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COMPLIANCE AND NON-COMPLIANCE OF HEAVY VEHICLES LANE USAGE IN TOLL ROAD

Nahry Yusuf[1] and N. H. Hamid[2]
[1]Department of Civil Engineering, Universitas Indonesia, Kampus UI Depok, Jawa Barat, Indonesia
[2]Institute for Infrastructure Engineering, Sustainable and Management (IIESM), Universiti Teknologi Mara, Shah Alam, Selangor, Malaysia
E-Mail: norha454@uitm.edu.my

ABSTRACT

Heavy vehicles (HVs) are often considered as a hindrance in traffic flow especially at toll roads. Besides their large dimensions and slow movement, HVs also disrupt the traffic flow due to their indiscipline in using the lane that is designated to them. The aims of this study are to conduct a 24-hour traffic flow video recording data which divided into compliance and non-compliance state and to analyze the impact of HV drivers' indiscipline in using the HV lane on the traffic performance at Jakarta Outer Ring Road (JORR). By using the regression mathematical model, the traffic flow models of both states were generated to determine the impact of HV discipline on the traffic performance. The analysis shows that the frequency of HV indiscipline's during observation time is more than 70% of respondents. However, it turns out that the traffic in the non - compliance state is better due to the efficient space utilization. However, at very low density, the indiscipline does not affect the speed, but as the density increased, the speed of the non-compliance state is also increased by 28%. The actual road capacity of non-compliance state is also 17.5% greater than the one with compliance state. The efficiency of space utilization is also indicated by the higher jam density of non-compliance state for about 20.24%. In the current condition at JORR's, the density of vehicles is high for almost day time where the regulation concerning the HV lane restrictions becomes ineffective in improving the overall traffic performance. It is suggested to implement the access restriction for HVs during the day time only.

Keywords: compliance, heavy vehicle lane, lane usage, toll road, traffic flow.

1. INTRODUCTION

Congestion of vehicles becomes a crucial issue in many big cities and city centers around the world including Jakarta, Indonesia. The existence of toll roads with intended to become an alternative roadway which, free from obstacles has not been a solution to congestion problems in Jakarta. JIUT was the first ring road built in the central of Jakarta. It connects four neighboring cities of Jakarta, namely Bogor and Depok (southern part), Tangerang (western part) and Bekasi (eastern part) (Nahry, 2018). Due to the low traffic performance at Jakarta Intra Urban Toll Roads (JIUT), one of toll road system circles in the inner part of Jakarta had applied access restriction policy on certain corridors for the heavy vehicle (HV) for a specific time window such as from morning to evening. The policy certainly has an impact on the performance of congestions during specified times of the corridor window. In addition, if the policy was not implemented, its impact would have been worse than the current condition. It implies that the implementation of the policy is a right decision, though some parameters should be improved to attain sustainable transport system (Nahry, 2018).

At present, the Jakarta Outer Ring Toll Road (JORR) system with toll roads in the outer part of Jakarta has been experiencing the traffic performance decline when the overall ring road system was fully interconnected. The Jakarta Outer Ring Road W1 (JORR W1) was started operating in February 2010 as part of Jakarta Outer Ring Road System and alternative access for transporting goods toward the Tanjung Priok Port and Soekarno-Hatta Airport (Heru, 2012). The increasing numbers of heavy vehicles were suspected as one of the main reasons of the current traffic performance decline yearly. Currently, the JORR regulates HV to use the two outer lanes with the exception of passing another vehicle. However, the two outer lanes are not exclusively for HV, other types of vehicles are allowed to use it as well. This situation causes the JORR operator to propose access restriction policy for HV as implemented in JIUT. Before implementing the policy to the road users, a proper study needs to conduct by exploring other attempts in regulating HV movements rather than restrict them to use the JIUT. Access restriction has been commonly applied in several big cities; however, each city actually has its own specific characteristics which required understanding of local situations to ensure the policy application is implemented (Irbany *et al,* 2016).

A clear example of the characteristic difference is the driver's behavior. It is widely accepted that the driving behaviors vary between drivers, according to their ages, genders, ethnicities, driving experiences, emotions, and others (Kuge et al, 2000; Papacostas and Synodinos; 1988; Al-Hemound *et al*, 2010; Daimon *et al,* 2000). Even for the same driver, driving behavior may alter from one situation to another situation (Angkrititrakul *et al,* 2009), which can be attributed to the driver behavior characteristics. Wahab et al, (2007) believed that the differences of each driver in the driver characteristics are due to the way drivers' subconscious mind works and responds, and the conversion from subconscious to conscious minds would also generate unique responds to how the brains work. In many cities, especially in developed countries where the law enforcement has been done effectively, the truck drivers' level of discipline to use the HV dedicated lane is high. Therefore, the truck movements have minimum impact on the other vehicles. In this situation, the access restriction for specific corridor might be not necessary. However, when the number of trucks reaches a certain level, it is unavoidable to ban them at the specific time window, especially at the peak hours.

Based on the above current situation, an investigation on driver behavior is required, especially to observe drivers' compliance with lane usage and the impact on JORR traffic performance. This study can be useful as reference for JORR operators and other toll road operators in making decision to apply the access restriction policy.

