Traffic Flow Analysis at T-Junction Near University in Jakarta Based on The LWR Model

Christianto Herpin, Margaretha Ohyver, Viska Noviantri

Abstract—**Jakarta is Indonesia's most congested city. Studying Jakarta's traffic flow is interesting so related parties can devise an optimal traffic management plan to minimize congestion. This study applies the Lighthill-Whitham-Richards (LWR) as a macroscopic model but modified it to a microscopic approach. This model can analyze traffic dynamics through the relationship between traffic flow, density, and speed under the Greenshield function. These models emphasize the role of critical density in triggering congestion. The T-junction of Rawa Belong Road and Kyai H. Syahdan Road in Jakarta, Indonesia, an area near a major university, was chosen here to get the data. This location is significant as the university's high student population contributes to unique traffic patterns and congestion, especially during peak periods. The data (the number of vehicles) was collected during off-peak hours (09:00 - 10:00) and peak hours (17:00 - 18:00). Then, it was observed based on road capacity to get the traffic category: free flow, moderate, or congestion. The simulation results show that density, speed, and traffic flow have a nonlinear relationship. Finally, average speed is the primary determinant of maximum current capacity.**

Index Terms—**Congestion, LWR, Microscopic modeling, Traffic Density, Traffic Flow, Road Capacity.**

I. Introduction

THE continuous increase in vehicle volume in modern urban areas has made traffic congestion one of the main problems faced by society today. According to data from the Central Bureau of Statistics (Indonesia), the number of vehicles in Indonesia has consistently risen over the years, with 126.5 million vehicles in 2018, 133.6 million in 2019, 136.1 million in 2020, 141.9 million in 2021, 148.221 million in 2022. This growth is particularly pronounced in major urban cities like Jakarta, where the vehicle population has surged significantly. From many resources, it makes Jakarta one of the world's most traffic-congested cities. The growing number of vehicles in Jakarta has contributed substantially to the overall rise in Indonesia's vehicle count, with 19.8 million in 2019, 20.2 million in 2020, 21 million in 2021, and 21.8 million in 2022. This steady growth shows no sign of stopping and is expected to continue in the coming years.

Congestion occurs when road space requirements exceed capacity, causing delays and reducing road efficiency. Analyzing traffic flow is very important to overcome this problem effectively, and it can be done using many approaches, including mathematical modeling. Yang and Liu [1] predict the chaotic traffic flow using time series. The results show that this method's prediction error is smaller than that of the neural network and least squares method. Traffic flow prediction can also be analyzed by higher-order graph convolutional network model [2]. The comparative experiments applied here for some datasets show good MAPE for accuracy. Belkadi et al. [3] use Arrhenius-type look-ahead rules in traffic flow models from nonlocal conservation laws. This model is solved numerically by an unstaggered central scheme to compare the accuracy with another scheme.

The Lighthill-Whitham-Richards (LWR) Model is widely used to analyze traffic flow. This model, introduced in 1955, is a macroscopic model that describes the relationship between vehicle density and traffic flow. Using an approach based on partial differential equations, the LWR model allows us to analyze changes in vehicle density at a certain point that affect vehicle flow along the road. This approach is very relevant for identifying potential congestion, predicting the development of traffic waves, and providing solutions that can be implemented to optimize traffic flow.

Many researchers use LWR models to analyze traffic flow using various approaches. In 2018, Maciejewski [4] used the LWR m model to compare density and speed by constructing density-dependent and speed-dependent equations. This study determined which formulation is more favorable to analyze traffic flow. Stochastic LWR model applied by Martinez and Jin [5] to heterogeneous vehicles. It allows us to investigate the impact of driver heterogeneity on macroscopic relations of traffic flow, both through simulations and analytically. The computational method to solve Local Fractional LWR in a Fractal Vehicular Traffic Flow has been released by Dubey et al. [6]. Agrawal et al. [7] use a two-dimensional LWR model for the continuous macroscopic longitudinal and lateral dynamics traffic flow. This model was applied to bicycle simulation and reproduced the evolution of the lateral density profile with asymmetric behavior.

