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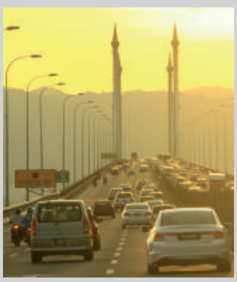

Research Report

A Study on Commercial Vehicle Speed and its Operational Characteristics

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Abstract

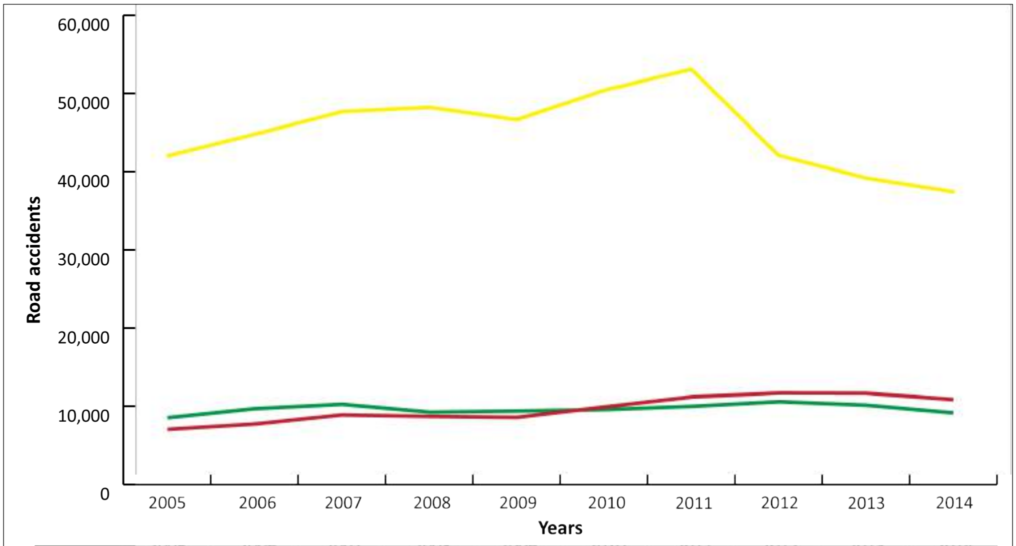
A commercial vehicle is the backbone of the logistics industry which drives a vibrant economy of a country. Nevertheless, commercial or heavy vehicle-related accident is drawing serious attention. In 2014 alone, a total of 57,430 road accidents involving lorry, bus, and taxi was recorded (Kementerian Pengangkutan Malaysia, 2014). The height, weight and width dimension of the commercial vehicles reduce the visibility of other drivers and thereby increase the risk of an accident. Furthermore, due to the evolution of technology, larger trucks are now equipped with higher horsepower where a lot of speeding-related accidents were reported.

This study is set to evaluate the speed profile for different types of commercial vehicles at different road hierarchy. The speed profiles are of very useful in assisting the authority in road and infrastructure design. For instance, appropriate traffic calming measures can be deployed based on the speed profiles on the specific roads.

A total of 7168 commercial vehicles were observed on the four types of roads. Nearly 50% of them were collected on primary roads. About one-third of the samples were light lorry with two axles while two axles heavy lorry constituted 16%. The results indicate that in general most of the heavy vehicles (4.39%–98.61%) travelled fast and did not comply with the speed limits posted on different types of road hierarchy. The lower the posted speed limit the higher the percentage of non-compliance rates which means that the compliance increase as the speed limit increase. Majority of the commercial vehicles (28%–57%) occupied the middle lanes and those smaller sizes of vehicles (as compared to other sizes of commercial vehicles) had more tendencies to travel on the fast lane.

1. Introduction

A commercial vehicle is the backbone of the logistics industry, which drives a vibrant economy of a country. Nevertheless, commercial or heavy vehicle-related accident is drawing serious attention. In 2014 alone, a total of 57,430 road accidents involving lorry, bus, and taxi was recorded (Kementerian Pengangkutan Malaysia, 2014). Figure 1 shows the commercial vehicles road accidents from 2005 to 2014 where a decreasing trend was detected since the year 2012. However, commercial and heavy vehicle-related accident is still challenging looking by the fact that the numbers of accidents are more than 10,000 vehicles per year and yearly new registered commercial vehicles are constantly on the rise.



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Lorry	42,062	44,767	47,696	48,250	46,724	50,438	53,078	42,158	39,276	37,481
Bus	8,594	9,700	10,285	9,356	9,380	9,580	9,986	10,617	10,123	9,193
Taxi	7,043	7,751	8,809	8,769	8,669	9,899	11,197	11,680	11,651	10,856

Figure 1 Road accidents involving commercial vehicles from 2005 to 2014

In Malaysia, commercial vehicle is the term used for all the public service vehicles and goods vehicles (Commercial Vehicles Licensing Board Act 1987). Goods vehicles are then divided into two categories according to their weight; below 2500 kg and more than 2500 kg. It is further classified into the types such as rigid lorry, rigid trailer lorry, tipper/dumper, prime mover, semi-trailer, and container prime mover (Kementerian Pengangkutan Malaysia, 2014). The goods vehicles definition may have some difference according to the country policy. In European Nation (EU), Heavy Goods Vehicles are referred to vehicles over 3.5 tons/3500 kg maximum permissible gross weight (Evgenikos et al., 2016).

Commercial vehicle poses threats to other road users due to its physical size and traffic operational characteristics. The height, weight and width dimension reduce the visibility of other drivers and limiting the manoeuvre ability other road users (Mussa & Price, 2004). On rolling and mountainous terrain, larger truck can hinder the traffic flow (Mussa & Price, 2004). However, due to the evolution of technology, larger trucks are now equipped with higher horsepower. This is true as we can frequently see commercial/heavy vehicles speeding on the roads.

While the presence of a commercial vehicle is unavoidable, its coexitence with other types of vehicles on the road is worrying. Many countermeasures such as truck restriction strategies have been implemented. For instance, commercial vehicles are restricted by speed, time, lane, and route. In addition, numerous research were also conducted to explore the impact of various attributes such as vehicle and driver characteristics, environmental factors, restraint usage, alcohol impairment, roadway geometrics and other related factors on injury severities in accidents involving large trucks (Alassar, 1988; Campbell et al., 1988; Joshua & Garber, 1992; Brown & Bass, 1997; Chang & Mannering, 1999; Khorashadi et al., 2005; Chen & Chen, 2011). Works are also carried out to understand the difference of truck-related accidents in urban and rural areas (A. Khorashadi et al., 2005).

In Malaysia, all the commercial vehicles are limited to maximum 90 km/h on the expressway and 60 km/h to 80 km/h on the federal and state roads. A preliminary study on bus speeding on North-South Expressway was conducted during festive season found that 45% of 1041 buses exceeded the speed limit (90 km/h) and 67% of the buses traveled in the middle lane (MIROS, 2010). Another unpublished work by MIROS at Port Klang revealed that most of the truck or heavy vehicles were driving above 90 km/h (MIROS, 2015). The speeding issues not only expose other road users to the risk of accident but also to the passengers in the vehicles. A study pointed out that speeding contributed 22.6% of the total crashes (Oluwole, 2015).

Little was known about the speeding problems of the other commercial vehicles particularly trucks and trailer. Its operational characteristics such as the preference travel lane by each type of commercial vehicles, the speed profile in the traffic stream as well as in the different road environment.

This study is set to evaluate the speed profile for different types of commercial vehicles at different road hierarchy. The speed profiles are of very useful in assisting the authority in road and infrastructure design. For instance, appropriate traffic calming measures can be deployed based on the speed profiles on the specific roads.

1.1 Aims and Objectives

The main aim of this study is to evaluate the speed profiles of commercial vehicles on different road hierarchy.

The objectives include:

i. To collect speed data of commercial vehicles on different lanes of roads;
ii. To establish speed distribution of commercial vehicles along different types of road hierarchy as compared to other vehicles;
iii. To assess the travel behaviour of the commercial vehicles.

1.2 Scope and Limitation

The scope of the study includes normal road carriageway and non-exclusive motorcycle lane roads. Data of commercial vehicles on four different road hierarchy (expressway, primary road, secondary road, and collector road) and non exclusive motorcycle lanes which distributed in the north, south, and east of Peninsular Malaysia were identified and included in the study.

Field observation was conducted for one hour during off-peak period on weekdays only. The data was collected by using video recording technique and a specific software was developed to reduce the required data from the video.

2. Methodology

The goal of this study is to capture the operational characteristics such as speed and lane occupancy for various commercial vehicles on the different hierarchy of roads (expressway, primary road, secondary road, and collector road). There are five essential tasks in this study as shown in Figure 2.