2. FINDING FROM PREVIOUS RESEARCHERS

The increase of truck traffic has a large impact on highway transportation in many cities. In congested big cities, an increased truck traffic worsens the delay traveling time, road user safety, energy consumption, and emissions of carbon dioxide. Even though the local governments of most cities are aware the adverse impacts of freight on the urban environment but yet they do not know how to control goods transport activities (Dablanc, 2007). In general, local public policies regarding freight transportations are scarce and out-of-date. Most cities conduct and regulate freight activities using methods similar to 20 years ago by setting the delivery time windows to vehicles according to their size or weight. Most cities view truck traffic as something they should ban or at least strictly regulate (Qiu *et al*, 2015) and few of them considered freight activities as a service to help them organize in a more efficient manner (Dablanc, 2007). As a whole, the only means of control of freight traffic within the city are the municipal regulations on access, speed, parking, maximum vehicle dimensions and loads, and others. However, it is also noteworthy that in many countries, there are few controls and regulations that are seldom observed (Crainic *et al,* 2004).

Truck or HV lane restriction is the issue that is highly related to the existence of freight vehicle, where HV are restricted to use of designated lanes. In several cases, designated lane is exclusively dedicated to the HV movement. In some cases, the use of designated lane is less exclusive in which the lane can also be used for other types of vehicles. The HV lane designation has the same purpose with other strategies which is to achieve an efficient transport network in terms of delay time and enhanced safety that could be achieved by separating HV from other types of vehicles (Al-Eisaeia *et al*, 2017). Various studies had been conducted on HV lane restriction such as El-Tantawy *et al*, (2009) to implement algorithms for measuring safety at different scenarios of truck lane restriction and dedicated truck lanes using microscopic traffic simulation. They evaluated the safety measures of several HV lane restriction strategies using Paramics Microsimulation software at Gardiner Expressway in Toronto, Canada. Four lane management strategy simulations was carried out by taking into account different HV percentages and three measures of effectiveness, namely lane change, merging and rear-end conflicts. The results showed that the left dedicated HV lane provided the most efficient strategy in terms of the safety measures. The other finding was that HV lane management strategies were more efficient when the HV percentage was over 15%.

Abdelgawad *et al.* (2010) studied the impact of exclusive HV lanes on the network from a traffic efficiency perspective in Greater Toronto Area (GTA) in the United States of America. Moreover, Al Eisaeia *et al*, (2017) conducted a study on the impact of HV space restriction strategy for different class of HV on traffic congestion at one section of Princess Highway in Melbourne, Australia. VISSIM traffic simulation software was used to evaluate several restriction strategies. They found that by restricting all HV was deemed the most efficient restriction strategy in terms of the traffic. Kurle *et al*, (2016) considered lane utilization behavior in terms of lane utilization factor on each of the lanes using five different vehicle categories and taking Delhi-Gurgaon Expressway as a case study. The lane utilization factor of i^{th} lane was defined as the ratio of traffic volume of i^{th} lane to total volume. SPSS software is used for multivariate analysis in connection with a lane utilization factor over a wider range of traffic flow rates. Lane utilization was used as a dependent variable, and classified traffic volume, average speed of each category of vehicle, traffic composition and stream speed were used as independent variables in the multivariate analysis.

As discussed in earlier researches, the investigation on lane usage has many perspectives, in which the lane usage distribution can be connected to the maintenance, safety or flow efficiency issues. Most of the research works on lane usage and distribution are conducted in developed countries and the studies were conducted in countries with different traffic and drivers' characteristics with those in Indonesia, especially in the level of compliance with traffic regulations. Actually, drivers' behaviour is significantly affected by cultural differences among countries, including behaviour in lane changing and lane utilization (Ferrari, 1989; Ozkan *et al*, 2006; Gunay, 2007; and Nordaen and Rundmo, 2009).

Based on description factors above, an extensive study needs to be conducted by observing the characteristic of HV lane usage in JORR. It is represented by the drivers' discipline by using designated lane and the impact on overall traffic performance. The law enforcement on the HV lane usage regulation can actually improve the road performance by avoiding or postponing the restrictions for HV in the specific time corridor window.

3. RESEARCH METHODOLOGY

Figure-1 shows the flowchart of research methodology for compliance and non-compliance of heavy vehicle lane using the toll road. The activities involve in this empirical study are data collection using 24-hour video recording, data reduction, descriptive analysis, calibration of speed flow, density, model validation and comparison of compliance and non-

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compliance status. Figure-2 shows the visual observation of the truck lane usage at the selected JORR section with 75m long using 24-hour video recording during traffic data collection activity. The section under consideration is 4 lane divided road without any road shoulders. The recorded data was processed to get volume, density and speed per 5 minute intervals at four different vehicle types which are light vehicles, medium vehicles, large buses, and large trucks. In accordance with relevant regulations issued by toll road operators (Badan Pengatur Jalan Tol, 2016), the HV terminology in this research is used for two types of vehicle such as large bus and large truck. Then, the data were grouped into two states, namely compliance state (HVs use the designated two outer lanes) and non-compliant state (HVs do not use their designated lanes). Next, the data were analyzed through descriptive statistics analysis to determine the level of compliance for HV. Subsequently, this level of compliance refers to toll road operators' regulations which allow HV to use lane 3 and lane 4, with an exception of lane 2 when they passed other vehicles. Moreover, the threshold of non-compliant state was occurred when there are more than six HVs in two inner lanes.

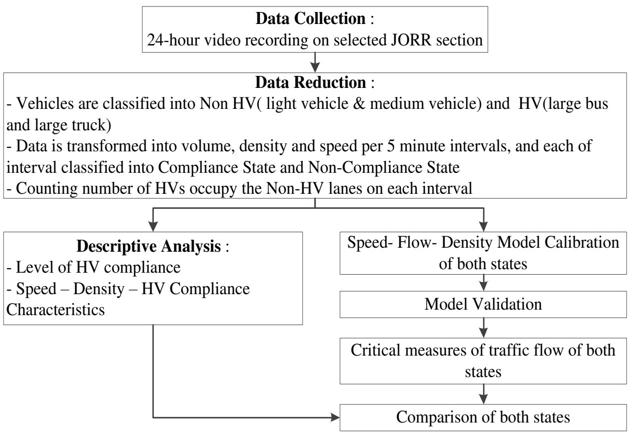

Figure-1. Flowchart for research methodology.

