

# Variables influencing lane changing behaviour of heavy vehicles

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## 1 Introduction

Lane changing manoeuvres have a fundamental impact on macroscopic and microscopic characteristics of traffic flows due to their interfering effect on surrounding traffic (Daganzo *et al.*, 1999; Mauch and Cassidy, 2002; Sasoh and Ohara, 2002; Uddin and Ardekani, 2002; Chen *et al.*, 2004; Al-Kaisy and Jung, 2005). The interference effect of lane changing is more significant during the lane changing manoeuvres of heavy vehicles. Heavy vehicles impose physical and psychological effects on surrounding traffic (Uddin and Ardekani, 2002; Al-Kaisy and Hall, 2003; Al-Kaisy and Jung, 2005). These effects are the result of two main factors: the physical characteristics of heavy vehicles (e.g. length and size) and their operational characteristics (e.g. acceleration, deceleration and manoeuvrability).

The number of heavy vehicles increased dramatically over the past three decades and this trend is likely to continue over the next decade (BTS, 2002). In Australia, the national capital city freight task is forecast to increase by 50% between 2006 and 2020 (Wright, 2006). However, previous lane changing studies are mainly associated with passenger cars. Despite the importance of increasing numbers of heavy vehicles on freeways, the heavy vehicles lane changing manoeuvre has received little attention.

In order to develop a heavy vehicle lane changing model, it is important to identify the explanatory factors which cause lane changing manoeuvres. Heavy vehicle lane changing models can be applied in variety of traffic and transportation studies including the development of traffic management policies and lane use management and lane use restriction strategies. Design and assessment of traffic policies and lane use restriction strategies is very difficult in real transportation networks due to the cost and risks of field trials. Therefore, microscopic traffic simulations are used to evaluate new policies and strategies. Due to the increasing reliance on microscopic traffic simulations, it is important to improve their accuracy in modelling drivers' decisions. One of the essential components of any microscopic traffic simulation is lane changing models. Therefore, developing a more accurate lane changing model is an important priority in model development.

Lane changing manoeuvres can be divided into three sequential stages: the motivation to change lanes, the selection of a lane to change into and the execution of the lane change. The first two stages constitute the lane changing decision and the final stage is associated with the lane changing performance. The aim of this research is to investigate the explanatory factors in lane changing decisions of heavy vehicles in motorways using detailed vehicle trajectory data under congested traffic conditions. Therefore, the important factors which motivate the heavy vehicle drivers to change lanes are investigated first. Then, the factors which appear to influence the choice of a lane to change into are considered.

This paper is structured as follows. In the next section, the literature on lane changing models is reviewed and summarised. The following section presents the trajectory data used in this study. It is followed by an examination of the explanatory factors in different stages of heavy vehicles lane changing decisions. The final section summarises the findings and conclusions of the paper and identifies directions for model development research.

## 2 Literature review

Gipps (1986) proposed a model for the structure of lane changing decisions. This model is useful to explain the lane changing decision in freeways and also urban streets where traffic signals, obstructions and heavy vehicles influence the decision procedure. In Gipps' model, a driver's decision to change lanes is the result of considering three factors: whether it is physically possible and safe to change lanes, whether it is necessary to change lanes and whether it is desirable to change lanes. He defined three zones to characterise the drivers' decisions during the lane changing manoeuvre which are based on the distance to the intended turn.

Gipps' lane changing model has been applied in several microscopic traffic simulations. Despite, the popularity of his lane changing model, like all models, it is based on some simplifying assumptions. The lane changing occurs when a gap of sufficient length is available and it is safe to change lanes. However, this assumption may cause some limitations in congested traffic conditions where appropriate gaps are rarely available and they are created by either the lag vehicles' courtesy or the subject vehicles' forcing. In addition, in Gipps' model, zones are defined deterministically and the differences between drivers and the differences within drivers over time have not been considered.

Ahmed (1999) developed a probabilistic model to describe drivers' lane changing decisions, based on discrete choice framework. He modelled the lane changing decision as a sequence of three stages: decision to consider a lane change, choice of the target lane and acceptance of a sufficient size gap in the target lane. He defined three categories of lane changing movements: Mandatory Lane Changing (MLC), Discretionary Lane Changing (DLC) and forced merging. MLC happens when drivers leave the current lane due to reasons such as taking an exit off-ramp. DLC occurs when drivers want to gain some speed advantages. Forced merging occurs in heavily congested traffic conditions, when a gap of sufficient size is 'created' by drivers to enable them to change lanes.

Ahmed's lane changing model captures the differences between drivers' lane changing decision in MLC, DLC and forced merging. However, this model is unable to capture the trade off between the MLC and DLC decision process. Ahmed's model, like Gipps' model, assumes that the existence of the MLC situation is based on the distance to the exit off-ramp. In addition, the difference between the lane changing decision of heavy vehicles and passenger cars is only considered through a dummy variable for subject heavy vehicles. The dummy variable for subject heavy vehicles has a significant t-statistic value only in the DLC model. The dummy variable only captures the difference in the size of the acceptable gap between a passenger car and a heavy vehicle. This is a very coarse and simplistic way to account for the differences in operational characteristics of these two types of vehicles.

Brackstone *et al.* (1998) and Wu *et al.* (2000) developed a fuzzy logic motorway simulation model (FLOWSIM). They established fuzzy sets and systems for the motorway driving decision model. To model the lane changing decision, they classified the lane changing manoeuvres into two different categories: lane changing to the near side and lane changing to the off side. Lane changing to the near side is mainly performed to prevent disturbing the fast moving vehicles which approach from the rear. Lane changing to the off side lane is mainly performed with the aim of getting speed advantages. Two variables are used in their near side lane changing model: pressure from rear and gap satisfaction in the nearside lane. Pressure from rear is measured as the time headway of the following vehicle(s) and gap satisfaction is measured by the period of time that it would be possible for the vehicle to stay in the gap in the near side lane without reducing speed. To establish the offside lane changing model they defined two variables: overtaking benefit and opportunity. The overtaking benefit is the speed gained when an offside lane change is performed. The opportunity is the time headway to the first lag vehicle in the offside lane. They showed that

fuzzy logic can be successfully used to describe driver's lane changing decisions in a situation where appropriate motorway data can be collected.

Hidas (2002; 2005) developed a lane changing behaviour model which considers the courtesy of the lag vehicle in the target lane during the MLC. Considering the different interaction types among the subject vehicle and the target lag vehicle and also the gap between the lead and lag vehicles in the target lane, Hidas defined a three type classification of the lane changing decisions: free lane changes, forced lane changes and cooperative lane changes. In free lane changes, there is no observable difference in the space between the lead and lag vehicles in the target lane during the lane changing manoeuvre. In forced lane changes the space between the lead and lag vehicles decreases before the start of lane changing and increases after that. Cooperative lane changes have a reverse pattern with respect to the forced lane changing decision.