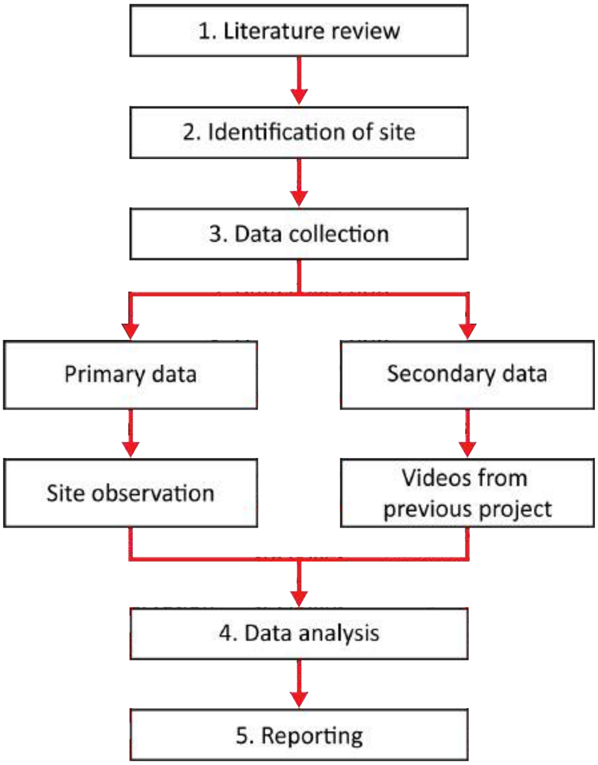


Figure 2 Research workflow

2.1 Site Identification

The data can be categorised into two types: characteristics of commercial vehicles on normal road and road with non-exclusive motorcycle lane. Therefore, two sets of data are needed in this study. The former data set was obtained from the video data from the other project (which was able to maximise the time, human and monetary resources) and the latter was collected on site for this study.

The selection of data collection site was based on the following criteria:

i. The observation section of the road shall be on a straight section. This is to ensure that the observed heavy vehicle maintains their speed on a straight road section. It is because theoretically, a vehicle would reduce speed at a horizontal or vertical alignment.
ii. Each section of the road shall have at least 5% of heavy vehicles from the total traffic volume. This is to ensure the validity of the results.
iii. Each section of the road shall have a vantage point to set up the equipment.
iv. Data collection shall be during off-peak hours and during clear weather for good visibility. This is also to ensure the consistency of the operational characteristics.

Similar criteria were applied to the study of commercial vehicles on non-exclusive motorcycle lanes.

2.2 Data Collection

The video camera was used to record the traffic flow during the off-peak period for an hour at each site. As space mean speed method was used, a distance of 30–40 metre (depending on-site condition) was first determined on site and marked with a traffic cone as shown in Figure 3. Another 100 vehicle speeds of other vehicles except commercial vehicles were also captured by using a speed gun. This is to compare and validate the speed reduced from the video. Site measurement was also conducted to obtain the road geometry data.

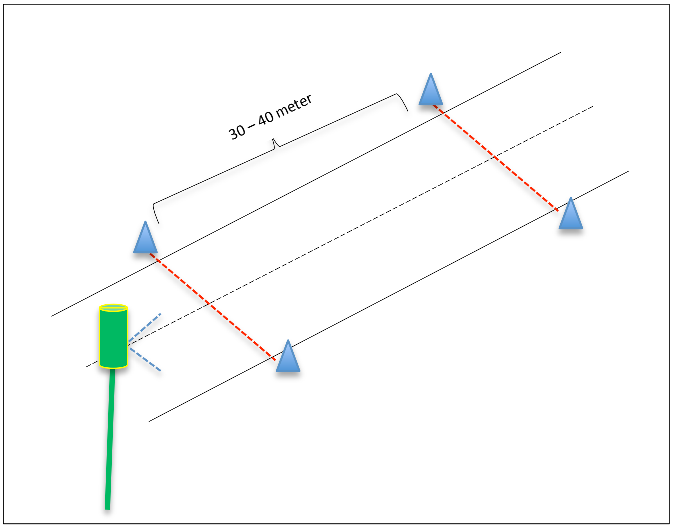


Figure 3 Observational set up

2.3 Data Reduction

The software was developed to assist the data reduction of commercial vehicles. The software was named as Commercial Vehicles Speed Operational Characteristics Software (CVSOC). Figure 4 shows the snapshot of the software where the information such as characteristics of the roads, types of commercial vehicles and lane travelled. The videos (after selection) are in sync with the data logger interface in terms of the time (up to milliseconds) in order to calculate the speed of the observed commercial vehicles.

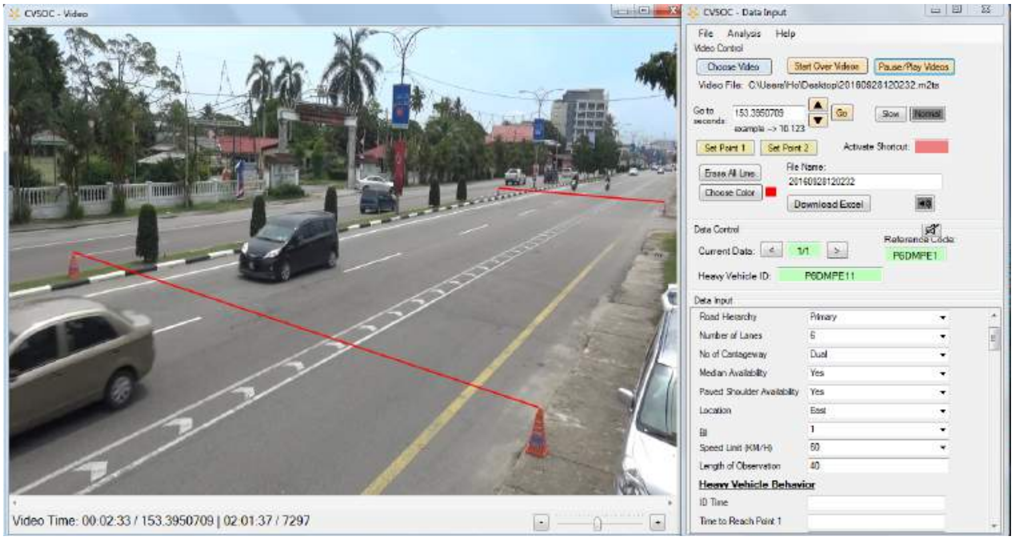


Figure 4 Screen shot of the CVSOC software

Heavy goods vehicles built in different dimensions in terms of their weight, length, and axles number. Based on this fact, there is a difficulty to classify one good vehicle because the classes may differ from one country to another. In Malaysia, the vehicle classes are clearly stated in the specific act but none to be simplified into a graphical form that can be easily understood. Graphical form prepared by PLUS Malaysia Berhad is available on their website as shown in Table 1. However, the vehicle classes provided is to reflect the toll rates.

Table 1 Vehicle classes (*Source:* PLUS Malaysia Berhad)

Class	Icon	Description
Class 1		Vehicles with 2 axles and 3 or 4 wheels excluding taxis
Class 2		Vehicles with 2 axles and 5 or 6 wheels excluding buses
Class 3		Vehicles with 3 or more axles
Class 4		Taxis
Class 5		Buses

Heavy vehicles in Australia on the other hand, is categorised into three classes namely Class 1 heavy vehicle which includes special purpose vehicle, agricultural vehicle and oversize vehicle, Class 2 heavy vehicle: freight-carrying vehicles, buses, vehicle carriers and livestock vehicles and Class 3 heavy vehicles (NHVR, 2014).

A study by Yang et al. (2016) to investigated truck acceleration capability at metered on-ramps used the vehicle classification standard by Federal Highway Administration (FHWA). The truck is defined into three categories namely light truck, medium truck and heavy trucks. The detail of each truck category is shown in Table 2.

Table 2 Truck type defined in the study by Yang et al. (2016)

Truck type	FHWA vehicle classification	Vehicle description	Typical model
Light truck	Class 5	Single unit 2-axle trucks	
Medium truck	Class 6 & 7	Single unit 3 or more axles trucks	
Heavy truck	Class 8 & 9	Single trailer, 3, 4, 5 axles trucks	

For the purpose of this study, the commercial vehicles were classified as per the Table 3 below.

Table 3 Description of variables in CVSOC

Category	Description	Reference
Types of vehicle	Van: a) Factory van b) School van c) Goods	
	Bus: a) Factory bus b) School bus c) Stage bus d) Mini bus	

e) Chartered bus
f) Express bus

Lorry:
a) Lorry with 2 axles light
b) Lorry with 2 axles heavy
c) Lorry with 3 axles
d) Lorry with 4 axles
e) Lorry with 5 axles
f) Lorry with 6 axles
g) Lorry > 6 axles
h) Prime mover

Example of lorry with two axles light:




Example of lorry with two axles heavy:



	Prime mover: 
	Taxi a) Normal taxi b) Limousine
Loading	a) Empty b) Loaded c) Overloaded
Presence of other vehicles	a) No vehicle b) In between c) Left d) Right e) Front f) Tailing
Lane occupancy	a) Fast lane b) Middle lane c) Slow lane d) Shoulder e) MC lane
Overtaking	a) Being overtaken b) Overtaking c) No/Not applicable

2.4 Data Analysis

2.4.1 Statistical Analysis

Since the data were collected from roadside observations where the underlying factors to behaviour of the commercial vehicle driver cannot be determined (e.g. commercial drivers' inherent attitude to the road environment or to safety), additional heterogeneity across observations could be presence (see Jones & Jørgensen, 2003). In light of the inherent deficiencies of current observation data, statistical and econometric methods have been developed to address this issue as unobserved heterogeneity (variations in the effect of variables across the sample population that are unknown to the analyst, see Revelt and Train (1998), Jones and Jørgensen (2003), Dupont et al. (2013) and Abdul Manan (2014)). Bias from unobserved heterogeneity is particularly important to take into account because estimates of the effect of independent variables will be biased even if the unobserved heterogeneity is not correlated with the observed independent variables (Washington et al., 2003). Unobserved heterogeneity is typically dealt with either by conditioning through random effects, or by transforming the data to eliminate individual-specific fixed effects (Revelt & Train, 1998).