Figure-2. Observation at segment (JORR) on left side lane.

Furthermore, the threshold was set by considering the scarce condition of no HV using the inner lanes within 5 minutes. The condition at which the HV is in lane 2 to pass another vehicle didn't categorize as non-compliance. The measure of compliance is represented by the ratio of number of HV in the designated lane to the total number of HV with 5-minute interval. This measure is defined as a HV compliance percentage. From the data on volume and speed, the data from traffic density is derived based on two variables and a mathematical model is developed to describe the relation among the traffic flow variables using the regression technique. The calibration process of the model uses ± 80% of observation data. Furthermore, the calibrated traffic flow model is validated using ± 20% of observation data through ANOVA Test. By validating the model, cross-tabulation analysis was done to determine the impact of HV compliance using the designated lane on the overall traffic performance parameters.

4. RESULTS AND DISCUSSIONS

4.1 Characteristics of HV Compliance on Lane Usage

From a total number of 288 data based on 5-minute interval observation, 215 incidents with 74.65% were classified as non-compliance incident and 73 incidents with 25.35% were compliance incident. The average percentage of the HV in lane 3 and 4 which designated lanes for heavy vehicle as compared to the total number of HV during 5-minute interval is 55.59% which considered as compliance state. It means that more than half of the total HV is using the lanes designated for them, while the rest of them are using other lanes. The higher the score of compliance percentage means fewer HVs are using non designated lanes, with the exception when they are passing another vehicle. From both of these parameters, we can conclude that the non-compliance incident of more than 70% is quite significant for this study. In addition, the percentage of non-compliant HV (per 5-minute interval) is also quite big, which is 44.41% of the total vehicles passing through lane 2 and lane 1. This data showed that the regulations on the lane designation for the HV is not followed and fully complied yet.

Figure-3 describes the pattern of traffic density per 5 minute interval for the percentage of HV compliance. It can be observed that non-compliance incidents occur almost all day with almost random pattern and quantities. However, based on the trend of those three parameters during 24 hours, the observation period can be divided into 4 time groups, namely 00.00-05.00, 05.01-12.00, 12.01-19.00, 19.01-24.00. The mean of each parameter in each time group is shown in Table-1. From midnight to early morning (00.00-05.00) when average density is 15 pcu/km (with 29% of HV), average % of HV compliance is 51%. In this time group, total volume and density are at the lowest, so that HVs have more space for movement. This result was more opportunity of HV to use lane 1 and 2. In the next time group, namely 05.01-12.00 with average total volume is increased to 419 pcu/5 minutes and density is 218 pcu/km. During this period, the average % of HV compliance is 59%. This number shows that the HV is only 7% of total vehicles is more compliant in using their designated lanes. This might be triggered by higher volumes of other types of vehicles, more congested

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traffic, and the presence of toll road patrols or traffic policemen to ensure the smoothness of traffic flows.

In the afternoon time group, namely 12.01-19.00 where average volume is still stable in 393 pcu/5minutes with less density as 144pcu/km and % of HV is 6%, the HV compliance is declining to 52%. This might be caused by less surveillance by the toll road patrol or police. After 19.00 to midnight, the traffic flow is smoother, where volume is decreased to 213 pcu/5minutes and the density is low (35 pcu/km), and the average HV compliance increased to 61%. Under time group, % of HV starts to increase around 10%. With the smoother traffic flow, the HV compliance is better. In the next time group, with the fast increasing number of HV, where the traffic flow is quite low and HV compliance is declining again.

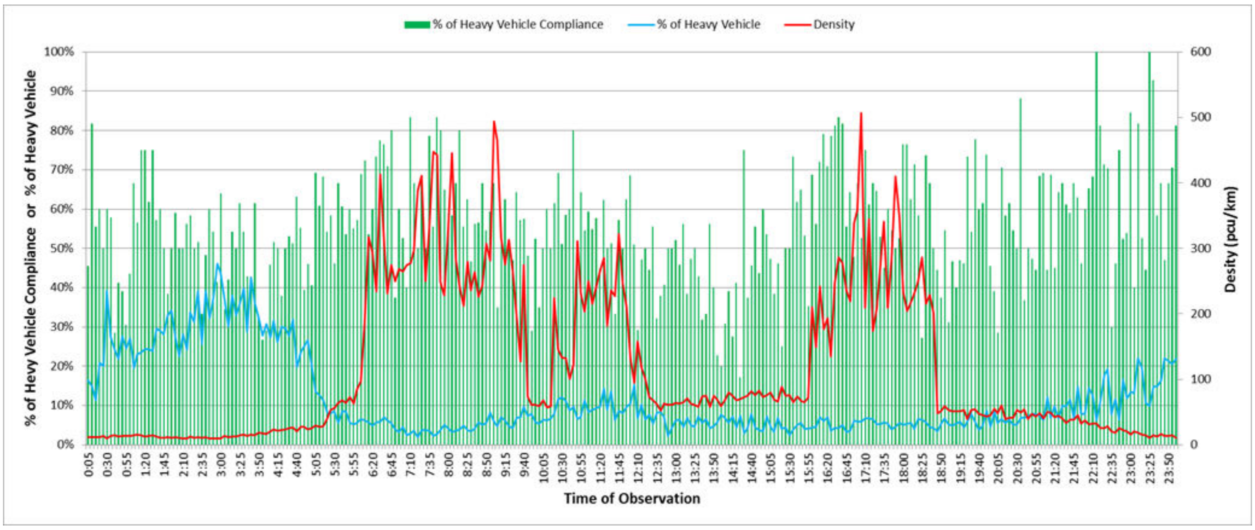

Figure-3. Density of vehicles during time of observation.