Hidas assumed that a lane changing manoeuvre is feasible if there is a gap of sufficient size for the driver in the target lane. The driver can move into the target lane without forcing the vehicles in the target lane to slow down significantly. In addition, the lane changing is feasible if the deceleration or acceleration required for the subject vehicle to move behind the new leader is acceptable and at the same time the deceleration required for the new follower to allow the subject vehicle to move into the target lane is sufficient. His lane changing behaviour model was implemented in a microscopic traffic simulation model, called ARTEMiS. Then, the effects of the lane change model on both microscopic traffic characteristics (individual vehicles) and macroscopic traffic characteristics (the relationship between average speed and flow rate) were compared to real microscopic and macroscopic traffic characteristics respectively.

Toledo (2003) developed an integrated probabilistic lane changing model which allows drivers to consider both MLC and DLC at the same time. He used a discrete choice framework to model the lane changing decision process and developed a probabilistic lane changing model. In his model, the lane changing decision is considered to comprise two steps: first, choice of the target lane and second, the gap acceptance decision. Toledo used a four group classification of the explanatory variables underlying lane changing decisions: neighbourhood variables, path plan variables, network knowledge and driving style.

In Toledo's model, after selecting the target lane and finding a gap of sufficient size, the drivers perform a sequence of accelerations and decelerations in order to move into the target gap. In addition, he developed a three stage model of acceleration behaviour for the subject vehicle to select the target gap. First, an acceleration model is applied for the time that the subject vehicle wishes to stay in the current lane. Second, an acceleration model which is applied when the subject vehicle performs a lane changing manoeuvre to the gap which is alongside the subject vehicle. Third, an acceleration model which is used when the subject vehicle accelerates or decelerates in order to move into the target gap which is not directly alongside the subject vehicle.

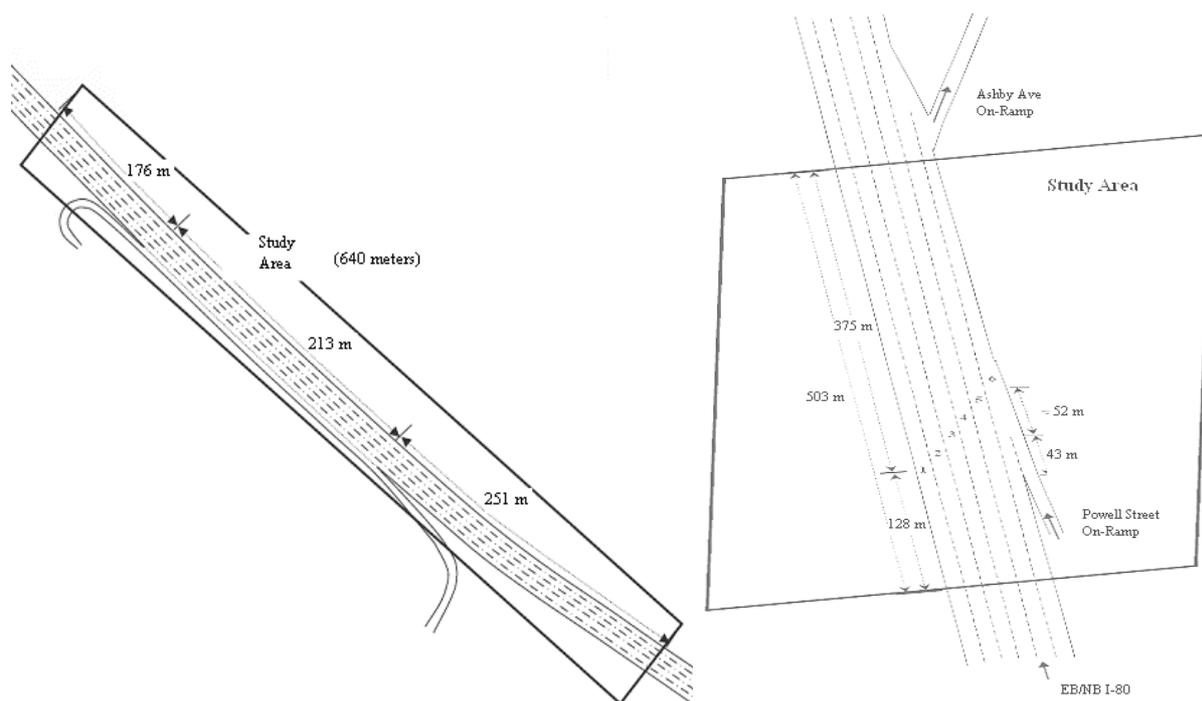
Reviewing the literature, it was found that previous lane changing studies are mainly associated with passenger cars. Despite the importance of increasing numbers of heavy vehicles on freeways and the differences in physical and operational characteristics of heavy vehicles and passenger cars, the heavy vehicles lane changing manoeuvre has received little attention.

### 3 Trajectory dataset

The trajectory data set which is used in this study was prepared by Cambridge Systematics (2005a;b) for the Federal Highway Administration (FHWA) as a part of Next Generation SIMulation (NGSIM) project. In December 2005, NGSIM provided the video images of two highways in California, namely Hollywood Freeway (US-101) and Berkeley Highway (I-80). Then, the video images were processed and the vehicle trajectory data was provided from the video images.

The section considered on US-101 (see Figure 1 left) is 640 metres long and it has five main lanes with one auxiliary lane. The speed limit in this section is 90 km/h. (FHWA, 2005). Eight stations were used to cover the site and the data was collected from 7:50 to 8:30 a.m. with a video capture rate of 10 frames per second. This site has one on-ramp and one off-ramp exit. The map of this site and the surrounding area shows that there is no other on-ramp or off-ramp in the near upstream or downstream sides of the study area which would influence traffic flow conditions or drivers' decisions.

The section of I-80 (see Figure 1 right) is 503 metres long and it has five main lanes with one auxiliary lane (FHWA, 2005). The speed limit in this section is 90 km/h. Seven video cameras covered this site and the data were collected from 4:00 to 4:15 p.m. and 5:00 to 5:30 p.m., again using a video capture rate of 10 frames per second. There is one on-ramp in this study area and one exit off-ramp in the downstream part of this study area. Similar to US-101, there are no other on-ramps or off-ramps, either immediately upstream or downstream of the study area, which would be expected to affect the traffic flow conditions or drivers' decisions.



**Figure 1 – The studied areas used in the trajectory dataset: Freeway US-101 (left) and Highway I-80 (right).**

NGSIM has classified vehicles as motorcycles, automobiles and heavy vehicles. The details of the composition of the traffic, along with macroscopic traffic flow parameters for each study area are shown in Table 1.