In view of the above reasoning, fitting a multilevel model is an alternative strategy that allows for the possibility that the effects of variables (e.g. commercial drivers' behaviour, road environment attributes, zones, road hierarchy, etc.), which are correlated with the occurrence of speeding, may vary across the observations and circumvent all of the problems with traditional generalized linear model techniques. Mixed-effects logistic regression is logistic regression containing both fixed effects and random effects. It allows for not just one, but many levels of nested clusters of random effects (see Jones & Jørgensen, 2003; Dupont et al., 2013 & Abdul Manan, 2014). For example, in a three-level model, random effects can be specified for 'Zones' ('Zones' comprise of Northbound, Southbound, Westbound, and Eastbound) and then for Type of Commercial Vehicles (TCV) nested within Zone. In this model, the variable Commercial Vehicle Drivers (CVD) comprise the first level, the Type of

Commercial Vehicles (TCV) comprise the second level, and 'Zones' comprises the third level.

Following Jones and Jørgensen (2003), Dupont et al. (2013) and Abdul Manan (2014), a three-level multilevel model for binary data with a single explanatory variable that has both fixed effect and random effect was proposed. It was observed that yijk, a binary response for commercial vehicle driver (i) in a commercial vehicle (j) and xij, an explanatory variable at the Level 1. Then, it defines the probability of the response equal to one as pijk = Pr (yijk = 1) and let pijk be modelled using a logit link function. The standard assumption is that yijk has a Bernoulli distribution. Then the three-level model can be written as:

$$yijk = \log [pijk/(1 - pijk)] = \beta 0 + \beta 1xijk + u1jk\ xijk + v0k + u0jk \qquad (1)$$

where i, j, and k are index, respectively, Level 1, 2, and 3, v0k and u0jk are the random intercepts for Level 3 and Level 2, respectively, and u1jk is the random coefficient for the explanatory variables xijk. Thus, to incorporate this model into the study, it could let the Level 1, 2 and 3 represent CVD, TCV and zone respectively. Alternatively, Model (1) can be described as by the multiple equation systems:

$$\begin{aligned} \log[pijk/(1 - pijk)] &= \beta 0jk + \beta 1j\ xij && \text{(Level 1 model)} \\ \beta 0jk &= \beta 0k + u0jk && \text{(Level 2 model)} \\ \beta 1j &= \beta 1 + u1j && \text{(Level 2 model)} \\ \beta 0k &= \beta 0 + v0k && \text{(Level 3 model)} \qquad (2) \end{aligned}$$

The conditional density for (3) is still identical to that for the logistic regression; but with three random effects in the model, the unconditional density is a high-dimensional integral (Guo & Zhao, 2000: Dupont et al., 2013).

In Model (2), both u1j and v0k are random quantities, whose means are equal to zero; they form the random part of the model. The assumption is that, being at different levels, these variables are uncorrelated, and that they follow a normal distribution so that it is sufficient to estimate their variances σ2u0 = var (u1j) and σ2v0 = var (v0k) respectively (Jones & Jørgensen 2003, Rasbash et al., 2009). It is the existence of the two random variables that marks it out as a multilevel model. The variances $\sigma2u$ and $\sigma2v$ are referred to as random parameters of the model, whereas the quantities $\beta0$ and $\beta1$ are known as fixed parameters. A multilevel model of this type, where the only random parameters are the intercept variances at each level, is known as a variance components model. However, in a more complex model, the random parameter may have either a random intercept or a random slope (or both) associated with the level (see Abdul Manan, 2014).

The mixed logistic model proposed in this study will not only indicate the significant commercial vehicle drivers' behaviour or road environment factors that are associated with CVD speeding behaviour, but it will also indicate the percentage of variation in each level, i.e. Zones (Level 3), and TCV (Level 2), with relation to the factors associated with speeding behaviour.

In order to ensure the robustness of this model, several mixed-effect logistic regression models are developed. Each model's goodness-of-fit for this study is measured in terms of Akaike's Information Criterion (AIC). The smaller the value, the better and more preferred the model would be, i.e. the best-fitted model (Abdel-Aty & Radwan 2000; Ayati & Abbasi 2011).

The models are also compared in terms of their random parameters' residual variance at each level. To estimate the proportion of overall residual variability that is associated with each level, it is normal to calculate the ratio of each of the two-variance terms to total variance (Jones & Jørgensen, 2003). The result is known as the intra-unit correlation coefficient (ICC), ρ and it can be calculated using the formula:

$$\text{ICC Level 1}, \rho1 = (\sigma2e0)/(\sigma2u0 + \sigma2e0 + \sigma2v0) \quad (3)$$
$$\text{ICC Level 2}, \rho2 = (\sigma2u0)/(\sigma2u0 + \sigma2e0 + \sigma2v0) \quad (4)$$
$$\text{ICC Level 3}, \rho2 = (\sigma2v0)/(\sigma2u0 + \sigma2e0 + \sigma2v0) \quad (5)$$

where $\sigma2e0$, $\sigma2u0$ and $\sigma2v0$ are the variances for Level 1, 2 and 3 residuals, respectively. As a guide, if the ICC Level 2 ($\rho2$), approaches zero, then the random parameter effect would be considered useless and simple regression would suffice.

On the other hand, if the ρ2, approaches one, then there is no variance to be explained at level one, or in other words: all commercial vehicles on the roads are the same.

3. Results

3.1 Characteristics of Sites and Traffic Composition

A total of 42 sites (inclusive of six roads with non-exclusive motorcycle lane) has been selected for the purpose of this study (as shown in Figure 5). The details of the road sections were listed in Table 4. Majority of the sites located on primary roads while expressway sites accounted for 15%. Five non-exclusive motorcycle lanes were identified for this study.

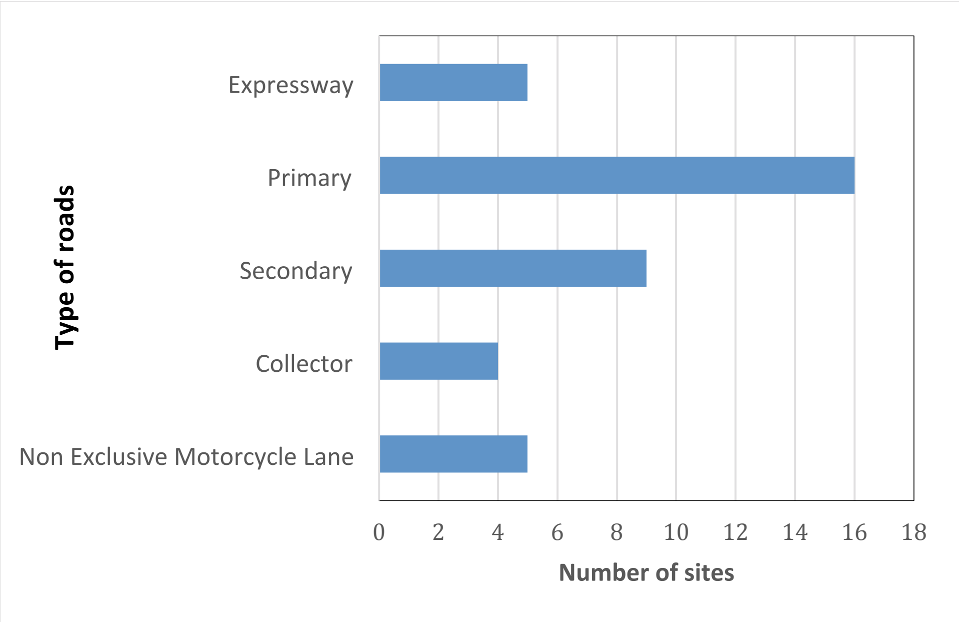


Figure 5 Number of sites for each type of roads

The details characteristics of the sites were listed in Table 4. The speed limit on expressway varies between 80 km/h to 90 km/h. Primary roads have wider range of speed limits from 50 km/h to 90 km/h depending on the land use type. Half of the sites were dual carriageway and 38% of the samples had paved shoulder.