From the above description, there is a correlation between traffic volume and density, % of HV and the presence of toll road patrol or policemen on the road which associated with HV compliance in using their designated lanes. Compliance decline as the density is low, especially when the HV composition is high. On the contrary, when density level is high and the HV composition is low, the compliance is better. This is also due to the more intensive inspection by toll road patrol. Correlation test (Pearson) and *p*-value (Pearson) with a significance level α=0.05 are done to see the correlation among the density, % of HV and % of HV compliance quantitatively. The tests results were strengthened the trend in Figure-3 whereas the density is higher, % of compliance increases, the higher the % of HV and the lower the HV compliance.

Table-1. Categorized four-time period of observation.

Period of Observation	Average Volume (pcu/5minutes)	Average Density (pcu/km)	Average of % of HV	Average of % of HV Compliance
00.00-05.00	103	15	29%	51%
05.00-12.00	419	218	7%	59%
12.00-19.00	393	144	6%	52%
19.00-00.00	213	35	10%	61%

4.2 Speed Characteristics

Furthermore, the analysis is conducted to see the trend of speed change of HV as well as non-HV and the density by taking into account the HV compliance. Figure-4 shows the trend at which the time when the HV is compliant and non-compliant during the observation time. It is evident that as the speed of non-HV is almost always higher than the speed of HV in both states, and they are experiencing speed change in a relatively similar pattern. This statement can be strengthened by the correlation test with significance level α=0.05, which is showing quite a high correlation among the density, speed of HV and speed of the non-HV (ranged between 0.855 ~ 0.938). From the correlation score, it is shown that the increased density reduces speed for both types of vehicle and the increase or decrease in speed of HV is followed by the increase or decrease in speed of non-HV. Table-2 shows that in the morning time group with vehicle density is low, the speed of both types of vehicle is relatively high and there is quite a big difference in average of speed (24.87 km/hour). However, starting at 5 a.m., when the vehicle density is increasing, the speed of both vehicle types is

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decreasing, with speed difference that is not very significant (8.32 km/hour). As the density decreased in the afternoon, especially at 13.00 clock, the speed is increasing, and it is going back to decrease in the late afternoon (16.00) during the peak hours. In 19.00 the density is decreased and it impacts the speed to be increasing, where the speed difference between the two types of vehicle is also widening (24.02 km/hour).

Table-2. Average speed of heavy vehicle and non-heavy vehicle.

Period of Obser vation	Non Heavy Vehicle		Heavy Vehicle		Average Difference between HV speed and Non-HV speed (km/hour)
	Average Speed (km/hour)	Standard Deviation (km/hour)	Average Speed (km/hour)	Standard Deviation (km/hour)	
00.00-05.00	94.09 (136% of HV's speed)	12.08	69.23	11.24	24.87
05.00-12.00	38.16 (128% of HV's speed)	27.56	29.84	22.22	8.32
12.00-19.00	53.77 (122% of HV's speed)	27.71	44.12	23.49	9.66
19.00-00.00	79.10 (144% of HV's speed)	9.51	55.08	14.69	24.02
Entire day	63.65 (133% of HV's speed)	30.70	47.96	23.92	15.69

4.3 Speed, Density and Volume Relationships

Figure-5 shows the relationship between speed and density of 221 data HV for non-compliance states. The R-squared value for the curve is 0.8101. Meanwhile, Figure-6 shows the relationship between volume and density of 221 data HV for non-compliance state with R-squared value of 0.667.

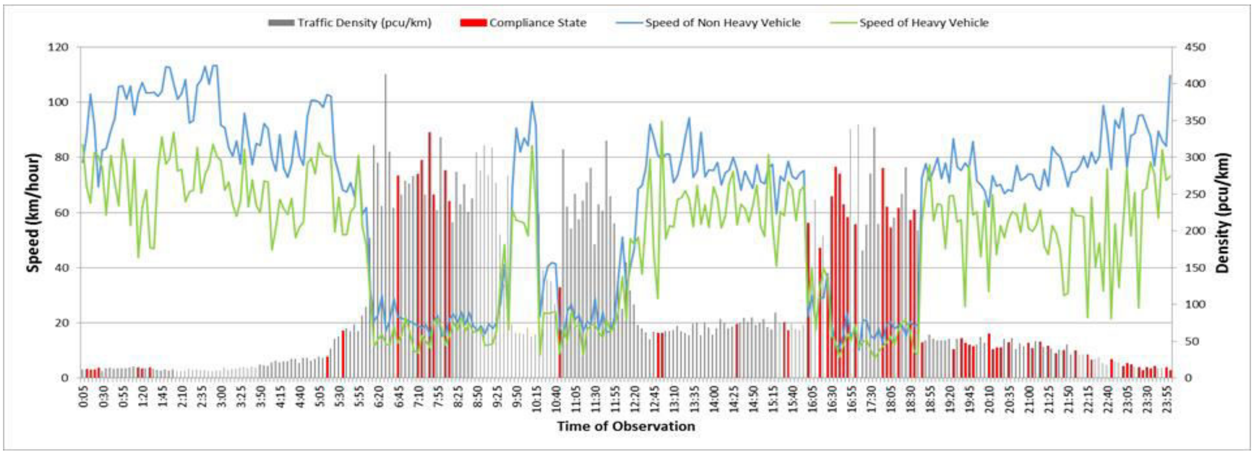

Figure-4. Correlation of density, speed of HV and non-HV

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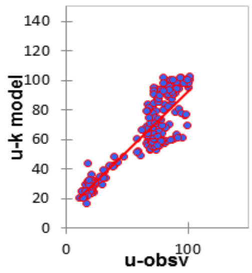
Table-3. Correlation Test of Non-Compliance State.