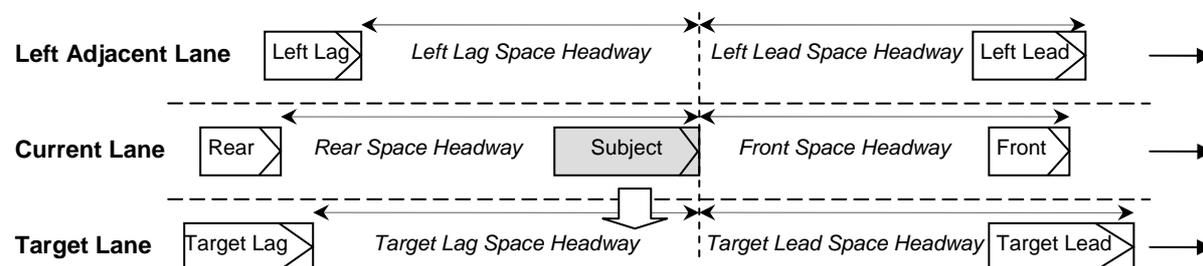
**Table 1 – The distribution of different vehicle types in each study area.**

Site Name	Motorcycles	Automobile	Heavy Vehicles	Flow (veh/h)	Speed (km/h)	Density (v/km)
US-101	45 (0.7%)	5919 (97.0%)	137 (2.2%)	8612	41.30	209
I-80	55 (1.5%)	5,408 (95.2%)	215 (3.8%)	8144	28.74	283
<b>Total</b>	<b>100 (0.8%)</b>	<b>11,327 (96.2%)</b>	<b>352 (3.0%)</b>	<b>8378</b>	<b>35.02</b>	<b>239</b>

In order to determine the exact number of lane changing manoeuvres in the large dataset for each study area, a program was written in Visual Basic. The program determines all heavy vehicles which perform a lane changing manoeuvre. The heavy vehicle lane changing manoeuvres obtained from the program were compared with the video images and the incorrect lane changing manoeuvres were eliminated. There were 15 successful lane changing manoeuvres in US-101 and 27 successful lane changing manoeuvres in I-80.

#### 4 Analysis of the Lane Changing Decisions

A lane changing decision can be divided into two stages: being motivated to change lanes and the selection of which lane to move to. In this section, the explanatory factors in these two stages of heavy vehicles lane changing decisions are investigated separately. The detailed trajectory data used in this study provides very rich information on the subject heavy vehicle (which is to perform the lane change) and the surrounding traffic. Figure 2 shows the vehicles for which, information would typically be available during the lane changing event. The trajectory dataset makes it possible to determine all relevant positions, space headways, speeds and accelerations, at discrete time points throughout the analysis period.



**Figure 2 – Identification of reference vehicles in lane changing decision analysis (lane change to right).**

The explanatory factors which are investigated in this study include the speeds and accelerations of the reference vehicles which are shown in Figure 2 and the space headways and relative speeds of those vehicles respect to the subject vehicle. Through statistical analysis, it was found that these explanatory factors in lane changing decision are normally distributed. Therefore, with a confidence level of 95%, the intervals for some of these explanatory factors are calculated which are presented in Table 2.

In order to investigate the explanatory factors in the lane changing decision process of heavy vehicles, the lane changing events are analysed from several seconds before the start of lane changing until several seconds after the end of the lane changing event. The start and end of the lane changing event are the times that the lateral movements of the subject vehicle are initiated and finished respectively. To reduce complexity and aid comprehension, all the figures in the following subsections are based on the values of the explanatory variables at the start of the lane changing event.

**Table 2 – The intervals for the investigated factors in lane changing decisions.**

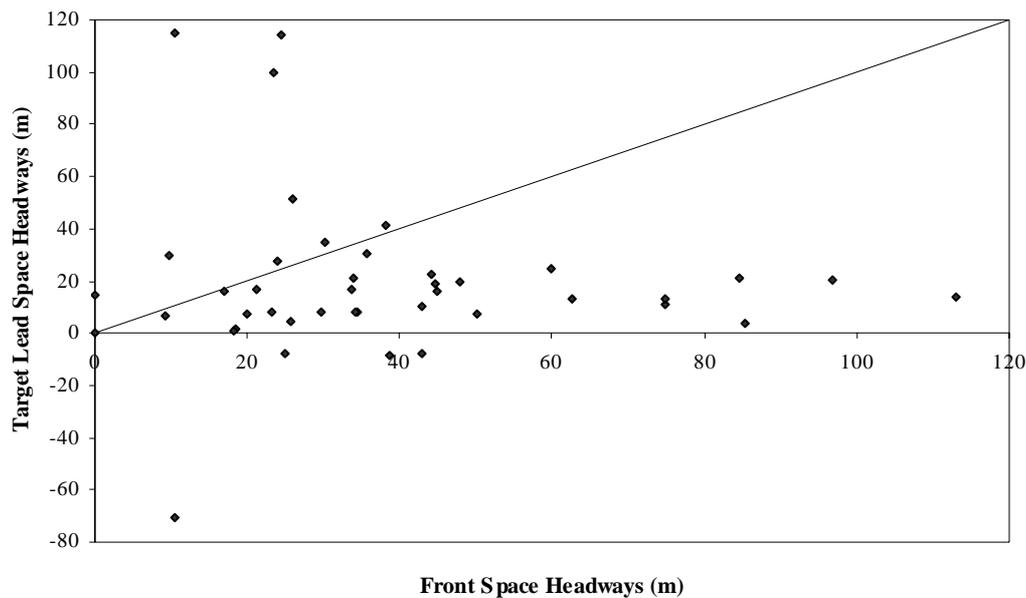
Traffic Characteristic	Mean	Standard Deviation	95% Confidence Level	
			Lower Bound	Upper Bound
Subject Speed (m/s)	5.02	0.58	3.88	6.16
Subject Acceleration (m/s <sup>2</sup> )	0.67	0.27	0.14	1.21
Front Speed (m/s)	9.56	0.87	7.86	11.27
Front Space Headway (m)	39.44	4.72	30.18	48.70
Front Acceleration (m/s <sup>2</sup> )	0.21	0.24	-0.26	0.68
Rear Speed (m/s)	9.05	0.79	7.49	10.61
Rear Space Headway (m)	-26.85	1.59	-29.95	-23.74
Rear Acceleration (m/s <sup>2</sup> )	-0.08	0.25	-0.57	0.41
Target Lead Speed (m/s)	10.66	0.73	9.54	12.08
Target Lead Space Headway (m)	16.83	4.27	8.47	25.20
Target Lead Acceleration (m/s <sup>2</sup> )	-0.11	0.22	-0.53	0.32
Target Lag Speed (m/s)	8.48	0.87	6.77	10.18
Target Lag Space Headway (m)	-28.72	5.14	-38.79	-18.64
Target Lag Acceleration (m/s <sup>2</sup> )	0.01	0.17	-0.32	0.34
Lead Speed in Alternative Lane (m/s)	10.86	1.45	7.86	13.86
Lead Space Headway in Alternative Lane (m)	14.06	2.98	7.88	20.25
Lead Acceleration in Alternative Lane (m/s <sup>2</sup> )	0.04	0.23	-0.42	0.51
Lag Speed in Alternative Lane (m/s)	10.32	1.38	7.42	13.21
Lag Space Headway in Alternative Lane (m)	-12.60	1.95	-16.68	-8.51
Lag Acceleration in Alternative Lane (m/s <sup>2</sup> )	0.08	0.22	-0.38	0.54