Table 4 Characteristics of the selected road sections

No.	Location name	Lc	RN	RH	NL	CW	SL	RW (m)	MW (m)	SW (m)
1	SILK Highway	W	E18	E	8	D	80	3.65	2.0	-
2	Seberang Jaya	N	E1	E	6	D	90	3.65	3.0	3.00
3	UPM, Serdang Rest Area	W	E1	E	6	D	90	3.65	3.0	3.00
4	LDP, Kelana Jaya, SS2	W	E11	E	6	D	90	3.65	2.0	-
5	Changlun, Kedah	N	E1	E	4	D	90	3.50	5.0	-
6	Jln Sultan Mohammad	E	FR3	P	6	D	70	3.50	2.0	1.70
7	Jln Skudai - Johor Bahru	S	FR1	P	6	D	80	3.70	4.0	-
8	Jln Kuantan Terengganu	E	FR3	P	4	D	90	4.00	4.0	1.70
9	Tmn Rimba Templer, Jln Rawang	W	FR1	P	4	D	80	3.60	2.7	1.70
10	Kuala Selangor - Sabak Bernam	W	FR5	P	4	D	90	3.80	-	2.00
11	Air Hitam - Kluang	S	FR50	P	4	D	80	3.50	-	-
12	Hill Park - Jalan Batu Arang	W	B49	P	4	D	50	3.50	-	-
13	Alor Setar, Kedah	N	FR1	P	4	D	70	3.60	4.0	-
14	Jalan Skudai - Pasir Gudang	S	FR17	P	4	D	90	4.00	3.0	-
15	Jalan Skudai - Pontian	S	FR5	P	4	D	70	3.70	2.0	-
16	Seriap - Simpang Ampat, Kedah	N	FR7	P	2	S	90	3.70	-	1.70

17	Batu Pahat - Muar	S	FR5	P	2	S	60	3.50	-	3.00
18	Jln Kemaman - Kuala Terengganu	E	FR3	P	2	S	90	3.5	-	2.5
19	Uni. Kebangsaan Malaysia (Bangi)	W	B17	P	2	S	60	3.5	-	1.0
20	Pasir Gudang - Masai	S	J10	P	2	S	70	4.0	-	-
21	Meru - Klang	W	B2	P	2	S	70	4.0	-	-
22	Jln Kg. Tok Jemba	E	T145	S	2	S	60	3.6	-	1.2
23	Sg. Lang, Banting	W	B123	S	2	S	60	3.0	-	2.0
24	UiTM Arau, Perlis	N	R137	S	2	S	60	3.8	-	-
25	Jalan Parit Selangor	S	J116	S	2	S	60	3.3	-	-
26	Jalan Kg. Tengah	E	T141	S	2	S	60	3.3	-	-
27	Kuala Selangor - Bukit Rotan	W	FR54	S	2	S	70	3.9	-	-
28	Titi Tok Bandar, Arau, Perlis	N	FR194	S	4	D	90	3.6	3.070	2.8
29	Jalan Tengku Mahmood	E	FR215	S	4	D	60	3.7	2.30	-
30	Pulau Indah, Klang	W	FR181	S	4	D	80	3.5	1.00	-
31	Puchong Perdana	W	-	C	2	S	60	3.0	-	-
32	Jalan Sutera Danga	S	-	C	4	D	60	3.9	3.50	-
33	Persiaran Kayangan	W	-	C	4	D	60	3.9	2.00	-
34	Tasik Prima, Puchong	W	-	C	4	D	60	3.2	4.3	

Legend:
Lc: Location, N: North, E: East, S: South, W: West
RN: Road Number
RH: Road Hierarchy, E: Expressway, P: Primary, S: Secondary, C: Collector
NL: Number of lanes
CW: Carriageway type, D: Dual, S: Single
SL: Speed limit (km/h)
RW: Road width,
MW: Median width
SW: Shoulder width

This study had observed a total of 7168 commercial vehicles that include van, bus, different axles of lorries, taxi and prime mover. Figure 6 shows the distribution of commercial vehicles in this study samples. The highest sample sizes (46.42%)

obtained from primary roads and 2 axles light lorry accounted for the biggest proportion of the commercial vehicles.

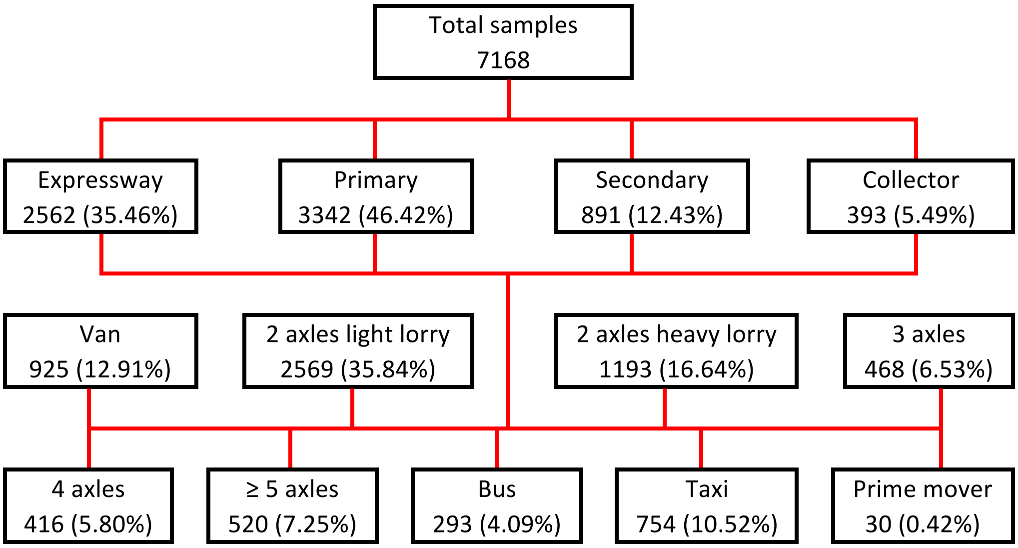


Figure 6 Distribution of samples

3.2 Analysis of Heavy Vehicle Speeds

Table 5 presents the speed data for all sites. The average speeds of commercial vehicles ranged between 47.60 km/h to 69.94 km/h on the four types of road hierarchy. It also exhibits that 85% of the commercial vehicles on these roads travelled above the minimum speed limits for the respective road hierarchy. On the other hand, the compliance rates for various posted speed limits configuration were also shown in Table 5. The results indicate that in general most of the heavy vehicles (4.39% to 98.61%) travelled fast and did not comply to the speed limits posted on different types of road hierarchy. The lower the posted speed limit the higher the percentage of non-compliance rates which means that the compliance increase as the speed limit increase.

Table 5 Distribution of speeds by road hierarchy

Road hierarchy	N	Mean speed	85th percentile	Speed limit	% above speed limit	% above 85th traffic speed
Expressway	459	69.94	86.51	80	30.28	15.03
	2084			90	9.07	15.02
Primary	72	67.74	84.37	50	98.61	16.67
	482			60	43.94	15.20
	545			70	17.25	15.05
	1242			80	36.65	15.00
	1013			90	7.01	15.20
Secondary	154	62.29	75.10	60	60.37	15.24
	113			70	26.55	15.04
	570			80	4.39	9.82
	41			90	7.32	14.63
Collector	393	47.60	60.76	60	15.78	15.52

To understand the differential speeds between commercial vehicles and other types of vehicles in the same traffic stream, analysis of the speed difference (mean speed and 85th percentile speed) were carried out and presented in Table 6. It was seen that the differential speed was in opposite trend of the road hierarchy. In other words, the gaps between the speed of commercial vehicle and other vehicles became wider when the road hierarchy getting lower. In conclusion, the differential speeds on all the road hierarchy were statistically significant.

Table 6 The mean speed difference between commercial vehicles and other vehicles based on different road hierarchy

Vehicle speed (except for CV), (km/h) N= 100		Road hierarchy	Commercial Vehicle (HV) speed (km/h)			
			Expressway	**Primary road**	**Secondary road**	**Collector Road**
			N=2543	N=3354	N=878	N=393
		Mean	69.94	67.74	62.29	47.60
		85th %	86.51	84.37	75.10	60.76
Expressway	Mean	72.79	**2.85**			
	85th %	93.00	***6.49***			
Primary road	Mean	72.94		**5.20**		
	85th %	91.29		***6.92***		
Secondary road	Mean	72.26			**9.97**	
	85th %	90.00			***14.90***	
Collector road	Mean	62.35				**14.75**
	85th %	80.00				***19.24***

The *italic* numbers are the difference between commercial vehicle and other vehicle 85th percentile speed. The **bold** figures indicate that the mean speed of motorcycle is statically significant with the mean speed of other vehicles, according to the two sample t-test ($p<0.05$).

The speeds of commercial vehicles were then compared between the various road hierarchies to understand performance of commercial vehicles on different road hierarchies. The results reveal that the speed of commercial vehicles on expressways did not differ much from their counterparts on the primary roads (Table 7). The highest differential speeds were between the collector road and expressway where a difference of 22.34 km/h was observed for those two types of roads. T-test analysis was conducted and the results show that all the differential speeds were statistically significant.

Table 7 The mean speed difference between heavy vehicles on different road hierarchy

HV speed (km/h)		Road hierarchy	Expressway	Primary road	Secondary road	Collector road
			N=2543	N=3354	N=878	N=393
		Mean	69.94	67.74	62.29	47.60
		85th%	86.51	84.37	75.10	60.76
Expressway N=2543	Mean	69.94				
	85th%	86.51				
Primary road N=3364	Mean	67.74	*2.2*			
	85th%	84.37	**0.00**			
Secondary road N=891	Mean	62.29	*7.65*	*5.45*		
	85th%	75.10	**0.00**	**0.00**		
Collector road N=393	Mean	47.60	*22.34*	*20.14*	*14.69*	
	85th%	60.76	**0.00**	**0.00**	**0.00**	

The mean differences shown in the table are statistically significantly different, according to the two sample t-test ($p<0.05$). The *italic* numbers are the difference between motorcycle and other vehicle 85th percentile speed. The **bold** figures indicate that the mean speed of motorcycle on the described top section of the table is statistically significantly higher ($p<0.05$) than the motorcycle on the described left section of the table.

3.3 Analysis of Commercial Vehicle Travel Behaviour

There are many statements claim that commercial vehicles tend to hog on the middle lane or fast lane despite numerous traffic sign of reminding the heavy vehicles to travel in the slow lane. Thus, this section was established to examine the travel behaviour such as lane occupancy, travel speed as well as their operation characteristics.

