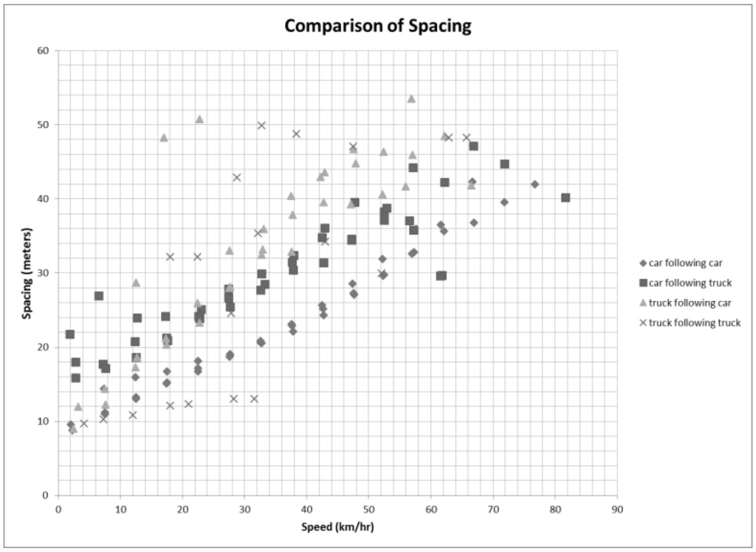

Figure 4 Comparison of Spacing

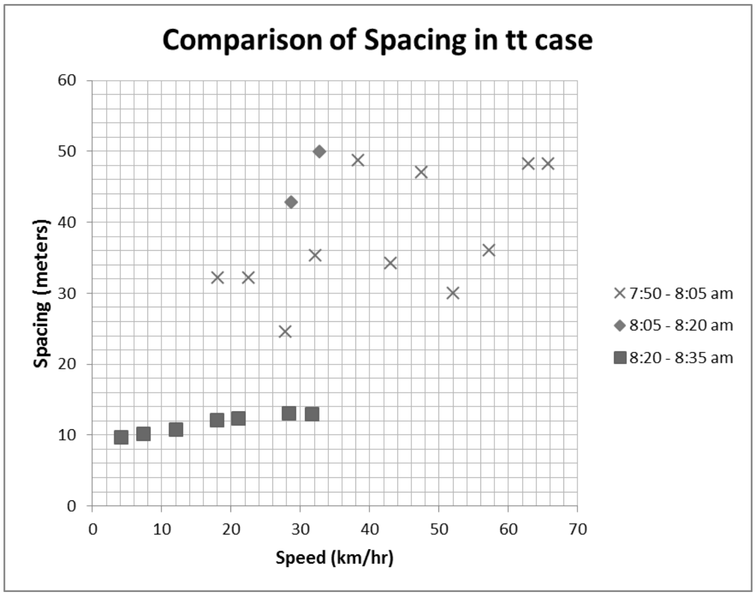

Figure 5 Comparison of Spacing in Truck following Truck

Analysis of Headway

The headway (or time headway) is defined as the time in seconds to travel from the front end of subject vehicle to the front end of the preceding vehicle. Figure 6 shows the headways for all combinations of vehicles for all times. In general, the tt case had highest headways and cc case the lowest which indicate that there is significant difference in the vehicle following behavior between the two subject vehicles. Again, the headways in tt case were quite different in different time periods which were further explored in Figure 7. The variation occurred due to speed difference in different time periods. Both during high and low speed ranges (time periods t1 and t3), headway decreased from about 8 to 2 seconds as speed of subject vehicle increases. Close to peak conditions, t2, the headway had an average value of about 6 seconds.

