

The impact of truck access restriction on toll road traffic performance

Nahry Yusuf¹ and Grace Helen Yuliana Tambun^{1,*}

¹Department of Civil Engineering, Universitas Indonesia, Depok, Indonesia

Abstract. The freight vehicle access restriction policy in 2011 has had an impact on the performance of the Jakarta Intra Urban Toll way (JIUT) system. Though most of the truck operators are not in favour of this policy, truck restriction has become common strategy to reduce congestion in many cities in the world. The purpose of this study is to analyse the impact of the existence of trucks in the traffic stream on the JIUT system. The analysis will show the impact of access restriction on the toll road performance from a macroscopic point of view, which is represented by the speed - flow - density model. The model will be calibrated by the data of 24-hour observation in a certain segment of JIUT. The model when the trucks are prohibited to use in that condition will be compared to the one when the trucks are allowed to travel. The difference between both models will indicate the impact of the policy. The comparison between both conditions shows a 28.17% better speed performance based on free flow speed and 28.17% higher efficiency at maximum flow rate. This study will benefit the toll operator as well as local transport authority in making decisions on similar policy in order to gain a more optimal advantage of the implementation.

1 Introduction

As the capital of Indonesia, Jakarta experiences a massive amount of logistics activities. The main choice for freight carriers in DKI Jakarta is by land vehicles, especially trucks. Trucks are believed to be the most efficient choice concerning cost, especially in urban areas [4]. However, within the city, there is a clash between freight carriers and urban traffic. Large trucks are perceived as slow-moving and are hindering the free flow movement of traffic [2]. Their activity is presumed to worsen congestion in urban traffic, particularly during peak hours.

One of the most popular measures to deal with a city's logistics and capacity limitations is a truck restriction. The truck restriction has been implemented in several cities, such as Bangkok, Seoul, and Paris, to mitigate traffic congestion [2]. By restricting large trucks during peak hours and shifting their activity to night deliveries, it is possible to avoid interference with urban traffic during rush hour.

On June 20th, 2011, the Ministry of Transportation Republic of Indonesia issued Ministerial Regulation No. 62 regarding the operation time arrangements for large freight

* Corresponding author: helentambun@hotmail.com

vehicles on Jakarta Intra Urban Tollway (JIUT), particularly the Cawang-Tomang-Pluit segment, from 10.00 p.m.-05.00 a.m.. After the regulation was applied, JIUT's traffic performance improved. However, in contrast, other segments in DKI Jakarta are experiencing over-capacity due to the shifting of freight carriers.

Based on this condition, it is necessary to evaluate the performance of the traffic in the Cawang-Tomang-Pluit segment of JIUT due to this restriction on a macroscopic level. Based on previous researches, a macroscopic level is considered most appropriate for understanding the phenomenon of traffic flows and analyzing the overall operational efficiency of the system [3]. The objective of this paper is to create a macroscopic traffic stream model and analyze the performance of JIUT due to the truck restriction regulation.

The research is based on the observation of traffic condition for two days on the Cawang-Tomang-Pluit segment of JIUT (Fig. 1). A traffic flow model was created to show the effect of truck restriction.

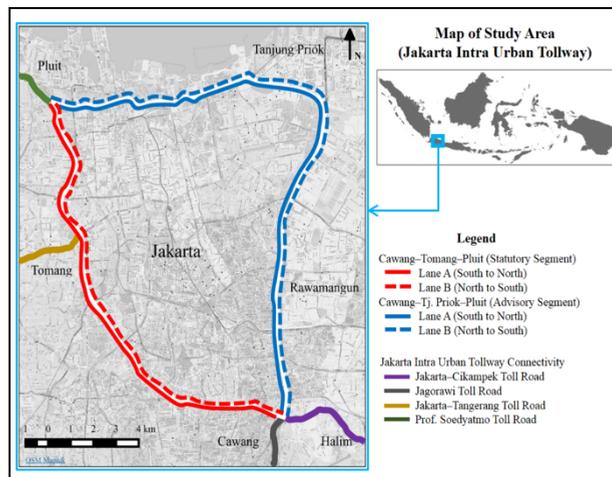


Fig. 1. Jakarta Intra Urban Tollway system [5].

2 Research methodology

The research was initialized by 48-hour traffic recording on the selected road segment, i.e., km 5+600 – km 5+700 (Fig. 2). The road's longitudinal slope is -0.2%. The recorded videos were then processed to obtain the traffic variables, namely traffic volume (q), space mean speed (s), and traffic concentration (k). A five-minute time interval was taken in accordance with [6] where time intervals between 5 and 15 minutes are appropriate for computing flow rates per hour. Space mean speed was gained by calculating the travel time of 30 sample vehicles passing through the study section for every five minutes.