#### 4.1 Motivation to change lanes

In the traditional classification, the lane changing events are classified as either MLC or DLC (Ahmed, 1999). MLC happens when a driver is forced to leave the current lane for instance when merging onto the freeway from an on-ramp or taking an exit off-ramp. DLC is performed when the driver is not satisfied with the driving situation in the current lane and wishes to gain some speed advantages. Therefore, based on the traditional classification of the lane changing events, entry via an on-ramp or exit via an off-ramp or the traffic characteristics in the current lane can be considered as motivations of changing lanes. Entry via an on-ramp or exit via an off-ramp depends on drivers' route choice and the drivers are forced to change lanes in order to take an on-ramp or an exit off-ramp. Alternatively, there are different traffic characteristics in the current lane which may motivate the drivers to change lanes. These traffic characteristics in the current lane which might motivate drivers to change lanes are investigated in this section.

##### 4.1.1 Relationship between the front space headway and the target lead space headway

The space headway between the subject vehicle and the front vehicle in the current lane is an important traffic characteristic which may motivate the drivers to change lanes. Therefore, the space headway between the subject vehicle and the front vehicle (front space headway) and the space headway between the subject vehicle and the target lead vehicles (target lead space headway) are compared. The front and target lead space headways at the start of lane changing are shown in Figure 3. In 32 out of 40 (80%) of the heavy vehicle lane changing events which have both front and target lead vehicles in the dataset, the front space headway is greater than the target lead space headway.

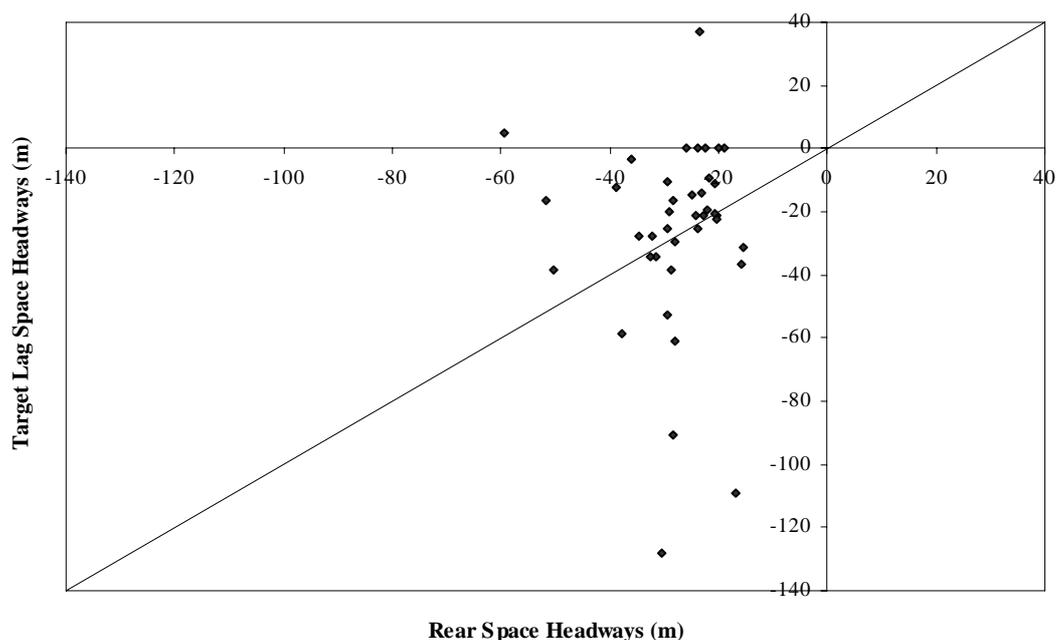


**Figure 3 – Front and target lead space headways at the start of the lane changing event.**

The large space headway between the subject and front vehicles may be due to limitations in manoeuvrability of the subject heavy vehicles. In most lane changing events, the lag vehicles increase their speeds from a few seconds before the start of lane changing (possibly because the subject vehicles indicate their intention to change lanes), in order to pass the slow moving heavy vehicle. Therefore, the lag vehicles a few seconds before the start of lane changing would have been the target lead vehicles at the start of the lane change. These would explain the larger front space headways and smaller target lead space headways.

#### **4.1.2 Relationship between the rear space headway and the target lag space headway**

The rear space headway and the target lag space headway are compared in Figure 4. In 20 out of 34 (59%) of the heavy vehicle lane changing events which have both rear and target lag vehicles, the rear space headway is greater than the target lag space headway at the start of the lane changing event.



**Figure 4 – Rear and target lag space headways at the start of the lane changing event.**

The larger rear space headway in the current lane implies the safety concerns of the rear vehicle drivers who are following the heavy vehicles. In addition, as noted earlier, in some lane changing events the lag vehicles increase their speed from a few seconds before the start of lane changing (possibly because the subject vehicles indicate their intention to change lanes), in order to pass the slow moving heavy vehicle.

#### 4.1.3 Relationship between the front speed and the target lead speed

An opportunity to gain speed advantage can motivate drivers to change lanes. In this part of the analysis, the front speeds and the target lead speeds are compared. As it seen in Figure 5, in 25 out of 39 (64%) of the heavy vehicle lane changing events which have both front and target lead vehicles, front speed is smaller than the target lead speed. Therefore, the small values of front speed may motivate the heavy vehicle drivers to change lanes.