Correlation matrix (Pearson):

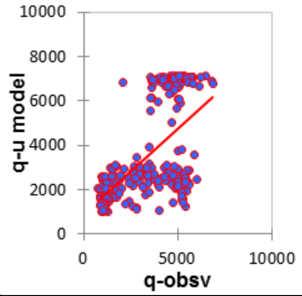
Variables	u-obsv	u-k model
u-obsv	1	**0.900**
u-k model	**0.900**	1

Values in bold are different from 0 with a significance level alpha=0.05

p-values (Pearson):

Variables	u-obsv	u-k model
u-obsv	0	**0.000**
u-k model	**0.000**	0

Values in bold are different from 0 with a significance level alpha=0.05



Correlation matrix (Pearson):

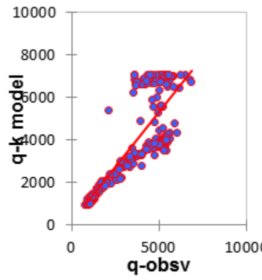
Variables	q-obsv	q-u model
q-obsv	1	**0.587**
q-u model	**0.587**	1

Values in bold are different from 0 with a significance level alpha=0.05

p-values (Pearson):

Variables	q-obsv	q-u model
q-obsv	0	**0.000**
q-u model	**0.000**	0

Values in bold are different from 0 with a significance level alpha=0.05



Correlation matrix (Pearson):

Variables	q-obsv	q-k model
q-obsv	1	**0.817**
q-k model	**0.817**	1

Values in bold are different from 0 with a significance level alpha=0.05

p-values (Pearson):

Variables	q-obsv	q-k model
q-obsv	0	**0.000**
q-k model	**0.000**	0

Values in bold are different from 0 with a significance level alpha=0.05

Whereas, Figure-7 shows the relationship between volume and speed for non-compliance state with the value of R-squared is 0.345. At non-compliance state, there is a situation where the HV is using its designated lanes and non-designated lanes. It can be recognized that the incidents would occur when the HV is non-compliant in all traffic situations. By using the regression techniques, it was found that a Log-model was the best model to connect all the variables as mentioned above using the trend line as shown in Figure-5, Figure-6 and Figure-7. The correlation parameters between observation data and the regression model is shown in Table 3. It can be observed that the models connecting the three pairs of variables have a good Pearson correlation coefficient between 0.587~0.900 with significance level α=0.05, and the score of *p*-values. Furthermore, it can be concluded that the regression model can represent the observation data well (Sander *et al,* 2016; Kristin, 2010).

In contrast, Figure-8, Figure-9 and Figure-10 show the distribution of 55 data HV for the compliance state. Figure 8 shows the relationship between speed and density curve line to represent the HR compliance state with R-squared value of 0.8531. Figure-9 shows the relationship between volume and density in compliance state which is represented as a curve trend line with R-squared value of 0.682. Meantime, Figure-10 shows the relationship between volume and speed for compliance state which represented as a regression curve with R-squared value of 0.424. Under compliance state, HV is compliant to use the designated lanes during the observation time interval with the exception that HV passes other vehicles in front of them. It was found that Log-model is also the best model to represent these data, where the Pearson correlation coefficient for the three models ranging between 0.651~0.924 with the significance level α=0.05. Under the situation where the HV was at a compliant state which is represented by regression model which is obtained from observation data with *p*-value.

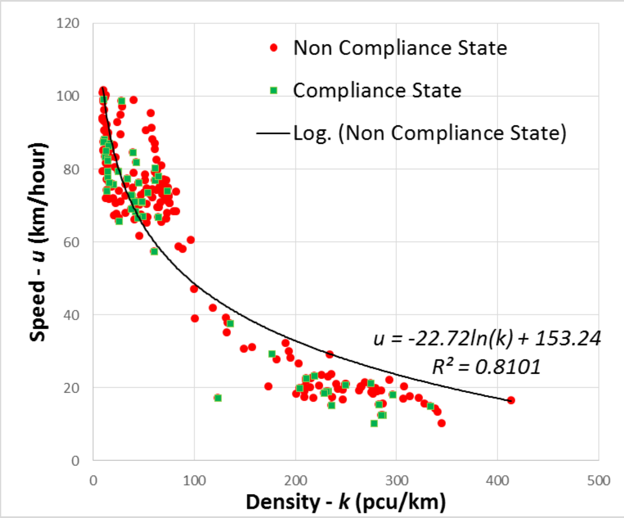


Figure-5. Speed-Density Relationships for Non-Compliance State.

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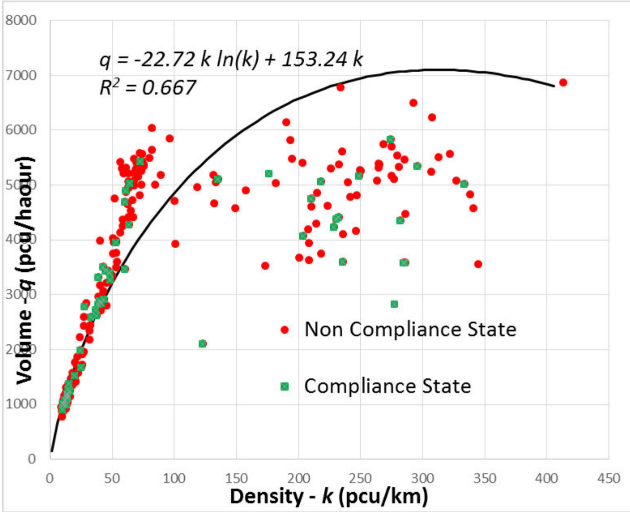

Figure-6. Volume-Density Relationships for Non-Compliance State.