3.3.1 Speed Analysis Based on Lane Occupancy

Figure 7 shows the distribution of commercial vehicles on the lanes of expressways. Majority of the commercial vehicles (28%–57%) occupied the middle lanes and those smaller sizes of vehicles (as compared to other sizes of commercial vehicles) had more tendencies to travel on the fast lane.

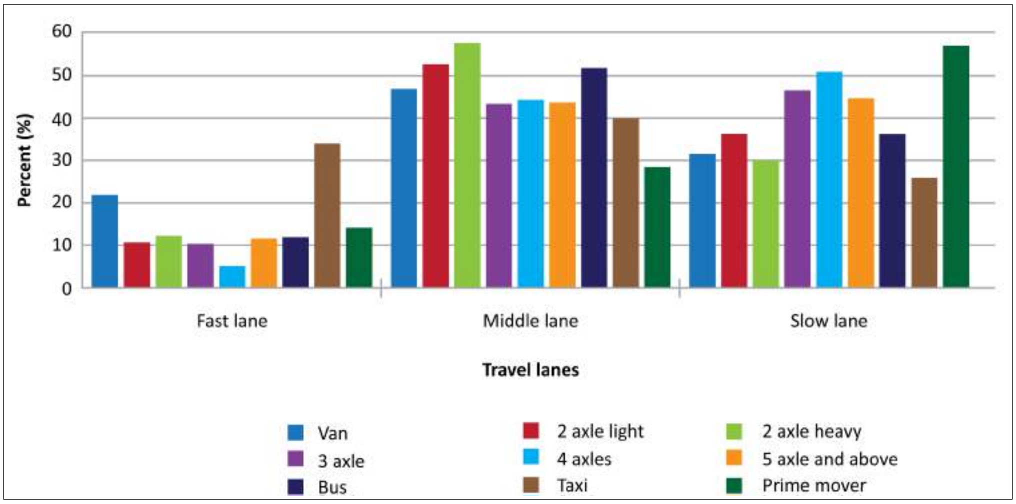


Figure 7 Distribution of volumes across the travel lanes on expressway

On primary roads (Figure 8), 42%–81% of the commercial vehicles were seen travelling in the slow lane while the second highest lane occupancy was on the fast lanes. As expected, more than 60% of the commercial vehicles travelled on the slow lane on secondary roads and collector road due to the slow speeds as shown in Figures 9 and Figure 10 respectively. Nevertheless, a higher number of lorries with 4 axles and above as compared to other types of commercial vehicles travelled on the fast lane on secondary roads while none of this vehicle class travelled on the fast lane on collector roads.

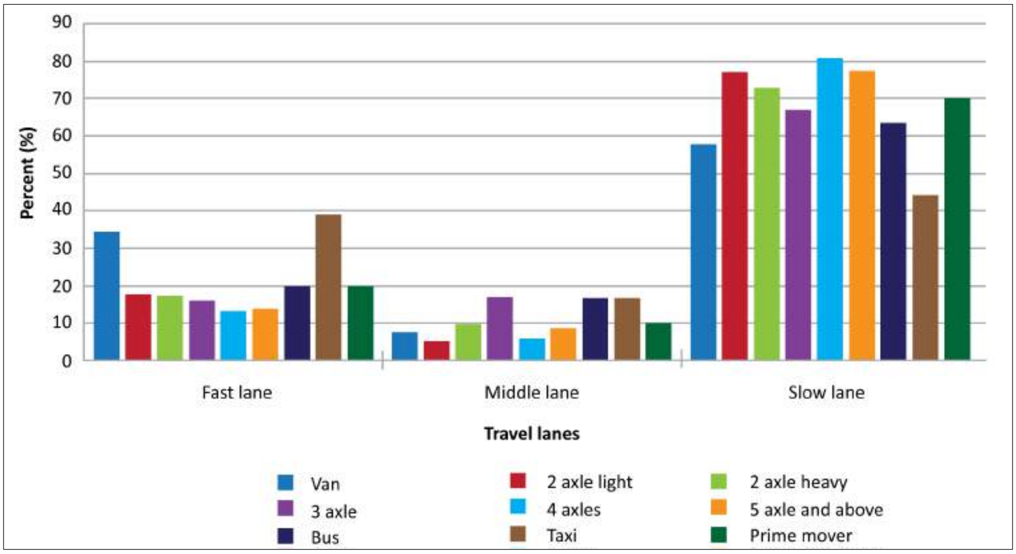


Figure 8 Distribution of volumes across the travel lanes on primary roads

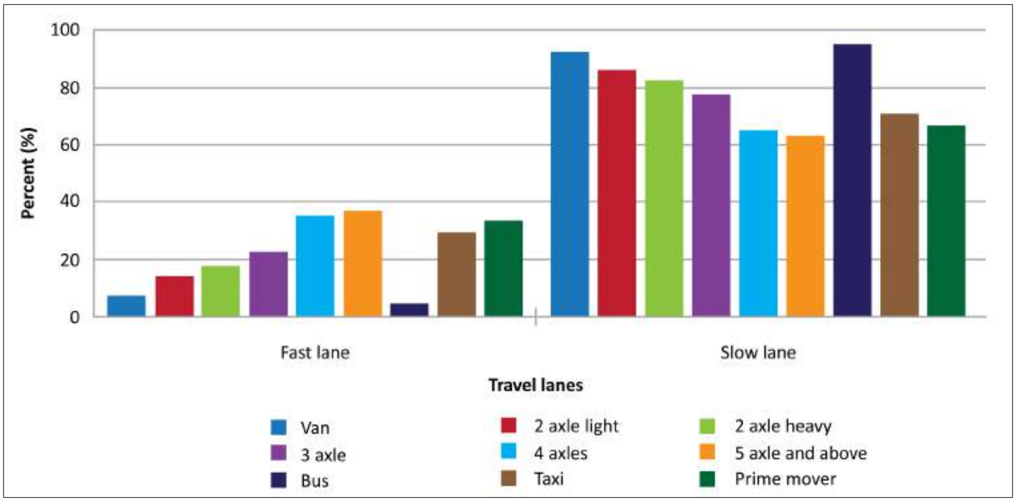


Figure 9 Distribution of volumes across the travel lanes on secondary roads

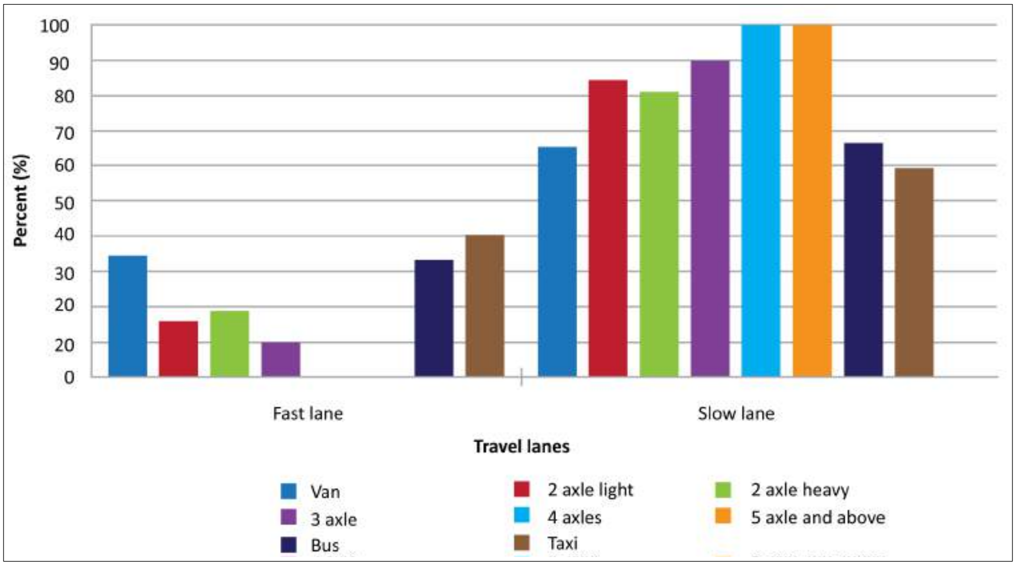


Figure 10 Distribution of volumes across the travel lanes on collector roads

Table 8 presents the speeds on each lane of different types of road hierarchy. As expected, the highest speeds were witnessed on the fast lane and the slowest on the slow lane. When comparing with fast lane, t-test results indicated there was a significant difference in the average lane travel speed with respect to the fast lane. Nevertheless, it is surprising to note the mean speeds between fast lane and lane 4 was not significant. This may be due to a very sample size (as only one expressway with four lanes).

Table 8 Distribution of speeds by lane (t-test results)

Road	Lane	1	2	3	4
Expressway	Mean	77.37	69.56*	67.30*	52.43
	85^{th}	102.82	85.91	80.79	64.94
Primary	Mean	80.87	76.50*	62.44*	-
	85^{th}	98.09	93.33	76.55	-
Secondary	Mean	67.08	60.78*	-	-
	85^{th}	76.30	74.87	-	-
Collector	Mean	57.48	44.46*	-	-

	85th	67.64	56.51	-	-

The mean differences shown in the table are statistically significantly different, according to the two sample t-test ($p<0.05$) with reference to the Lane 1.
Lane 1: Fast lane
Lane 2: Middle lane
Lane 3: Middle lane or slow lane
Lane 4: Slow lane

Another analysis was also performed to investigate if the proportion of commercial vehicles in the traffic stream had an effect on the speeds. As shown in Table 9, it was found that the higher the percentage of commercial vehicles, the lower the mean speeds for commercial vehicles on 2 lanes and 4 lanes roads. The reverse is true for 6 lanes road segment. Nonetheless, all the differential speeds between the commercial vehicles and other vehicles were statistically significant. No comparison was made on 8 lanes road due to limited sample sizes.