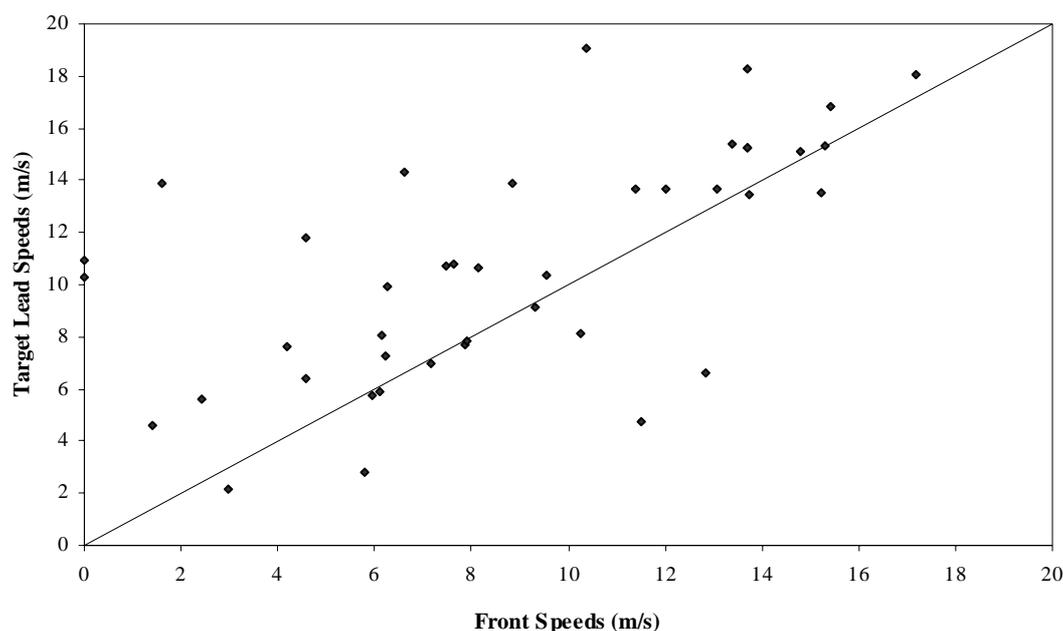


Figure 5 – Front and target lead speeds at the start of the lane changing event.

#### 4.1.4 Relationship between the rear speed and the target lag speed

Due to the large size of heavy vehicles, the traffic characteristics at the rear of the heavy vehicles need to be adequately investigated to understand their relationship with lane changing decisions. The relationship between the rear speed and the target lag speed at the start of the heavy vehicle lane changing events is shown in Figure 6.

In 21 out of 35 (60%) of the heavy vehicle lane changing events which have both rear and target lag vehicles, the rear speed is greater than the target lag speed. The obtained result shows that the target lag speed is mainly smaller than the rear speed in the lane changing of heavy vehicles. There is evidence in the data of lag vehicles that they adjust their speeds to accommodate the heavy vehicles lane change. It should be mentioned that in 6 out of 35 (17%) of the heavy vehicle lane changing events, the target lag vehicle reduces speed a few seconds before the start of the lane changing event and provides courtesy for the subject vehicle to move into the target lane.

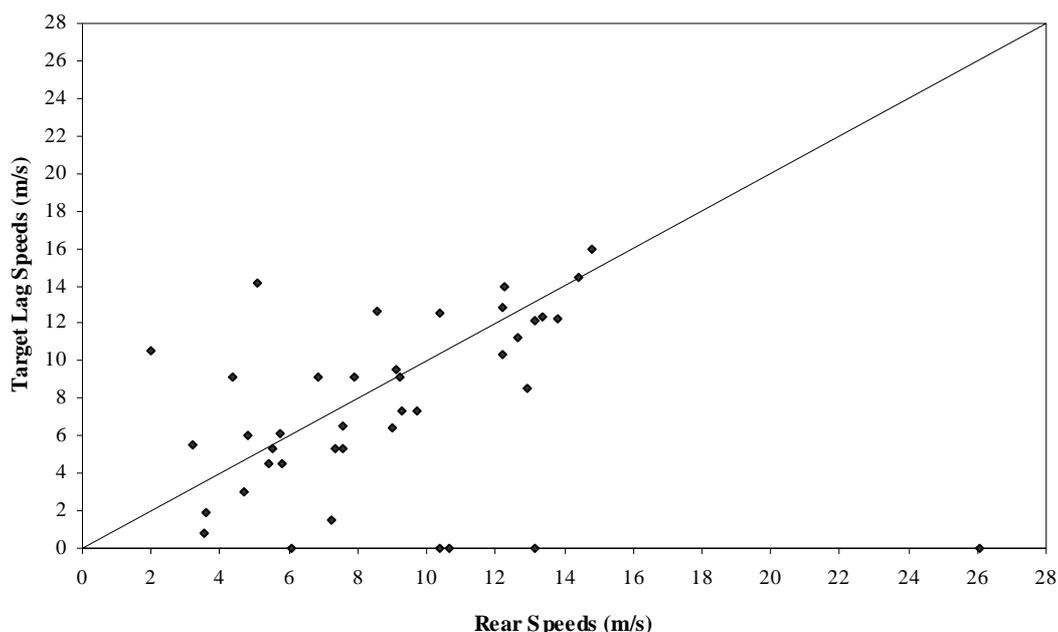


Figure 6 – Rear and target lag speeds at the start of the lane changing event.

#### 4.1.5 Relationship between the subject speed, front speed and rear speed

The traffic characteristics in the current lane can have a major influence on drivers' lane changing decisions. The front and rear speeds can motivate the heavy vehicles to change lanes. The relationship between the subject, front and rear speeds are shown in Figure 7.

In 13 out of 40 (33%) of the heavy vehicle lane changing events which have front vehicle, the front speed is smaller than the subject speed while in 9 out of 40 (23%) the front speed is greater than the subject speed by less than 1 m/s. Meanwhile, in 16 out of 39 (41%) of the heavy vehicle lane changing events which have rear vehicle, the rear speed is greater than the subject speed and in 17 out of 39 (44%) the rear speed is smaller than the subject speed by less than 1 m/s. The obtained results show that the front speed and the rear speed might be two factors to motivate the drivers to change lanes.