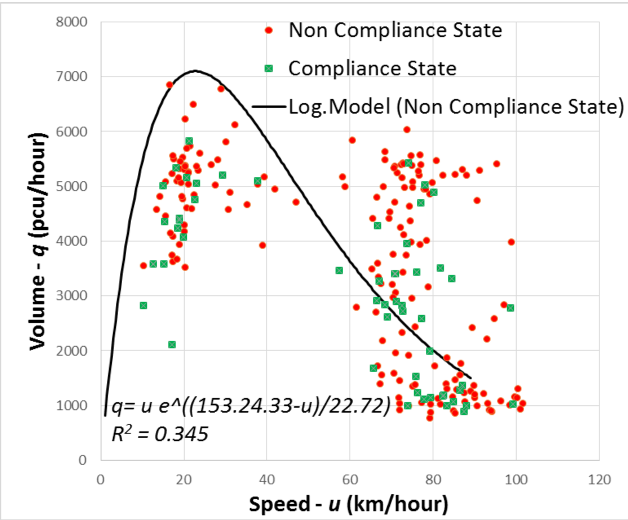

Figure-7. Volume-Speed Relationships for Non Compliance State.

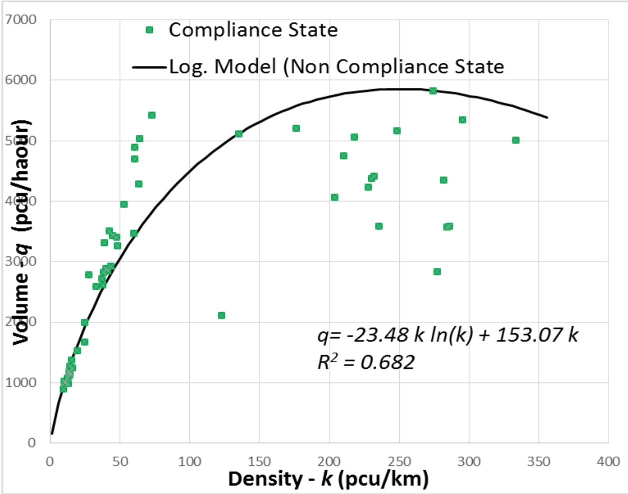

Figure-8. Speed - Density Relationships for Compliance State.

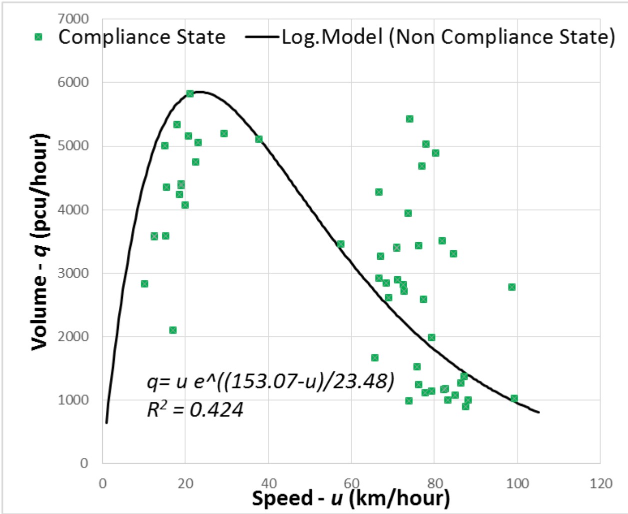

Figure-9. Volume - Density Relationships for Compliance State.

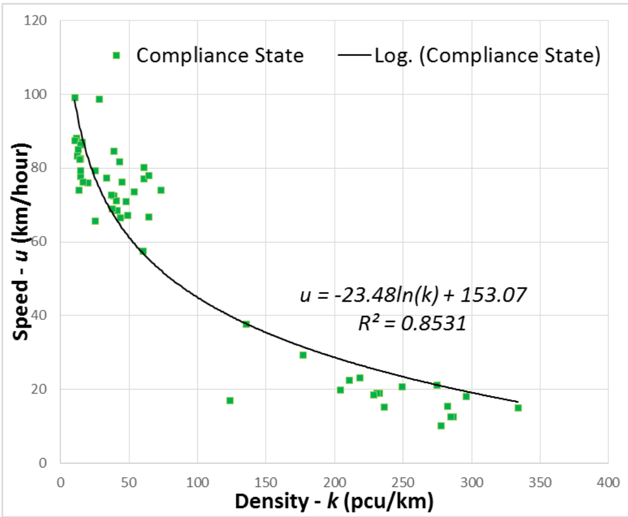

Figure-10. Volume - Speed Relationships for Compliance State.

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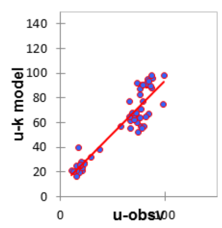
Table-4. Correlation Test of Compliance State.