More specifically, the traffic jam at the T-junction is interesting to observe. At T-junctions, minor roads meet main roads, and merging vehicles from minor roads creates traffic jams. This condition occurs due to significant vehicle interactions, which reduces road capacity and causes congestion [8]. This situation has been described for some regions by different researchers, such as in Cibiru-Cileunyi (Indonesia) [9], Pekeliling-Perak (Johor, Malaysia) [10], University of Benin Main Gate [11]. The area surrounding a university is one of the busiest places, frequently experiencing significant traffic congestion [12],[13],[14], and [15]. With a constant flow of students, the roads around the university are often overwhelmed, particularly during peak hours when classes begin or end. Furthermore, residential and business areas and the public transportation network around the campus

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Fig. 1. The map of The T-junction of Rawa Belong Road and Kyai H. Syahdan Road. Source: Google Earth

significantly influence increasing traffic volume and often cause congestion and delays.

One of the private universities in Indonesia that attracts a lot of student interest is located in a densely populated area. The culinary business, with low prices to meet students' needs, has also attracted the attention of people outside campus. This situation presents a complex traffic environment. To better understand the traffic conditions in this area, this study applies the LWR model to analyze traffic behavior and identify key congestion points. The research is conducted on the T-junction of Rawa Belong Road and Kyai H. Syahdan Road, Jakarta, Indonesia, focusing on traffic behavior in this area. The study examines traffic behavior on a macroscopic scale to analyze traffic patterns during peak hours, identify congestion points, and study traffic waves. Under this study, we may develop strategies to optimize traffic flow based on the model's findings.

II. Literature Review

The Lighthill-Whitham-Richards (LWR) model is one of the earliest and most influential macroscopic models in traffic flow theory. The model was independently introduced by Lighthill and Whitham in 1955 and later extended by Richards in 1956 [9,10]. The LWR model is rooted in fluid dynamics, where traffic flow is treated as a continuous stream, similar to the flow of liquids. This approach marked a significant departure from microscopic models, which focus on individual vehicles by instead concentrating on traffic density, flow rate, and speed as collective quantities.

The Lighthill-Whitham-Richards (LWR) model is based on the principle of conservation of vehicles, which means that vehicles within a section of road cannot simply appear or disappear; their number remains constant as they move along the road. Lighthill and Whitham derived the fundamental equation based on this conservation law, which relates to traffic density, as can be seen below:

$$\frac{\partial p(x,t)}{\partial t} + \frac{\partial q(p)}{\partial x} = 0, \tag{1}$$

where $p(x,t)$ represents the traffic density (vehicles per unit length) at position x and time t, while $q(p)$ is the flow rate (the number of vehicles passing a point per unit of time), which depends on the density $p(x,t)$

The Greenshield model complements the LWR model by providing a simple linear relationship between vehicle speed and density, which is essential to describe the flow rate in traffic analysis. It shows in the following equation:

$$v = v_{max}\left(1 - \frac{p}{p_{max}}\right). \tag{2}$$

Here, the flow rate $q(p)$ given as

$$q(p) = p.v(p). \tag{3}$$

Substitute (2) into (3) then

$$q(p) = v_{max}p\left(1 - \frac{p}{p_{max}}\right). \tag{4}$$

where v and v_{max} represent the vehicle speed and the maximum vehicle speed, respectively. The maximum speed of a vehicle when density approaches zero (when the road is clear), while p_{max} is the maximum density at which vehicles cannot move (speed approaches zero). Under the equation (4), the traffic flow is influenced by both the number of vehicles and their speed, which depends on traffic density.

The integration between Greenshield and LWR models provides the basic concept of the relationship between speed, density, and flow rate as the critical components of traffic flow analysis [16], [17], [18]. By defining a linear relationship between vehicle speed and density, the Greenshield model enables the derivation of the flow-density relationship, represented by a parabolic function. Moreover, these integrations give a more comprehensive analysis of traffic dynamics, including identifying congestion points and understanding traffic behaviour over time and space. Vehicles are free to move at high speed if the density is low. However, as density increases (approaching the critical point), traffic congestion increases, so speed decreases. This form of adaptation to local density provides variations between flow and speed, which are influenced by changes in traffic conditions.