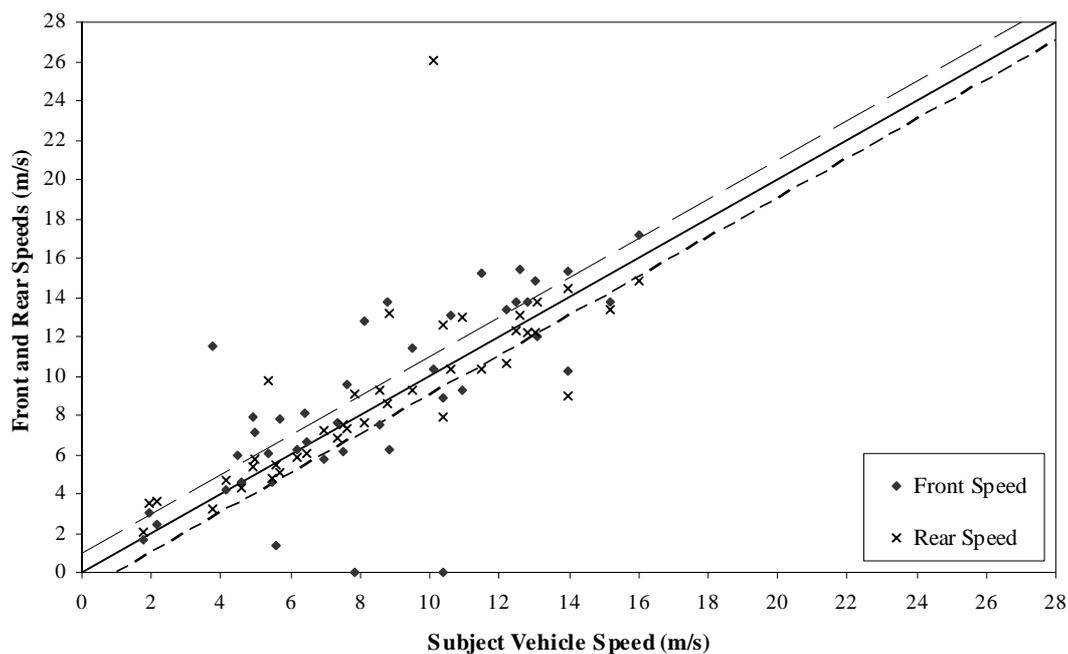


Figure 7 – Subject, front and rear speeds at the start of the lane changing event.

## 4.2 Selection of the target lane

To investigate the explanatory factors in the selection of the target lane for the lane change manoeuvre, the traffic characteristics in both adjacent lanes are analysed in this section.

### 4.2.1 Relationship between the subject speed, target lead speed and target lag speed

Figure 8 shows the relationship between the subject speed and target lead and lag speeds at the start of lane changing. In 37 out of 42 (88%) of the heavy vehicle lane changing events, the target lead speed is greater than that of the subject. In 20 out of 35 (57%) of the heavy vehicle lane changing events which have target lag vehicles, the target lag speed is smaller than the subject speed and in 11 out of 35 (31%) the target lag speed is greater than the subject speed by less than 2 m/s (7.2 km/h). According to the obtained results, the target lead and lag speeds might be significant factors in selection of the target lane.

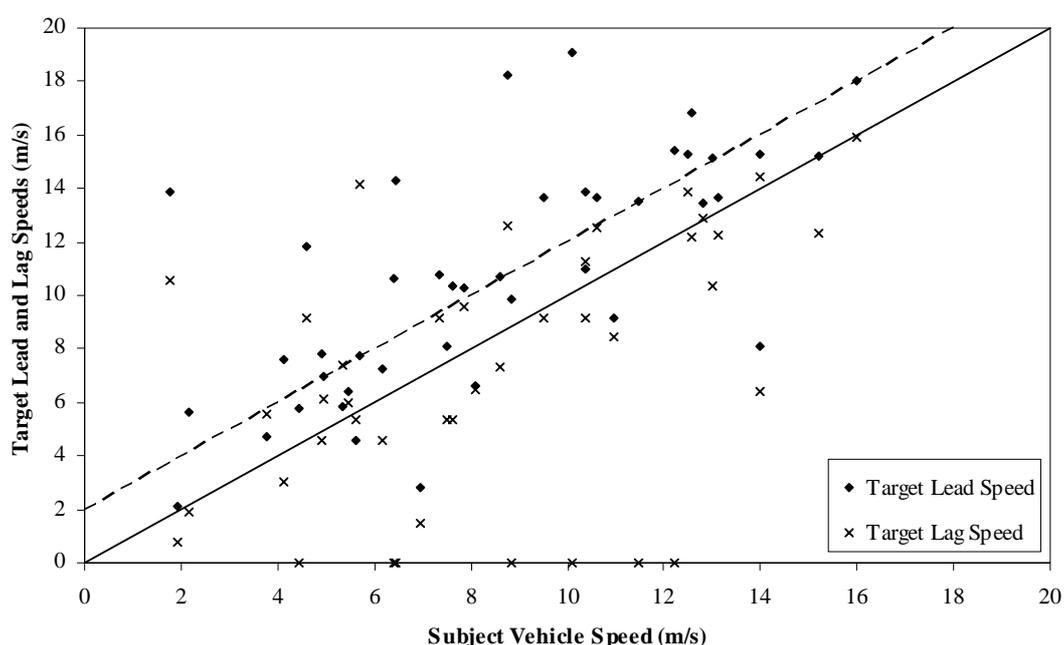
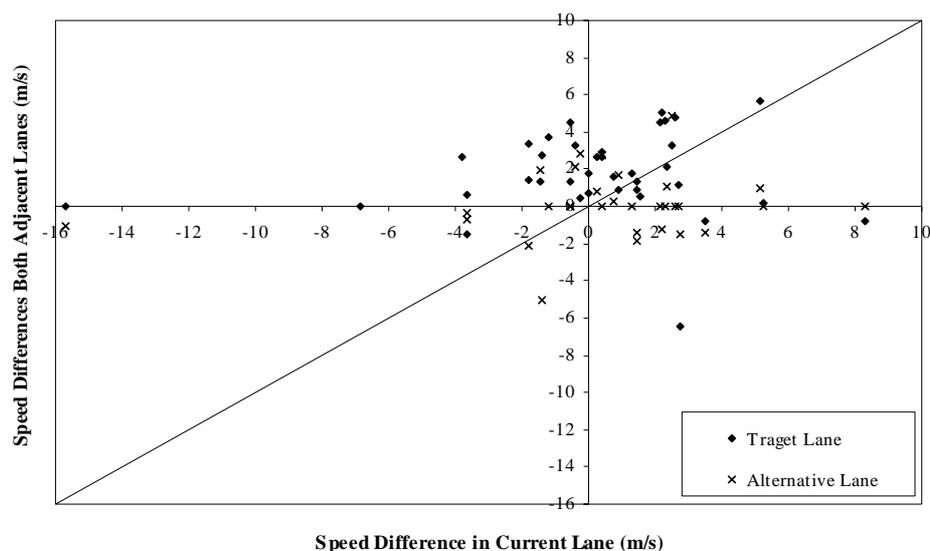


Figure 8 – Subject, target lead and lag speeds at the start of the lane changing event.

### 4.2.2 The speed differences in the current lane, target lane and the alternative<sup>1</sup> lane

The speed difference between the preceding and following vehicles in both adjacent lanes may be a significant factor in selection of the target lane. Therefore, the speed difference between the lead and lag vehicles in the target lane and the alternative lane are compared to the speed difference between the front and rear vehicles in the current lane. The comparison is shown in Figure 9 with the data relating to the start of the lane changing event.

<sup>1</sup> The alternative lane, or non target lane, may be either the left or right adjacent lane depending on which side was selected as the target lane.