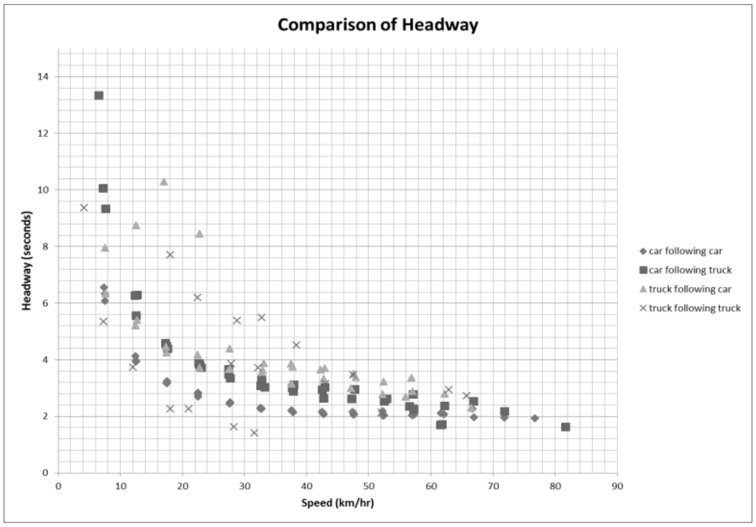

Figure 6 Comparison of Headways

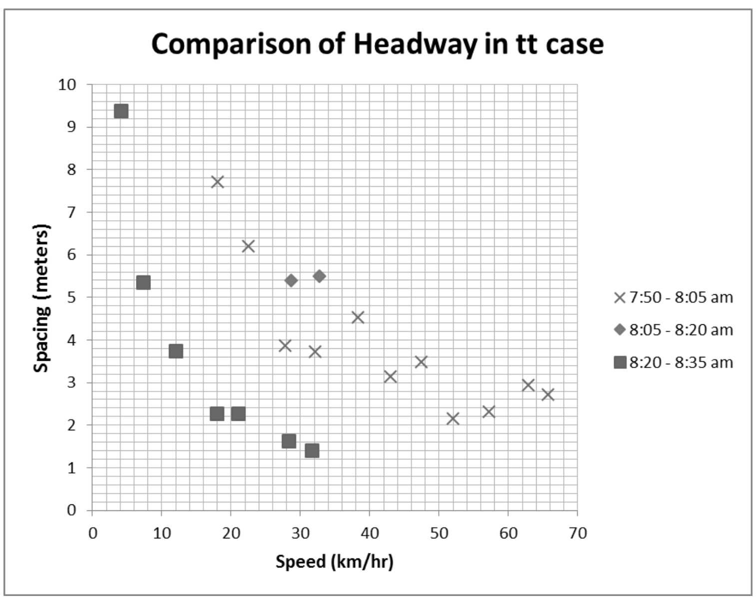

Figure 7 Comparison of Headway in Truck following Truck

Conclusions and Recommendations

Vehicle trajectory data for three time periods representing transition to congestion and congested conditions on US-101 were analyzed. Lane–by-lane analysis at the upstream of on ramp, between the two ramps and downstream of off ramp showed that average speeds by lane were quite similar for trucks and cars due to congestion effect.

Spacing and headway analyses were performed for four combinations of vehicle following pairs. It was found that cars kept smaller spacing while following cars and trucks kept higher spacing while following trucks. At lower speeds cars kept more spacing behind trucks compared to trucks' spacing behind cars but after the speed of 30 km/hr of subject vehicle reverse was true. Similar trend was observed in headway comparison where cc case had lowest headway and tt case had highest headway of the four cases. It can be said that the trucks significantly affect the capacity of roadways as different spacing and headway were observed at different regimes of speed.

To accurately simulate the observed traffic in a microscopic traffic simulation model like VISSIM, it is recommended to further explore the differences in acceleration and deceleration characteristics between cars and trucks and reflect these properties in the 'Lane change' parameters in driving behavior window. These parameters are used to calibrate the aggressiveness of drivers and cooperation to lane change. In addition to this, the car following parameters which control the safety distance between vehicles and sensitivity to acceleration / deceleration of preceding vehicles should be modified to reflect the difference between car and truck movements.

References

Aghabayk, K., Sarvi, M., & Young, W. (2012). Understanding the Dynamics of Heavy Vehicle Interactions in Car-Following. *Journal of Transportation Engineering, 138(12), 1468-1475*.

Gowri, A., Venkatesan, K., & Sivanandan, R. (2009). Object-oriented methodology for intersection simulation model under heterogenous traffic conditions. *Advances in Engineering Software, 1000-1010*.

Michaels, R. (1963). Perceptual factors in car following. *Proceedings of the Second International Symposium on the Theory of Road Traffic Flow, pp. 44-59*.

Moridpour, S., Sarvi, M., Rose, G., & Mazloumi, E. (2012). Lane-Changing Decision Model for Heavy Vehicle. *Journal of Intelligent Transportation Systems: Technology, Planning, and Operations*, *16:1, 24-35*.

Peeta, S., Zhang, P., & Zhou, W. (2004). Behavior-based analysis of freeway car–truck interactions. *ELSEVIER and Transportation Research Part B 39 (2005) 417–451*.

PTV Vision (2012). VISSIM 5.40 - User Manual, *Karlsruhe: PTV Planung Transport Verkehr AG.*

Punzo, V., & Tripodi, A. (2007). Steady-state solutions and multiclass calibration of gipps microscopic traffic flow model. *Transportation Research Board*, 104-114.

Ravishankar, K., & Mathew, T. V. (2011). Vehicle-Type Dependent Car-Following Model for Heterogenous Traffic Conditions. *American Society of Civil Engineers Transp. Eng., 137(11)*, 775–781.

Wiedemann, D. -I. R. & Reiter, D.-I. U. (1974). Microscopic Traffic Simulation: The Simulation System MISSION Background and Actual State.