Correlation matrix (Pearson):

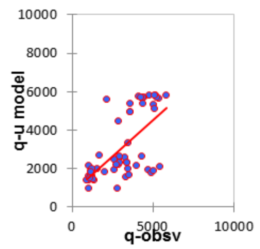
Variables	u-obsv	u-k model
u-obsv	1	**0.924**
u-k model	**0.924**	1

Values in bold are different from 0
with a significance level alpha=0.05

p-values (Pearson):

Variables	u-obsv	u-k model
u-obsv	0	**0.000**
u-k model	**0.000**	0

Values in bold are different from 0
with a significance level alpha=0.05



Correlation matrix (Pearson):

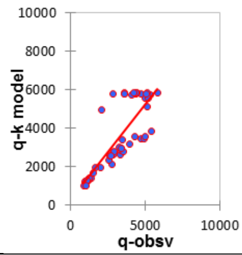
Variables	q-obsv	q-u model
q-obsv	1	**0.651**
q-u model	**0.651**	1

Values in bold are different from 0
with a significance level alpha=0.05

p-values (Pearson):

Variables	q-obsv	q-u model
q-obsv	0	**0.000**
q-u model	**0.000**	0

Values in bold are different from 0
with a significance level alpha=0.05



Correlation matrix (Pearson):

Variables	q-obsv	q-k model
q-obsv	1	**0.826**
q-k model	**0.826**	1

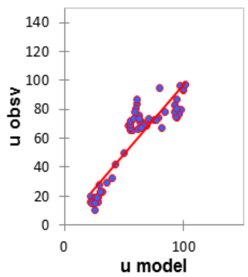
Values in bold are different from 0
with a significance level alpha=0.05

p-values (Pearson):

Variables	q-obsv	q-k model
q-obsv	0	**0.000**
q-k model	**0.000**	0

Values in bold are different from 0
with a significance level alpha=0.05

Table-5. Correlation Parameters of Validation Test.



Correlation matrix (Pearson):

Variables	u model	u obsv
u model	1	**0.904**
u obsv	**0.904**	1

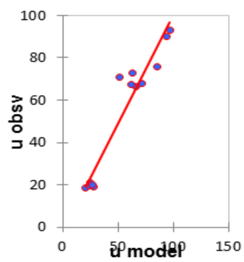
Values in bold are different from 0
with a significance level alpha=0.05

p-values (Pearson):

Variables	u model	u obsv
u model	0	**0.000**
u obsv	**0.000**	0

Values in bold are different from 0
with a significance level alpha=0.05

a. Correlation Test of Validation Test of Non-Compliance State



Correlation matrix (Pearson):

Variables	u model	u obsv
u model	1	**0.962**
u obsv	**0.962**	1

Values in bold are different from 0
with a significance level alpha=0.05

p-values (Pearson):

Variables	u model	u obsv
u model	0	**0.000**
u obsv	**0.000**	0

Values in bold are different from 0
with a significance level alpha=0.05

b. Correlation Test of Validation Test of Compliance State

Table-4 summarizes the correlation test for compliance state of speed with density, volume with the density and volume with speed. Furthermore, the model validation for both states is conducted using ± 20% of observation data (13 data for compliance and 56 data for non-compliance state). By using correlation test towards observation data and calibrated model, Table-5 shows the correlation parameters for validation test between the observation data and model for non-compliance and compliance state. Therefore, it can be concluded that this model is valid to be used for this study. Next, it is important to compare the finding between non-compliance and compliance states.

4.4 Comparison between Compliance State and Non-Compliance State

In order to determine the effectives of HR using the designated lane for toll roads, it is essential to compare the traffic characteristics of compliance and non-compliance states using the mathematical models. Figure-11 shows the comparison between compliance and non-compliance states for speed and density relationship. It can be noted that the non-compliance curve has slightly higher value than compliance status and the speed performance of the non-compliant state is better than the compliance state for various traffic densities. The speed difference for both states is increasing with the increase in density of HV. When the traffic density is very low, the speed difference between both states is close to zero. It means that the non-compliance HV are using designated lanes in this situation does not have any impact on the overall traffic speed. However, along with the increase in density, the speed difference for both states becomes bigger. As the density is 400 pcu/km, the speed of non-compliance state is higher by 4.72 km/hour (28%) than the speed of the compliance state. In this condition, the non-compliance of HV can actually increase the overall traffic speed. This might be caused by the optimized use of the non-HVs lane by the HV. Thus, if the efficiency using lane utilization is improving, then the overall vehicle speed is also improved. Although the speed difference between both states is only 4.72 km/hours, but 28% percentage is still significant by considering the speed for the high density for both states only ranges between 12-17 km/hour. Table 6 tabulates the mathematical equations for speed-density relationship, volume-density relationship and volume-speed relationship under compliance and non-compliance states.

Figure-12 shows the comparison of volume and density relationship for compliance and non-compliance states. When the density of the HV increases, the volume for both states is also increasing. In the very low density,

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the traffic volume will be the same in both compliance and non-compliance state. It means that during the low density, all the vehicles are free to choose which lane to use, but the non-compliance of HV does not have any impact on the traffic flow. However, with the increase in density, non-compliance of HV can actually increase the overall volume with the same reason explained previously such as optimized lane usage. Figure-13 shows the comparison between volume and speed relationship under compliance and non-compliance states. Table-7 presents speed, density, actual capacity and maximum density under compliance and non-compliance states. It can be seen that the actual road capacity of non-compliance state is 7101 pcu/hour which higher 17.50% than the one of compliance state of 5857 pcu/hour. Lane usage efficiency is also indicated on the jam density of the non-compliance state (850 pcu/km) which is 20.24% higher than the one of compliance state (678 pcu/km). However, the speed in the maximum flow condition for both states only differs by 3.34% for 22.72 km/hour and 23.48 km/hour under the non-compliance and compliance state, respectively.