**Figure 9 – Speed differences in the current lane, target lane and the alternative lane.**

In 22 out of 31 (71%) of the heavy vehicle lane changing events which have front, rear, target lead and target lag vehicles, the speed difference between the lead and lag vehicles in the target lane is greater than the speed difference between the front and rear vehicles in the current lane. However, in 10 out of 20 (50%) of the heavy vehicle lane changing events which have front and rear vehicles and lead and lag vehicles in the alternative lane, the speed difference between the lead and lag vehicles in the alternative lane is greater than the speed difference in the current lane.

The comparison of the speed difference between the lead and lag vehicles in both adjacent lanes shows the importance of these values in heavy vehicles lane changing decisions. The speed difference between the lead and lag vehicles in the target lane is greater than the speed differences between the front and rear vehicles in the current lane and the lead and lag vehicles in the alternative lane when heavy vehicles change lanes.

#### **4.2.3 The space headways in the current lane, target lane and the alternative lane**

The space headway between the preceding vehicle and the following vehicle in the current lane and both adjacent lanes may affect the selection of the target lane. The importance of the space headway may be due to the larger length of the heavy vehicles compared to passenger cars. The space headway between the front and rear vehicles in the current lane and the lead and lag vehicles in both adjacent lanes are shown in Figure 10.

In 24 out of 33 (73%) of the heavy vehicle lane changing events which have front, rear, target lead and target lag vehicles, the space headway between the lead and lag vehicles in the target lane is smaller than the space headway between the front and rear vehicles in the current lane. In 20 out of 21 (95%) of the heavy vehicle lane changing events which have front and rear vehicles and lead and lag vehicles in the alternative lane, the space headway between the front and rear vehicles in the current lane is greater than the space headway between the lead and lag vehicles in the alternative lane. The results show that the space headway between the front and rear vehicles in the current lane is greater than the corresponding values in both adjacent lanes.

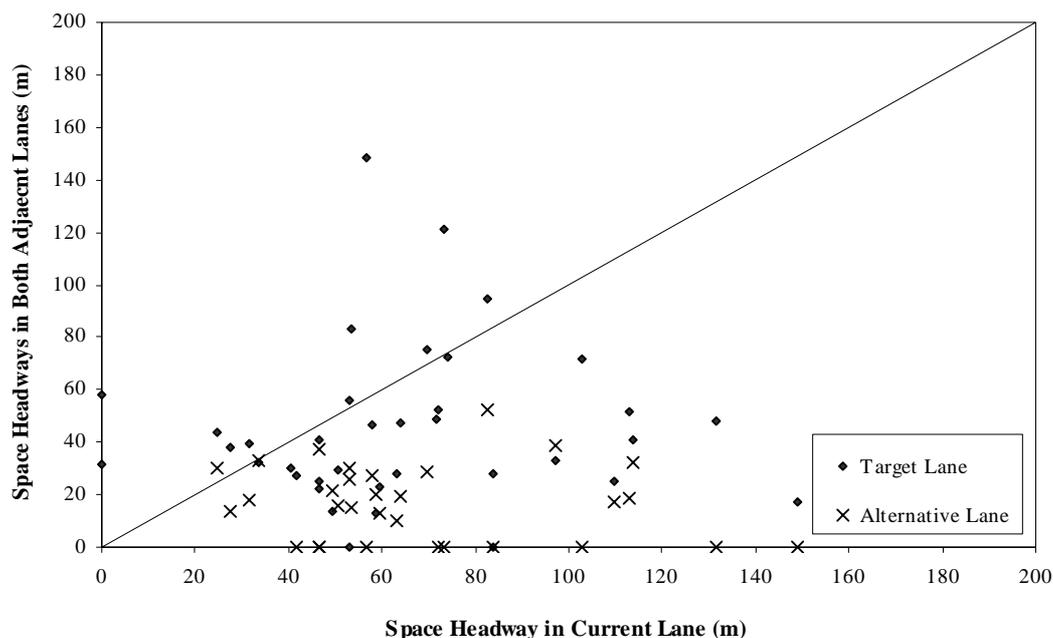


Figure 10 – Space headways in the current lane, target lane and the alternative lane.

#### 4.2.4 The relation between the lead and lag speeds in the alternative lane

Investigating the traffic characteristics in the alternative lane around the current lane which is not selected as the target lane is significant. Analysing the traffic characteristics in the alternative lane is useful in realising the important factors in drivers' selection of the target lane. In this section, the relative speeds of the lead and lag vehicles in the alternative lane are compared. Figure 11 shows that, in 12 out of 18 (67%) of the heavy vehicle lane changing events which have lead and lag vehicles in the alternative lane, the lead and lag relative speeds in the alternative lane have positive values. In addition, in the rest of the heavy vehicle lane changing events, both the lead and lag relative speeds in the alternative lane have negative values or the lead speed has negative and the lag speed has positive values.

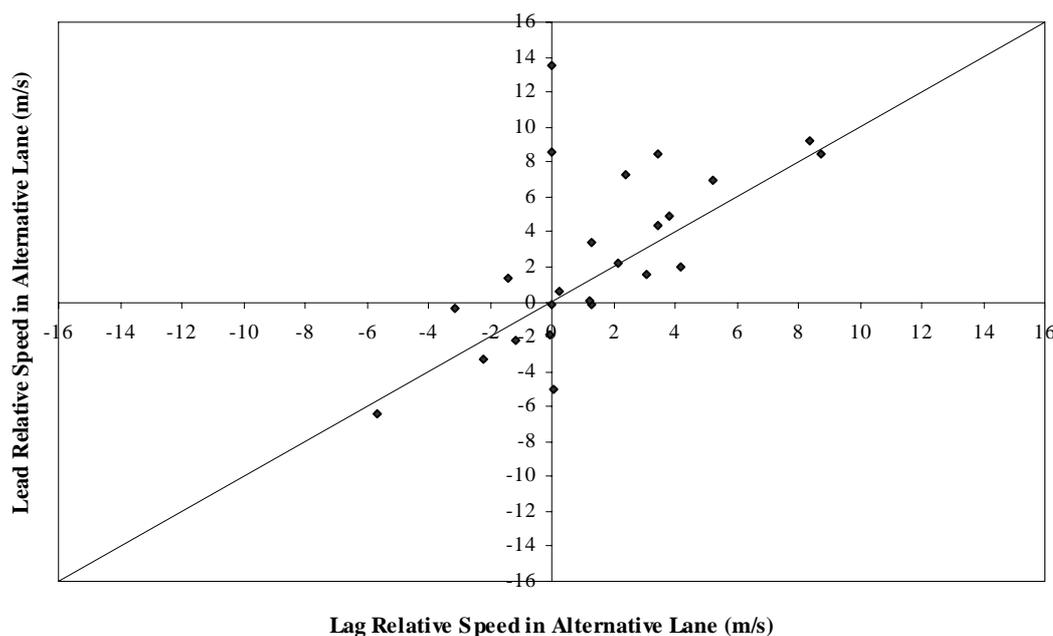


Figure 11 – Lead and lag speeds at the start of the lane changing event in the alternative lane.