III. Data and Simulation

A. Data Collection

The study is conducted at the T-junction between Rawa Belong Road and Kyai H. Syahdan Road . This intersection was selected because it connects two main Binus campuses, Anggrek and Syahdan campuses, making it a critical point for traffic congestion. This study focuses on merging traffic flow with two incoming and one outgoing flow in T-junction, as shown in Figure 1. In this picture, the incoming traffic describe by Segment A (Rawa Belong Road, which goes to the T-junction), and Segment B (Kyai H. Syahdan Road, which goes to the T-junction). The outgoing traffic describe by segment C (Rawa Belong Road, which goes from the T-junction).

In this study, the data collected will include the number of vehicles passing through the Segments A, B, and C at specific times. The times selected for observation are during the off-peak hours, from 09:00 to 10:00, and the peak hours, from 17:00 to 18:00. The data collection process involves counting the number of vehicles passing through each segment at the intersection over 60 minutes. The counts are recorded for each road segment, capturing incoming and outgoing traffic in T-junction. It will be used to analyze traffic dynamics at the intersection at different times of the day, including quiet and peak hours.

These data collections can be seen in Figure 2-4. From all these figures, we can see that the number of vehicles during off-peak hours fluctuates more than during peak hours. In peak hours, the number of vehicles increases with time. Furthermore, the order of road segments from the highest number of vehicles to the fewest during peak hours is Segment C which is up to more than 100 vehicles, Segment A which is 100 vehicles, and Segment B which is less than 90 vehicles. It makes sense since two segments (A and B) go to the T-junction and only one (C) outgoing from it.

B. Road Capacity

The dimensions (width and length) of the road affect the traffic flow passing over it. It is related to the road capacity as the one of important components in traffic dynamics. Road capacity define in different way depend on the assumption [19],[20],[21]. According to the Indonesian Road Capacity Manual, The road capacity can be calculated using the following formula:

$$Road\,Capacity = \frac{Road\;Area}{Vehicle\;Area}, \tag{5}$$

TABLE I
Road Capacity

Road	Free Flow	Moderate	Congestion	Total
A	0 - 44	45 - 88	89 - 133	133
B	0 - 39	40 - 78	79 - 117	117
C	0 - 44	45 - 88	89 - 133	133

and the road capacity is divided into three categories: free-flow, moderate, and congested, with maximum concentrations are

$$Free\;Flow = \frac{1}{3} \times total\;road\;capacity \tag{6}$$

$$Moderate = \frac{2}{3} \times total\;road\;capacity \tag{7}$$

$$Congested = \frac{3}{3} \times total\;road\;capacity \tag{8}$$

In this research, we use the following assumptions:

1) All vehicles are of the same type, with a length of 2 meters and a width of 1.5 meters, giving each vehicle an area of $3m^2$.
2) The observed road segments include 100 meters of Rawa Belong Road from the north with a road width of 4 meters, 100 meters of Kyai H. Syahdan Road from the east with a road width of 3.5 meters, and 100 meters of Rawa Belong Road to the south with a road width of 4 meters.

Under these assumptions, the road capacity in this intersection can be determined using equation (5):

1) Road capacity from the north (Rawa Belong Road) going to the T-junction:
$$A = \frac{100 \times 4}{3} = 133\,vehicles$$
2) Road capacity from the east (Kyai H. Syahdan Road) going to the T-junction :
$$B = \frac{100 \times 3.5}{3} = 117\,vehicles$$
3) Road capacity outgoing from the T-junction to the south of Rawa Belong Road:
$$C = \frac{100 \times 4}{3} = 133\,vehicles$$

,

IV. Result and Discussion

A. Road Capacity Citeria

Table I gives the maximum capacity in each category in each road based on equation (6) - (8). Based on this table, the range of vehicle numbers for each category for segment A and C is the same because the road dimensions are the same. Figures 5 - 7 illustrate the number of vehicles according to road capacity. The green and yellow lines describe the maximum limit for the number of vehicles for free flow and moderate conditions, respectively.