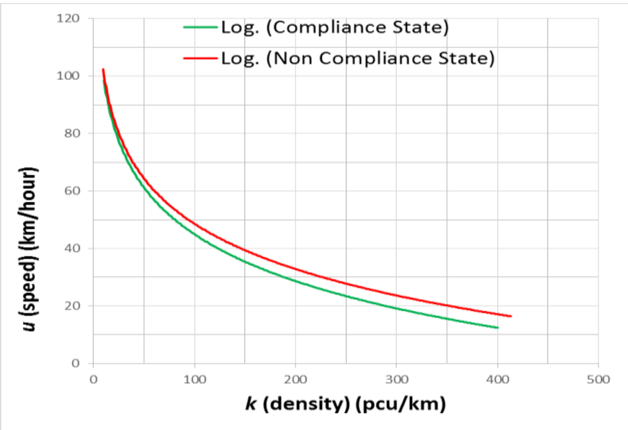

Figure-11. Speed - Density Relationships for Compliance and Non-Compliance State.

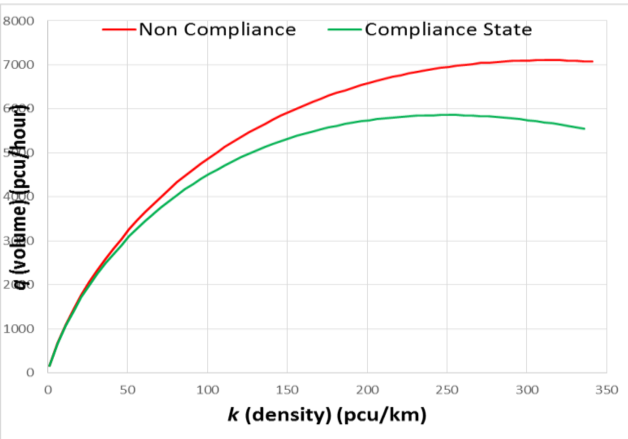

Figure-12. Volume versus density relationship.

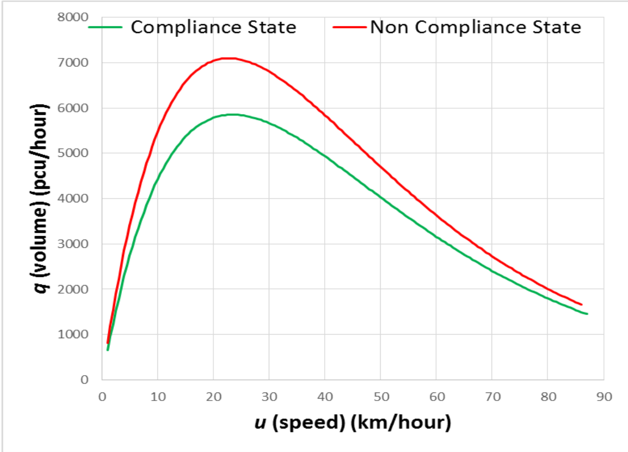

Figure-13. Volume - Speed Relationships for Compliance and Non-Compliance State.

5. CONCLUSIONS AND RECOMMENDATIONS

In this study, the observation video recording was conducted to determine the behavior of the HVs in complying with regulations on the toll road lane designation. The results show that the non-compliance incidents of HV during the 24-hour observation is quite high which is more than 70 %. Besides that, the high incidence frequency and the number of non-compliant HV in each 5-minute time interval is also enormous which is 44.41% of the total number of HV in the time interval. This result also shows that the regulation for lane designation for the HV is not yet fully complied and followed. From the analysis, it shows that there are some correlations between traffic volume, density and % of HV with the compliance on lane designation. The inspection of the toll patrol on the HV compliance also has an impact on the lane designation compliance. In a very low density, the speed of HV and non-HV is relatively high, but with the speed difference that is quite big between the two. However, with the increase in density, where the speed of both vehicle types is decreasing, the speed difference between them is becoming not very significant. As compliance and non-compliance state are compared, the speed performance of non-compliance state is better than the one of compliance state, for various traffic density levels. When density is very low, the speed difference between the two states is close to zero, which means the HVs using any lane is not impacting the overall traffic speed. However, with the increase in density, the speed difference between the two states is getting bigger, where at the density of 400 pcu/km; the speed in non-compliance state is higher by 4.72km/hour (28%) than the speed in compliance state. The situation at which the non-compliance state is better than the one of compliance is caused by the improved efficiency in lane usage in non-compliance state, where all the road space could be more utilized so that the overall vehicle speed (not the speed of individual type of vehicle) and actual road capacity is improved. However, these results do not mean that the non-compliance situation can be maintained, because various literatures show that the lane changing of HVs can increase the risk of accident. In case of JORR, where the density is already quite high in almost all the day and the HVs' discipline is very low, regulation on lane designation for the HV become ineffective to improve the overall traffic flow performance. With this current condition, it may be time already to have access restrictions for the HVs.

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Table-6. Volume, Density and Speed Relationship.

State	Speed-Density Relationship	Volume-Density Relationship	Volume - Speed Relationship
Non Compliance	$u = 153.24 - 22.72 \ln(k)$ (R^2= 0.8101)	$q = 153.24\,k - 22.72\,k\,\ln(k)$ (R^2= 0.667)	$q = u\,e^{\left(\frac{153.24-u}{22.72}\right)}$ (R^2= 0.345)
Compliance	$u = 153.07 - 23.48\,ln(k)$ (R^2= 0.853)	$q = 153.07\,k - 23.48\,k\,ln(k)$ (R^2= 0.682)	$q = u\,e^{\left(\frac{153.07-u}{23.48}\right)}$ (R^2= 0.424)

Table-7. Critical Measures of Traffic Flow Model.

State	u_m (km/hour)	q_m (pcu/hour)	k_m (pcu/km)	k_j (pcu/km)
Non Compliance	22.72	7101	313	850
Compliance	23.48	5857	249	678

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