The results show that either both the lead and lag speeds are greater than the subject speed or the lead speed is smaller than the subject speed. Therefore, the alternative lane is an inappropriate target lane choice. These differences would explain why a particular left or right adjacent lane was not selected as a target for lane change manoeuvre.

#### 4.2.5 Speed changes of heavy vehicles during the lane changing event

The speed changes which are required for the subject vehicle in order to change lanes may have an influence on the selection of the target lane. Therefore, the speed changes of heavy vehicles are investigated from a few seconds before the start of lane changing until the end of the lane changing event. The Coefficient of Variation (CV) which is the ratio of the standard deviation to the mean speed is used to analyse the speed changes of heavy vehicles.

Analysing the traffic characteristics around the time of a lane change manoeuvre is complicated by the number of lane changing in the traffic surrounding the heavy vehicle. However, the surrounding traffic behaviour was found to be more stable from about 8 seconds before the start of the heavy vehicle lane changing manoeuvre. Consequently, in the initial component of this analysis, the changes in the subject speed are analysed from 8 seconds before the start of lane changing until the start of lane changing event (Figure 12).

As shown in Figure 12, in 33 out of 38<sup>2</sup> (87%) of the heavy vehicle lane changing events, the CV of speed is smaller than 0.2. In the other 3 heavy vehicle lane changing events, the CV is smaller than 0.4. The CV and the mean subject speed are negatively correlated highlighting that when the mean subject speed increases, the CV decreases. In the second component of the analysis, the changes in the subject speed are analysed from the start of lane changing until the end of the lane changing event. In 37 out of 42 (88%) of the heavy vehicle lane changing events, the CV is smaller than 0.2. The CV and the mean subject speed have negative correlation which is similar to speed changes of heavy vehicles before the start of the lane changing event.

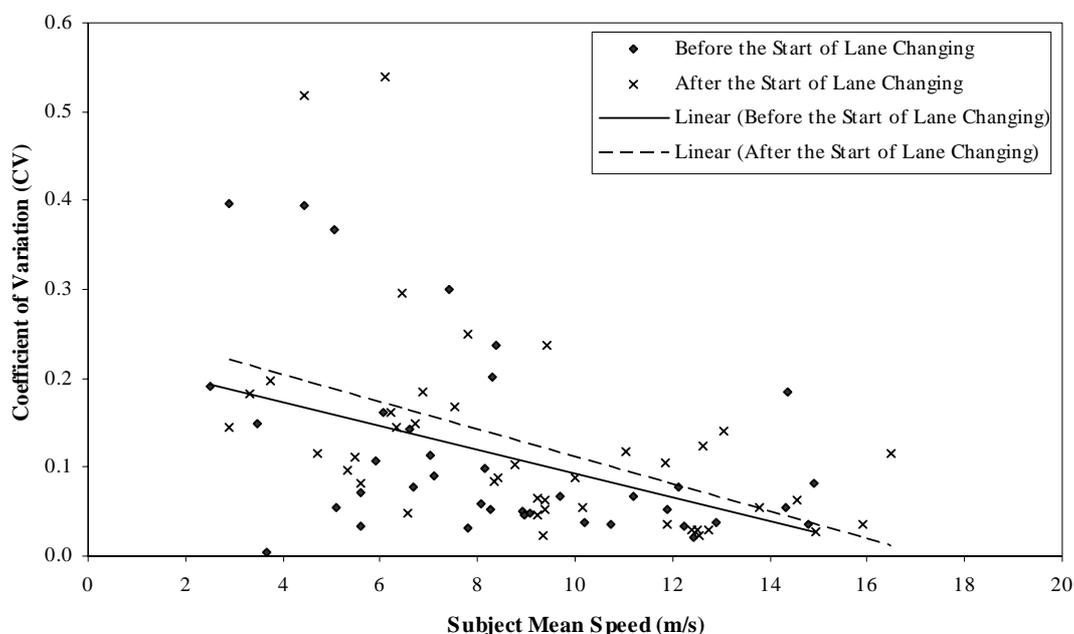


Figure 12 – Speed changes of heavy vehicles during the lane changing event.

<sup>2</sup> Information on the lane changing event is available from 8 seconds before the start of lane changing.

The small values for CV of speed show that the speed of the heavy vehicles remains relatively constant from a few seconds before the start of lane changing until the end of the lane changing event.

## 5 Discussion

Analysing the explanatory variables of heavy vehicle drivers' lane changing decisions highlighted the important relationships between these variables. First, in around 70% of heavy vehicle lane changing manoeuvres, the target lead space headway was smaller than the front space headway, and the target lead speed was greater than the front speed. Lag vehicle drivers mainly increased their speed from a few seconds prior to the start of lane changing (possibly because the subject vehicle indicates its intention to change lanes), to pass the slow moving heavy vehicle. Therefore, the target lag vehicles a few seconds before the start of a lane changing would have been the target lead vehicles at the start of the lane changing manoeuvre. This is more observable in heavy truck lane changing manoeuvres. This causes the larger target lead speed than the front speed and the smaller target lead space headway than the front space headway. The large front space headways may be due to limitations in manoeuvrability of the subject heavy vehicle.

## 6 Conclusion

Lane changing manoeuvres have a significant effect on traffic flows characteristics due to their interfering effect on surrounding traffic. The interfering effect of lane changing is more significant during the lane changing manoeuvre of heavy vehicles due to their physical and operational characteristics. Despite the increasing number of heavy vehicles operating on freeways, their lane changing behaviour has not been studied extensively since previous lane changing studies have primarily focused on passenger cars.

In this paper, a lane changing decision was divided into two stages: first, the motivation to change lanes and second, the selection of a lane to change into. The explanatory factors in heavy vehicles' lane changing decisions have been analysed for these two stages and through detailed vehicle trajectory data.

The speeds of the preceding vehicles and the following vehicles in the current lane and both adjacent lanes have effect on heavy vehicles lane changing decisions. The front speed and the rear speed are mainly similar to each other and the rear speed is mainly greater than the subject speed in the heavy vehicle lane changing events. The target lead speed is mainly greater than the subject speed, and the target lag speed is smaller than the subject speed. In addition, both the lead and lag speeds in the alternative lane are greater than the subject speed or the lead speed is smaller than the subject speed lane.

The next stage of this study is to develop a heavy vehicle lane changing decision model, based on a fuzzy logic approach, which uses the above explanatory variables to define the fuzzy rules in lane changing decision of heavy vehicles.

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