Based on Figure 5, it can be seen that the road condition is moderate on Segment A at 09.00. Then, by 09:19, it starts to flow freely until 10.00. Furthermore, the road condition is moderate also at 17:00, increasing vehicle numbers over

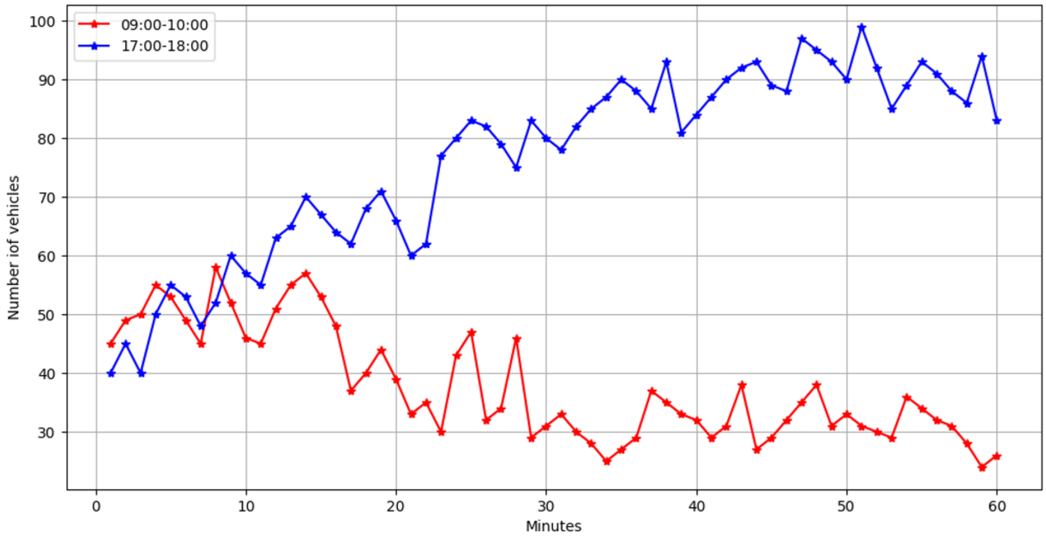

Fig. 2. The number of vehicles at Segment A from 09:00-10:00 and 17:00-18:00

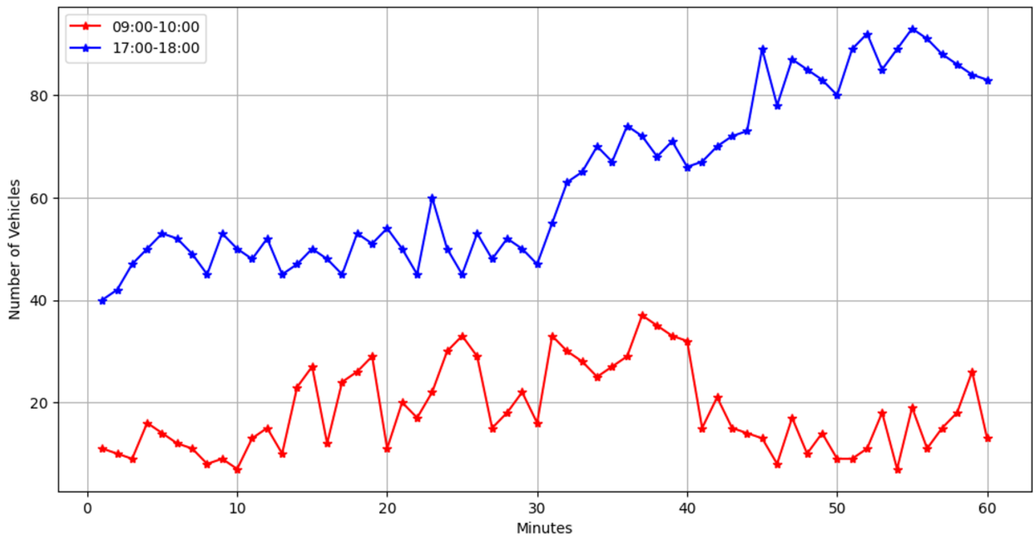

Fig. 3. The number of vehicles at Segment B from 09:00-10:00 and 17:00-18:00

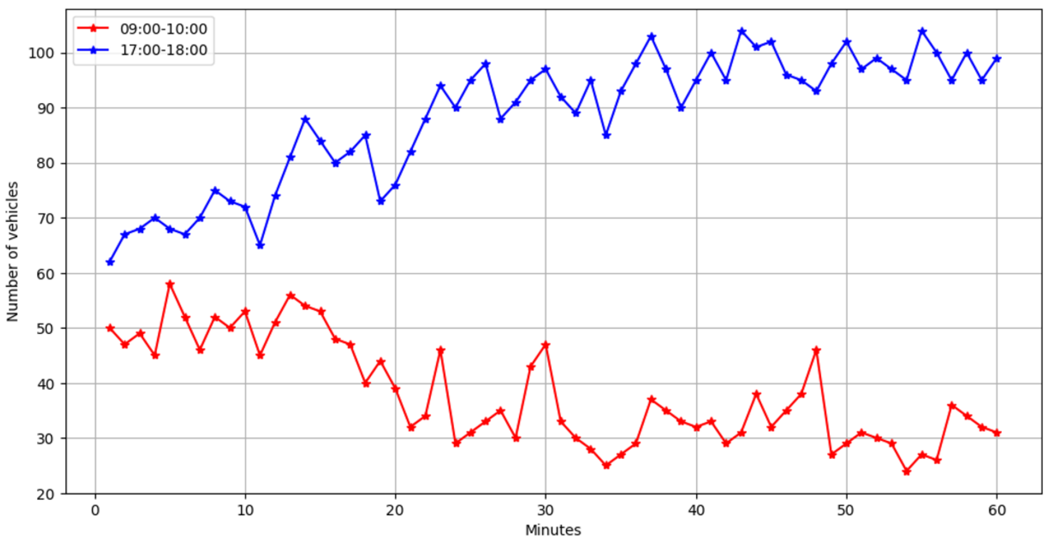

Fig. 4. The number of vehicles at Segment C from 09:00-10:00 and 17:00-18:00

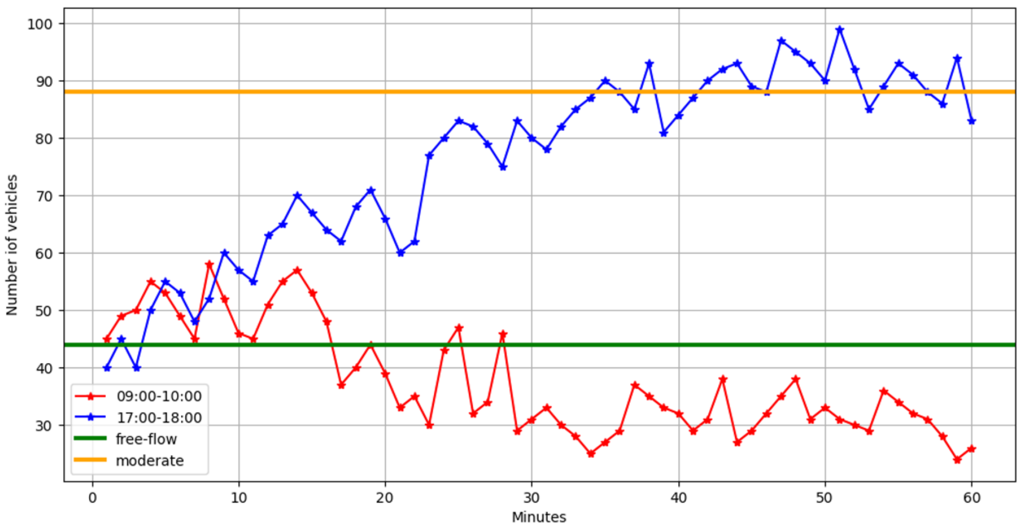

Fig. 5. The number of vehicles at Segment A according to road capacity