To analyze the traffic from a macroscopic approach, mathematical models were created to represent the relationship between traffic characteristics [7]. These models represent the dependency among the three traffic variables [1].

The most common methods of modeling the relationship between traffic variables are the existing methods from Greenshield (1935), Greenberg (1959), and Underwood (1961) [3]. These models use a single-regime two variables approach. Therefore, a single function was developed by calibrating two traffic variables, e.g., flow and speed, flow and density, and density and speed. From the models, other useful parameters can be inferred, such as maximum flow (q_j), free flow speed (u_f), space mean speed at maximum flow (u_m), and maximum traffic density (k_j).



Fig. 2. Study section of research on Jakarta Intra Urban Tollway.

The Greenshield model (1935) develops a linear function between space mean speed (s) - traffic density (k) and parabolic function between traffic volume (q) - space mean speed (s) and traffic volume (q) - traffic density (k). The Greenberg model (1959) creates a logarithmic function between s - k and parabolic function between q - s and q - k , while the Underwood model (1961) develops an exponential function between s - k and parabolic function between q - s and q - k .

The models were divided into two states, (1) model to represent the traffic without truck activity and (2) model to represent the traffic with truck activity. The first model was formed by using traffic characteristics from 05.00 a.m. to 10.00 p.m.. The second model was formed by using traffic characteristics from 10.00 p.m. to 05.00 a.m. as the variables. The empirical data were calibrated into the Greenshield model, Greenberg model, and Underwood model, as well as a Multi-Regime model. Finally, the best model was selected for both states, and the comparison was made to analyze the effect of the truck restriction.

3 Results and discussion

3.1 Traffic characteristics

Fig. 3 shows the observation result of speed, density, and flow rate in Truck Restriction State (05.00 a.m. to 10.00 p.m.), while Fig. 4 shows that of Non-truck Restriction State (10.00 p.m. to 05.00 a.m.). Due to contra-flow happening every workday from 06.00 a.m. to 09.30 a.m., the observation data on that time interval were eliminated.

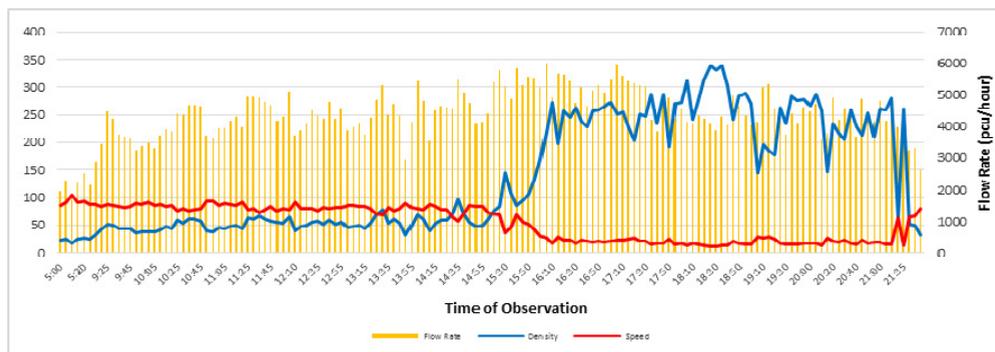


Fig. 3. Speed, density, and flow rate in Truck restriction state.

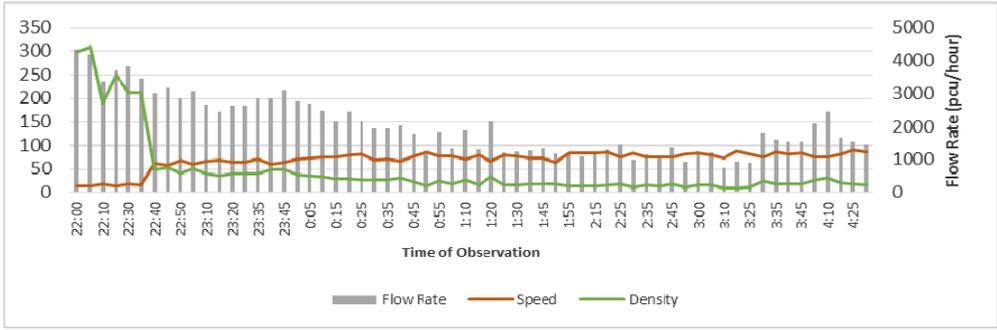


Fig. 4. Speed, density, and flow rate in Non-Truck Restriction State.