Table 9 The mean speed difference between motorcycles and other vehicles based on different number of lanes

% of traffic volume (except for HV)	**HV % traffic volume**	2L <10%	2L 10-20%	2L 20-30%	4L <10%	4L 10-20%	4L 20-30%	6L <10%	6L 10-20%
		N=166	N=1233	N=625	N=235	N=1018	N=2172	N=324	N=1200
	Mean	63.54	57.05	55.19	61.48	67.45	58.15	52.49	79.21
	85th %	77.37	71.62	68.91	75.27	80.93	71.50	60.49	91.04
2L >90% N=1063	68.13	**4.59**							
	86.23	**8.86**							
2L 80-90% N=786	66.17		**9.12**						
	87.01		**15.39**						
2L 70-80% N=300	65.27			**10.08**					
	85.01			**16.10**					
4L >90% N=1152	69.08				**7.60**				
	87.11				**6.18**				

4L 80-90% N=752	78.53					**11.08**			
	98.03					**17.10**			
4L 70-80% N=377	80.37						**22.22**		
	95.33						**23.83**		
6L >90% N=640	65.97							**13.48**	
	68.10							**7.61**	
6L 80-90% N=281	66.19								**13.02**
	85.25								**5.79**

The **bold** figures indicate that the mean speed of motorcycle is statically significant with the mean speed of other vehicle, according to the two sample t-test ($p<0.05$).

3.3.2 Speed Analysis by Loading Type

Table 10 Mean speed by loading type on different road hierarchy

Road hierarchy	Mean speed (km/h)		
	Unloading	Loading & Overloaded	P value
Expressway	70.85	69.73	0.1486
Primary road	67.10	67.90	0.2326
Secondary road	63.64	61.79	0.0306*
Collector road	45.83	47.99	0.1267

* Statistically significant difference according to t-test ($p < 0.05$) in comparison between number of lanes and the riding position in the lane/shoulder.

As seen in Table 10, commercial vehicles with loads/overloaded generally travelled slightly slower on the roads except on the primary roads and collector roads. Nonetheless, it should be highlighted here that the definition for loading is debatable as that box-type of commercial vehicles was classified as loaded in this analysis. The commercial vehicles travelled between 61.79 km/h to 70.85 km/h on the expressway, primary road and secondary roads while 45 km/h to 48 km/h travel speeds were detected on the collector road. It was also found that the differential speeds between unloading and loaded commercial vehicles on the secondary roads were found significantly different.

3.3.3 Analysis of Overtaking Manoeuvre

Table 11 presents the overtaking manoeuvre of the commercial vehicles on the different types of roads. It was seen that higher percentage (3.55% to 10.74%) of the commercial would overtake other types of vehicles when the number of lanes increases and at dual carriageway. Similarly, more commercial vehicles would also be overtaken (26.1%) when the opportunity available (more travel lanes and presence of median). Chi-square analysis was performed and noted that there was statistically significant for the operating manoeuvre on different lane configuration.

Table 11 The percentage of overtaking manoeuvre based on road hierarchy

Type of manoeuvre	Road carriageway		
	2 lane single	2 lane dual	>4 lane dual
Overtaking	1.44%	3.55%	10.74%
Being overtook	2.89%	11.37%	26.10%
No overtaking	95.67%	85.0%	63.16%
Total (n)	969	422	5651

* Statistically significant difference according to Chi-sq. test ($p < 0.05$) in the comparison between number of lanes and the riding position in the lane/shoulder.

3.4 Characteristics of Commercial Vehicles on Non-Exclusive Motorcycle Lane

Data were collected at 5 non-exclusive motorcycle lane sites located at Batu Pahat, Simpang Renggam, Alor Setar, Kota Bahru and Paka. A total of 549 commercial vehicles were observed. Table 12 shows the distribution of samples across the sites by type of carriageway. Based on the results, it was found that the speeds of the commercial travelled on single carriageway were higher than their counterparts on a dual carriageway and the difference was statistically significant. The travel speeds on single carriageway ranged between 68.6 km/h to 76.3 km/h while the speeds on dual carriageway varied between 41.6% to 53.6 km/h.

Table 12 Comparison of means speeds by type of carriageway

Type of vehicle	Single carriageway		Dual carriageway	
	Number (n)	Mean speed (km/h)	Number (n)	Mean speed (km/h)
Van	33	76.3	52	53.6*
2 axles light	67	68.6	50	47.6*
2 axles heavy	130	73.1	81	48.4*
3 axles	16	71.5	5	45.8*
4 axles and above	64	73.6	21	41.6*
Bus	10	73.7	20	48.5*
Total	320		229	

* Statistically significant difference according to t-test ($p < 0.05$) in comparison between number of lanes and the riding position in the lane/shoulder.

Distribution of commercial vehicles by lane (Figure 11) displays that less than 20% of the smaller size vehicles travelled on the fast lane and it is worth highlighting here that about 13% of the buses travelling on the motorcycle lane. This may be due to the presence of bus stops.

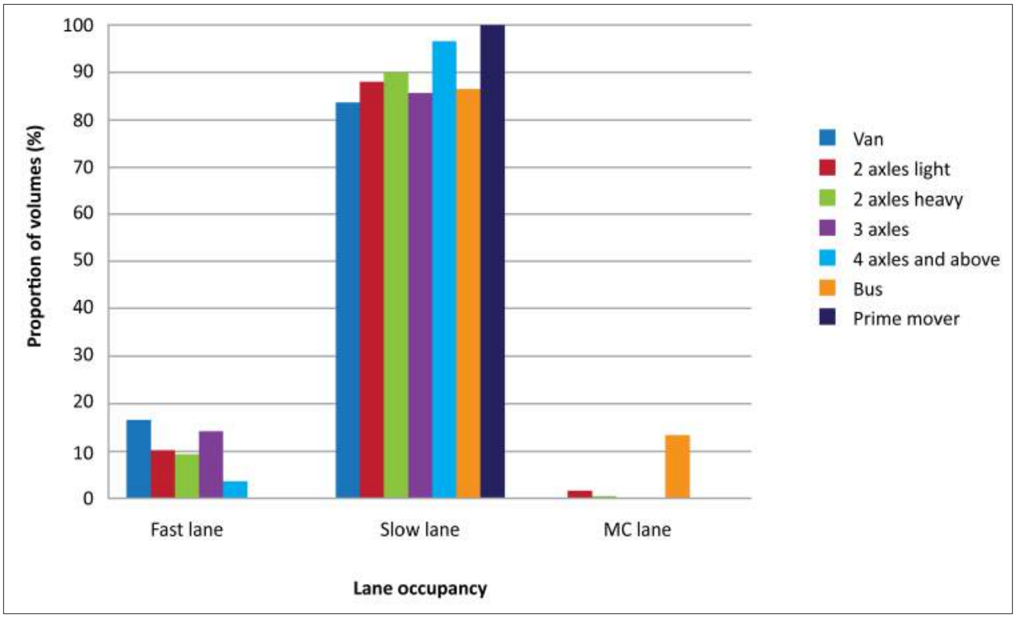


Figure 11 Distribution of commercial vehicles on non-exclusive motorcycle lanes

The analysis was also carried out to examine the relationship between travel speed and presence of other vehicles. It was found that in general, those commercial vehicles would travel at a higher speed when there was no other vehicle. The speeds of vans, 2 axles light, 2 axles heavy and 4 axles and above vehicles were significantly different at the two road conditions.

Table 13 Comparison of means speeds by presence of other vehicles

Type of vehicle	Presence of other vehicles		No other vehicles	
	Number (n)	Mean speed (km/h)	Number (n)	Mean speed (km/h)
Van	57	58.2	28.0	71.0*
2 axles light	82	56.0	35.0	68.0*
2 axles heavy	144	58.9	67.0	73.8*
3 axles	13	62.0	8.0	70.8
4 axles and above	51	61.4	34.0	72.1*
Bus	25	55.8	5.0	62.4
Total	372		177	

* Statistically significant difference according to t test ($p < 0.05$) in comparison between number of lanes and the riding position in the lane/shoulder.

3.5 Factors Associated with Excessive Speeding among Commercial Vehicles

Driving above or below the '85th percentile speed of other vehicles' is used as the dependent variable in identifying the factors associated with excessive speeding among commercial vehicles. This is because the speed limit violations among commercial vehicles are considerably high and it may indicate that the speed limit is not suitable for the road section due to improper design. On the other hand, the 85th percentile speed of other vehicles is a better indicator as it represents the optimal speed limit for the road sections in question. Table 14 to Table 16 show the tabulation of the number of a commercial vehicle moving above the 85th percentile speed of other vehicles (dependent variable) with respect to the various observation categories (independent variables).