3.2 Speed, flow rate, and density relationship

Model calibration was done using 147 data of truck restriction state and 139 data of non-truck restriction state. Using the correlation test, the Exponential Model is selected as the best model to represent the observation data of both states. The Pearson correlation coefficient (R) value ranged between 0.74-0.99 for truck restriction state and 0.83-0.97 for non-truck restriction state, with a significance level $\alpha = 0.05$.

Furthermore, model validation was conducted by calibrating 20% of the observation data from the second day survey. From the validation test, the value of R for truck restricted state ranged between 0.851-0.997 and for non-restricted state ranged between 0.881-0.996. In conclusion, the models are valid representations of both states.

Eq. 1, 2, and 3 show the mathematical model of truck restriction state with exponential regression and Fig. 5a-5c show models that represent the speed-flow-density relationships in truck restriction state.

$$u = 114.85 e^{-0.007 k} \tag{1}$$

$$q = 677.66 u - 142.86 u(\ln u) \tag{2}$$

$$q = 114.85 u e^{-0.007 k} \tag{3}$$

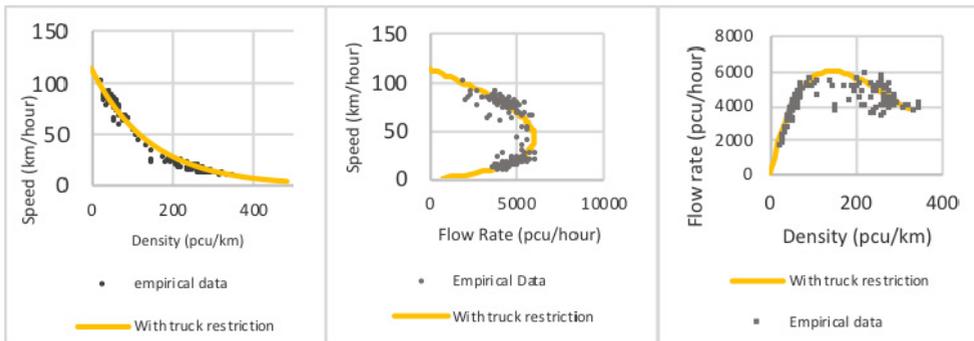


Fig. 5a Speed-Density relationship of traffic in Truck Restriction State.

Fig. 5b Speed-Flow Rate relationship of traffic in Truck Restriction State.

Fig. 5c Flow Rate-Density relationship of traffic in Truck Restriction State.

Eq. 4, 5, and 6 show the mathematical model of truck restriction state with exponential regression and Fig. 6a-6c show models that represent the speed-flow-density relationships in truck restriction state.

$$u = 89.61 e^{-0.007 k} \tag{4}$$

$$q = 642.21 u - 142.86 u(\ln u) \tag{5}$$

$$q = 89.61 u e^{-0.007 k} \tag{6}$$

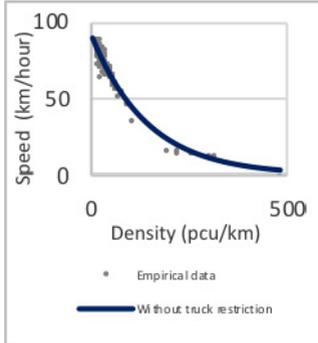


Fig. 6a Speed-Density relationship of traffic in Non-Truck Restriction State.

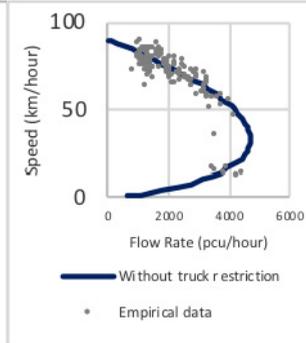


Fig. 6b Speed-Flow Rate relationship of traffic in Non-Truck Restriction State.

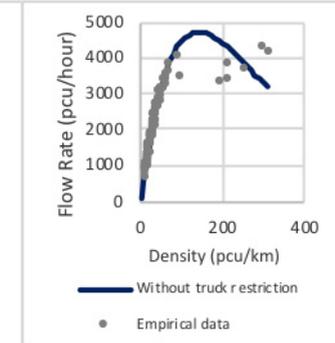


Fig. 6c Flow Rate-Density relationship of traffic in Non-Truck Restriction State.

3.3 Comparison of truck restriction state and non-truck restriction state

Table 1. Traffic parameters comparison of truck restriction state and non-truck restriction state.

State	N _{data}	q_m (pcu/hour)	u_m (km/hour)	u_f (km/hour)	k_m (pcu/km)
Truck restriction	148	6035.85	42.25	114.85	142.86
Non-truck restriction	134	4709.38	32.95	89.61	142.90
(%)		28.167%	28.22%	28.166%	0.02%

where q_m = maximum flow rate, u_m = speed at maximum flow rate condition, u_f = free flow speed, k_m = jam density.

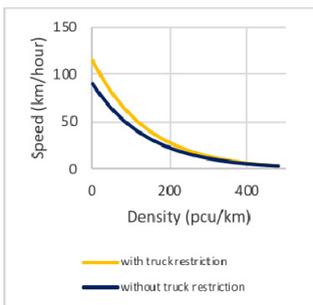


Fig. 7a Speed-Density relationship of Traffic in Truck Restriction State and Non-Truck Restriction State.

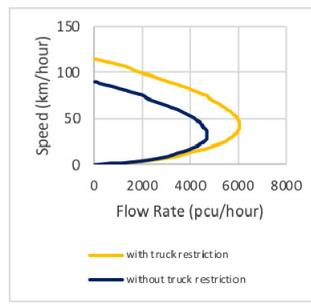


Fig. 7b Speed-Flow Rate Relationship of Traffic in Truck Restriction State and Non-Truck Restriction State.

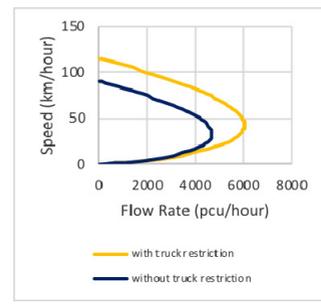


Fig. 7c Flow Rate-Density Relationship of Traffic in Truck Restriction State and Non-Truck Restriction State.

Fig. 7a-7c and Table 1 show the comparison of the flow-speed-density relationship between the two states. Based on Fig. 7a, there is a significant difference between both states on low-density traffic. The free flow speed (u_f) of truck restriction state is 114.85 km/hour, 28.166% higher than non-truck restriction state, the value of which is 89.61 km/hour. This shows there is a higher road efficiency in the traffic without truck activity. According to the literature, a truck moves at a slower pace, causing a decreased speed of traffic. Trucks also impact the characteristics of vehicles around them to reduce their speed, hence, and reduce traffic efficiency. This condition proves that truck activity impacts the traffic low-density condition.

On the other hand, the speed difference in both conditions decreases with the increase in density. When the density is 400 pcu/km, the value of speed in both states only differs in 1.54 km/hour. In high-density traffic, vehicles on both states show the similar condition of speed regardless of the restriction. This may be caused by the lack of space on the road, causing vehicles not to be able to move as freely.

Fig. 7b shows higher efficiency in truck restriction state. Truck restriction causes a higher chance of road utilization as more vehicles can occupy the road capacity. The maximum flow rate of truck restriction state (6035.85 pcu/hour) is significantly higher, by 28.167% than non-truck restriction state (4709.38 pcu/hour). The speed of maximum flow rate is also 28.22% higher in truck restriction state, a difference of 9.3 km/hour, verifying the improvement of performance in truck restriction state.

Fig. 7c shows the relationship between flow rate and density. In low-density condition, the difference of flow rate from both states increases significantly to the density of the maximum flow rate condition (km). This condition shows that truck restriction state presents a higher chance of vehicles to choose lanes because there is more free space. However, the values of density at a maximum flow rate in truck restriction state (142.86 pcu/km) are lower by 0.02% than non-truck restriction state (142.9 pcu/km). At maximum flow rate, vehicles in each state show a similar ability for lane-changing. In high-density condition, the difference of flow rate between both states decreases with the increase of density, proving that the ability of lane-changing in this condition grows smaller as the flow rates get higher.

4 Conclusions

The analysis on traffic model comparison shows that truck restriction state has better performance than non-truck restriction state, mainly in low-density condition. The speed performance in truck restriction state is significantly better in low-density traffic, with a higher value of free flow speed, i.e., by 28.166%. On the other hand, the vehicles in both states have similar performance in high-density condition. The efficiency of truck restriction state is also presented by a higher maximum flow rate, at 1326.4 pcu/hour (28.167%) and higher speed at a maximum flow rate, at 9.3 km/hour (28.22%). Both conditions show the performance improvement caused by truck restriction. Vehicles move more efficiently without the presence of truck activity. This situation supports the literature that the vehicles around trucks tend to move slower to maintain a distance from the trucks. On the other hand, as the density becomes higher, traffic shows quite similar performance.

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