Table 14 The tabulation of the number of commercial vehicle moving above the 85th percentile speed of other vehicles with road characteristics variables

Category: Road characteristics/Independent variables	85th % traffic speed	
	Below	Above
(1) Zone		
North	82	905
West*	122	3,708
South	316	1,716
East	33	309
(2) Road hierarchy		
Expressway	128	2,415
Primary*	370	2,994
Secondary	48	843
Collector	7	386
(3) Number of lanes		
2 lanes	68	1,018
4 lanes*	70	2,985
6 lanes	403	2,188
8 lanes	12	447
(4) Carriageway		
Single*	80	1,264
Dual	473	5,374
(5) Road median		
With road median*	447	5,204
Without road median	106	1,434
(6) Paved road shoulder		
With paved shoulder*	154	2,423
Without paved shoulder	399	4,215
(7) Speed limit category		
50 km/h*	8	64
60 km/h	53	993
70 km/h	26	633
80 km/h	317	1,959
90 km/h	149	2,989

**: Reference variable*

Table 15 The tabulation of the number of commercial vehicle moving above the 85th percentile speed of other vehicles with commercial vehicle characteristics

Category: Commercial vehicle characteristics/ Description of independent variables	85th % speed of other vehicles	
	Below	Above
(8) Commercial vehicle type		
Van*	101	845
2 axle light vehicle	116	2,454
2 axle heavy vehicle	83	1,110
3 axle vehicle	44	424
4 axle vehicle	15	402
>5 axle vehicle	19	501
Bus	36	257
Taxi	138	616
Prime mover	1	29
(9) Loading		
Empty*	103	1,375
Loaded	449	5,238
Overloaded	1	25

*: Reference variable

Table 16 The tabulation of the number of commercial vehicle moving above the 85th percentile speed of other vehicles with commercial vehicle driving behaviour

Category: Commercial vehicle characteristics/ Description of independent variables	85th % speed of other vehicles	
	Below	Above
(10) Lane occupancy		
Fast lane*	277	1,148
Second lane	141	1,437
Slow lane	135	4,046
(11) Presence of other moving vehicle		
No vehicle*	305	3,187
In between two vehicle	10	268
Beside a vehicle	179	2,276
In front of a vehicle	19	196
Tailing a vehicle	40	711

(12) Overtaking		
Being overtake	34	1,518
Overtaking	111	525
Not overtaking*	408	4,595
(13) Lane occupancy		
Fast lane*	277	1,148
Second lane	141	1,437
Slow lane	135	4,053
*: Reference variable		

Table 17 shows the results of two model estimations after several hours of computations. The mixed effect logistic regression result is divided into three sections: Fixed effects parameters, Random effects parameters or Hierarchical effects and Goodness-of-fit. After exhaustive attempts, there are only two models that are statistically significant to be considered; Model 1 and 2 are both statistically significant at the fixed and random parameters ($p<0.05$). In order to evaluate these models, each section of the table has to be examined.

Model 2 is better in explaining the factors and their variations in association with the occurrence of a commercial vehicle moving with excessive speed. From Table 17, both models hold the same fixed parameters except for the *Commercial vehicle driving behaviour* parameters (i.e. Moving with the presence of other moving vehicle, overtaking behaviour and lane occupancy) in Model 2. Since both models hold similar parameters, they also have almost similar odds ratios but different in statistical significant level. However, in testing the Goodness of fit of both models, it seems that Model 2 has a better fit than Model 1 based on the AIC, i.e. $AIC_{Model\ 2} < AIC_{Model\ 1}$. Moreover, Model 2 has more explanatory variables that are statistically significant ($p<0.05$) compared to Model 1.

The fixed effects parameters can be interpreted as a normal logistic regression. Thus, focusing on Model 2, we can see that *Expressway* roads ($OR_{Model\ 2} = 6.193$, 95% CI = 3.24–11.85) have the probability of **nine** times more likely than primary roads to have the commercial vehicle moving over the 85th speed of other vehicles. The analysis also shows that having a road *without paved shoulder* (or kerbed roads) and a road with *Median* has also the probability of **6** to **12 times** likely to have commercial vehicle moving at excessive speed (Without paved shoulder: $OR_{Model\ 2}$ = 2.241, 95% CI = 1.45–3.46, With median: $OR_{Model\ 2}$ = 11.808, 95% CI = 6.30–22.13) than road with paved shoulder and roads without road median. Moreover, roads with 60 km/h have the **highest likelihood probability** (16 times) of commercial vehicle moving with excessive speed compared to roads with speed limit of 70 km/h, 80 km/h, and 90 km/h.

In terms of commercial vehicle characteristics, the 2-axle light vehicle type ($OR_{Model\ 2}$ = 2.342, 95% CI = 1.07–5.13), 4-axle ($OR_{Model\ 2}$ = 3.662, 95% CI = 1.28–10.46) and the 5-axle or more vehicle type ($OR_{Model\ 2}$ = 4.123, 95% CI = 1.54–11.01) have **two** to **four** times likely to have commercial vehicle moving at excessive speed compared to a van. Surprisingly, a commercial vehicle that is loaded with goods ($OR_{Model\ 2}$ = 1.333, 95% CI = 0.97–1.83) are **more likely** to move with excessive speed compared to an empty commercial vehicle.

In terms of the driving behaviour that were displayed by commercial vehicle drivers, the model predicts that commercial vehicles that are tailing a vehicle ($OR_{Model\ 2}$ = 2.994, 95% CI = 1.94–4.63) and moving in between two vehicles ($OR_{Model\ 2}$ = 3.782, 95% CI = 1.73–8.25) are **three** to **four** times likely to move beyond the 85^{th} percentile speed, compared to those commercial vehicles that are moving without any other vehicle passing (see Table 17). The model also predicts that commercial vehicles that are being overtaken by other vehicles ($OR_{Model\ 2}$ = 2.912, 95% CI = 1.70–4.99) are **three** times likely to move with excessive speed compared to those commercial vehicles that are not overtaking other vehicles. Moreover, those commercial vehicles that moving into the second lane (i.e. middle lane out of three or more lane roads) ($OR_{Model\ 2}$ = 9.686, 95% CI = 6.62–14.17) and the slow lane ($OR_{Model\ 2}$ = 25.359, 95% CI = 17.05–37.72) are **10** to **25** times likely to move with excessive speed compared to commercial vehicles occupying the fast lane.

Table 17 Mixed effects logistic regression parameter estimates

Variables	Model 1				Model 2			
	OR	SE	95% C.I.		OR	SE	95% C.I.	
Fixed effects								
Intercept	1.352	0.94	0.35	5.30	1.201	0.70	0.38	3.76
Road hierarchy								
Espressway	6.193**	2.05	3.24	11.85	9.630**	3.58	4.64	19.97
Secondary	0.190**	0.05	0.11	0.32	0.109**	0.03	0.06	0.19
Collector	0.440*	0.22	0.17	1.15	0.232**	0.12	0.08	0.64
Road median								
With median	10.836**	3.32	5.94	19.76	11.808**	3.78	6.30	22.13
Number of lanes								
4 lanes	0.749	0.24	0.40	1.40	6.051**	2.34	2.84	12.91
6 lanes	0.014**	0.01	0.01	0.04	0.029**	0.01	0.01	0.08
8 lanes	0.026**	0.02	0.01	0.11	0.035**	0.03	0.01	0.16
Paved road shoulder								
Without paved shoulder	1.323	0.26	0.90	1.94	2.241**	0.50	1.45	3.46
Speed limit category								
60 km/h	7.486**	4.31	2.42	23.13	15.693**	10.18	4.40	55.98
70 km/h	4.910**	2.59	1.75	13.81	7.324**	4.29	2.33	23.07
80 km/h	2.336*	1.14	0.89	6.10	2.796*	1.52	0.96	8.11
90 km/h	3.930**	2.02	1.44	10.75	4.658**	2.57	1.58	13.72
Commercial vehicle type								
2 axle light vehicle	2.998**	1.03	1.52	5.90	2.342**	0.94	1.07	5.13
2 axle heavy vehicle	2.657**	0.98	1.29	5.48	2.010	0.87	0.86	4.68
3 axle vehicle	2.535**	1.01	1.16	5.53	1.969	0.90	0.80	4.82
4 axle vehicle	4.450**	2.08	1.78	11.14	3.662**	1.96	1.28	10.46
>5 axle vehicle	4.170**	1.81	1.78	9.76	4.123**	2.07	1.54	11.01
Bus	1.460	0.58	0.67	3.19	1.116	0.52	0.45	2.78
Taxi	0.880	0.32	0.43	1.80	0.875	0.38	0.38	2.03
Prime mover	7.309*	8.29	0.79	67.43	6.190	7.46	0.58	65.65
Loading								
Loaded	1.380**	0.20	1.04	1.83	1.333*	0.21	0.97	1.83
Overloaded	1.576	1.66	0.20	12.47	0.736	0.81	0.08	6.42
Presence of other moving vehicle								
In between two					3.782**	1.51	1.73	8.25

vehicle								
Beside a vehicle					1.843**	0.41	1.19	2.85
In front of a vehicle					1.706*	0.55	0.90	3.22
Tailing a vehicle					2.994**	0.66	1.94	4.63
Overtaking								
Being overtake					2.912**	0.80	1.70	4.99
Overtaking					0.686	0.17	0.42	1.12
Lane occupancy								
Second lane					9.686**	1.88	6.62	14.17
Slow lane					25.359**	5.14	17.05	37.72
Random effects/Hierarchical								
Level 1 (CV above 85th % speed)								
Intercept variance, σ^2_{e0}	1				1			
Level 2 (CV type), Num. of groups = 35								
Intercept variance, σ^2_{u0}	0.32	0.26	0.06	1.56	0.60	0.48	0.13	2.86
Level 3 (Zone) , Num. of groups = 4								
Intercept variance, σ^2_{v0}	0.17	0.11	0.05	0.59	0.23	0.15	0.06	0.83
Goodness-of-fit								
Number of observation	7191				7191			
Ll (model)	-1403.371				-1118.047			
df	25				33			
AIC	2856.741				2302.093			
BIC	3028.756				2529.153			
Integration method: mvaghermite								
Integration points	7				7			
Wald chi2	360.5				600.02			
P-value	0.000				0.000			
LR test vs. logistic regression:								
chibar2(01)	58.88				67.76			
Prob>=chibar2	0.000				0.000			

Intra-unit correlation:		
ICC Level 1, ρ1	0.872	0.799
ICC Level 2, ρ2	0.084	0.145
ICC Level 3, ρ3	0.044	0.056

OR: Odds ratio, SE: Standard Error, C.I.: Confidence Interval
CV: Commercial Vehicle
* p < 0.1, ** p < 0.05, ***= significant at p<0.05 level based on the likelihood ratio test versus ordinary logistic regression (fixed effect parameters)
mvaghermite: Mean-variance adaptive Gauss–Hermite quadrature
AIC: Akaike's Information Criterion, BIC: Bayesian Information Criterion

One of the key interests of fitting a multilevel model here is to determine if, after controlling for the variables in the fixed part of the model, there is any statistically significant variation in the *commercial vehicle moving with excessive speed* outcomes within a certain zone or commercial vehicle type attributes. The variance between the three levels of each model may be neatly summarised by the three parameters σ^2_{e0}, σ^2_{u0} and σ^2_{v0} (see Table 17: Intra-unit correlation). They are known as variance parameters, as they measure the variance in the parameters at Level 1, 2 and 3. In other words, they show the relative variability in the model residuals that may be attributed to the effects of *each Commercial vehicle* (at Level 1) and the variation of *Type of commercial vehicle* (at Level 2) and *Zone* (at Level 3), as seen in Figure 12. In this case, the Level 1 variance parameter is constrained to the value 1 to correspond to a binomially distributed response, as stipulated by Jones and Jørgensen (2003), and this value is multiplied by $\pi^2/3$, which is extensively described in Jones and Jørgensen (2003) and also in Rasbash et al. (2009).

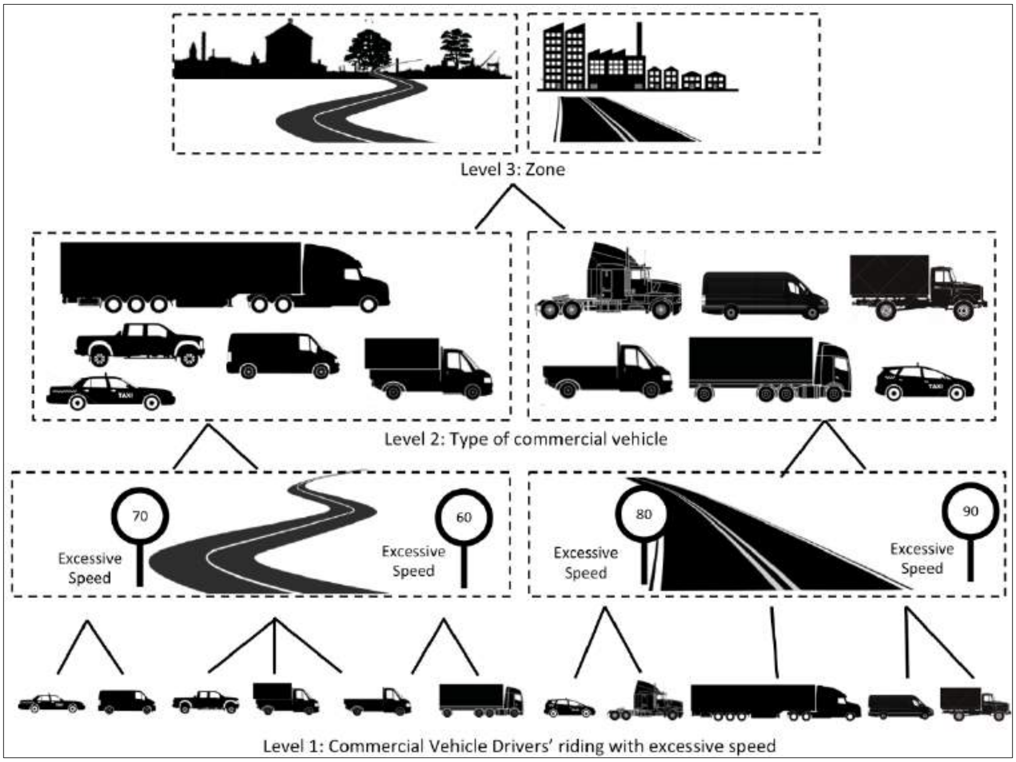


Figure 12 The diagram of the Mixed Effect Logistic Regression Based on Model 2

To estimate the proportion of overall residual variability, which is associated with each level, equation 3, 4 and 5 are used (see Table 17: Intra-unit correlation). Model 2 shows that 79.9% of the variations come from Level 1, i.e. *each commercial vehicle*, while the *type of commercial vehicle* (Level 2) and different type of *Zone (Level 3)* only constitute up to 14.5% and 5.6% respectively. Comparing the two models, Model 2's variations for Level 1 (14.5%) and Level 2 (5.6%) are higher than the variations in Model 1 due to the increasing number of explanatory variables (commercial vehicle driver's driving behaviour) into the model that reduces the variation at Level 1.

The high variation connected to *each commercial vehicle* may indicate that there can be additional *commercial vehicle drivers' characteristics and riding behaviour* associated with driving at excessive speed, which is yet to be identified. Furthermore, these variations also show that *commercial vehicle driver's characteristics and riding behaviour* are still the main factors compared to *Zone* and *type of commercial vehicle*. On the other hand, the level of variation for *Zone* associated with excessive speeding is lower than the other factors clearly indicate that the different type of zone may not be associated with excessive speeding. In other words, commercial vehicle may move with excessive speed regardless of the type of zones.

4. Conclusion and Recommendation

The data used in this study was collected from an observational study on various road hierarchies such as expressway, primary road, secondary road, collector road as well as non-exclusive motorcycle lane in Malaysia. This is to examine the effects of road characteristics on the occurrence of driving above the speed limit and excessive speeding. To ease the data reduction, a software known as CVSOC was specifically developed. The characteristics of the commercial vehicles such as the type of vehicle, speed, lane occupancy and moving manoeuvre were recorded.

A total of 7168 commercial vehicles were observed on the four types of roads. Nearly 50% of them were collected on primary roads. About one-third of the samples were light lorry with two axles while two axles heavy lorry constituted 16%.

Evidence from the results shows that most of the commercial vehicles travelled above the speed limits of the respective roads. When comparing with other vehicles in the traffic stream, the differential speeds were found statistically significant. The wide gap of speeds in the same traffic stream may elevate the risk of accidents. Johnson (2005) proved that there will be more interactions with other vehicles when a vehicle's speed differs from the mean speed, thereby increase the risk of accidents.

While divided road can reduce the potential head-on accidents, it was found that probability of speeding is increasing on the dual carriageway. The results were further reinforced by the model developed in this study where it shows that commercial vehicles were 12 times more likely to speed on the dual carriageway. It was also noted that the lower the speed limit, the higher the speed violation rates. This finding coupled with the high differential speeds among the traffic stream informs us that the risk of an accident is very high. To worsen the situation, lower speed limits are usually applied at the area where most of the human activities (i.e. pedestrian crossing or cycling activities) are anticipated.

Higher proportion of commercial vehicles travelled on the middle lane of the expressway and most of the commercial vehicles occupying the fast lanes were smaller in size. The 85^{th} percentile speed on the fast lane reached 103 km/h and was significantly different with other commercial speeds on the middle and slow lanes. Nevertheless, it should be highlighted that 10% each of the commercial vehicles with higher horsepower or high-performance trucks were observed travelling in the fast lane. It is quite alarming as it contributes to the overall risk of an accident.

On the other hand, it is interesting to see the opposite trend on non-exclusive motorcycle lane. Speeds of the commercial vehicles were relatively slower on the dual carriageway as compared to their counterparts on the single carriageway. Significant different of speeds between the two carriageway were observed among van, 2 axles light lorry, 2 axles heavy lorry and lorry with 4 axles and above. The high travel speeds on single carriageway may trigger another problem such as excessive overtaking that result in a head-on accident.

Based on the findings, it is suggested to segregate fast and slow moving vehicles as well as the vehicles and the vulnerable pedestrians. The mix of fast and slow road users creates serious problems and it increases the risk of head-on and rear-end accidents. In most of the accidents, the vulnerable road users are always being the victims. Nevertheless, segregation by non-physical painting (non-exclusive motorcycle lane) observed some illegal occupying of commercial vehicles particularly bus on the lanes. Proper designs of bus stop location, as well as side parking are of essential, especially in urban areas. Lane restriction on trucks as implemented in other countries may be considered to be applied on the local expressways. Apart from this, enforcement by the relevant authority is indeed equally important in managing the speeds as well as overloading issues.

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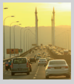

Research Report

A Study on Commercial Vehicle Speed and its Operational Characteristics

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