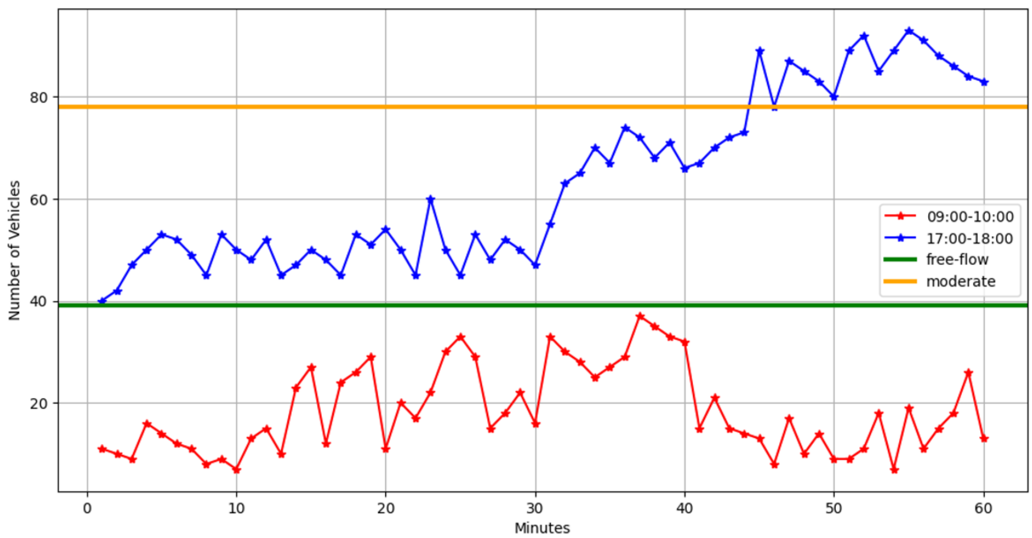

Fig. 6. The number of vehicles at Segment B according to road capacity

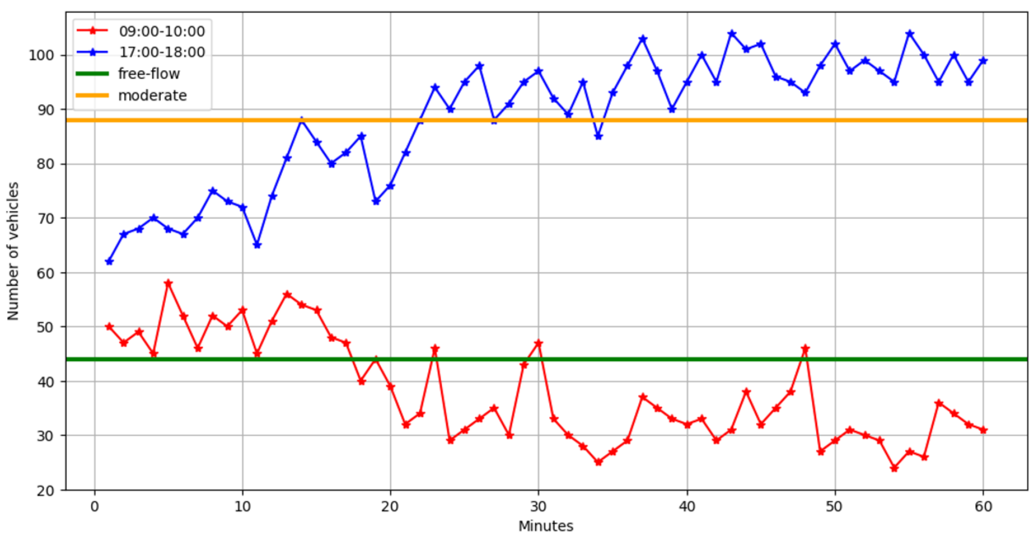

Fig. 7. The number of vehicles at Segment C according to road capacity

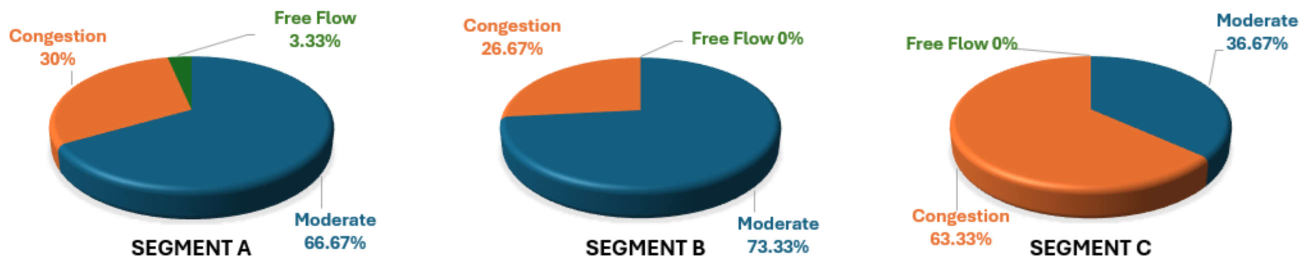

Fig. 8. Traffic category percentage for each segment

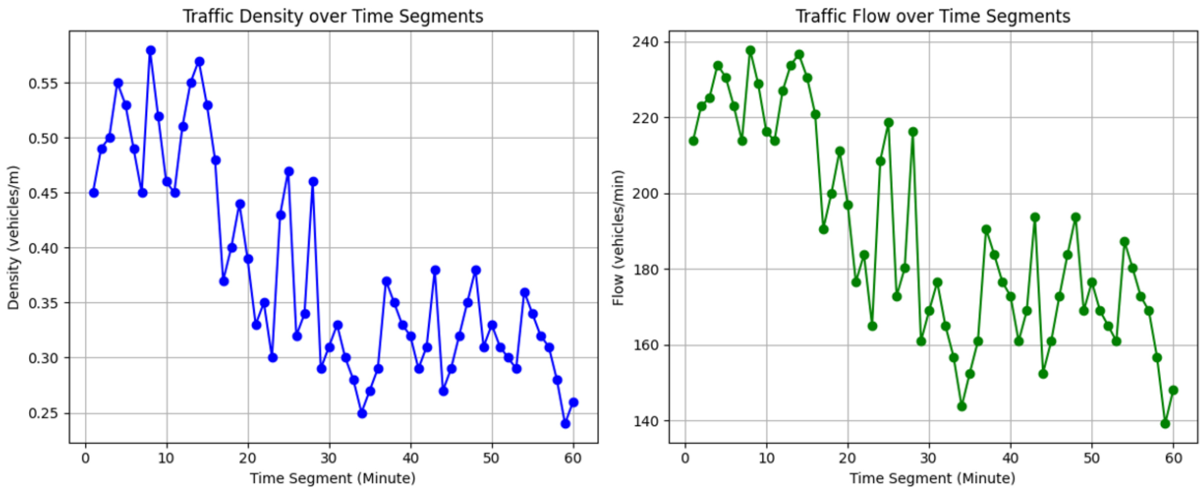

Fig. 9. The traffic density and flow over time on Segments A between 09.00 – 10.00

time. Then, the traffic eventually reaches a congested state at 17:35 when the vehicle numbers are more than 89. The same pattern is shown in Figure 7. The Segment C is moderate at 09.00. However, by 09:18, the road started to flow freely until 10:00. At 17:00, the road condition began as moderate, with the number of vehicles increasing. Eventually, it reaches a congested state at 17:23, faster than at Segmnet A. The different condition occurs on Segment B as in Figure 6. This road is free-flowing from the east at 09.00 and remains so until 10.00. At 17.00, the road condition starts as moderate and reaches a congested state at 17.45.

In comparison, all the figures show that only Segment B has a free flow between 09:00 and 10:00. Meanwhile, other segments have moderate flow at the beginning of the observation, in the first 15 minutes, then continue with the free-flow condition for the rest. Furthermore, the duration percentage of each category from each segment is shown in Figure 8. At the peak hours (17:00 - 18:00), only Segment A consists of the free flow category, which is 3.33% of observed duration. Segment C has the most extended congestion duration. Segment B has the most duration in the moderate category, and Segment C has the most duration in congestion. These results related to the campusses location, which is Syahdan campus in Segment B and Anggrek campus in Segment C.

In this study, data collection will be processed to obtain traffic density and flow rate over time based on the LWR model with the Greenshield function.

B. Traffic Density and Flow

To simplify the LWR model, it is assumed that all three roads share the following characteristics:

1) The same maximum density p_{max}, which is 140 vehicles per 100 meters, or 1.4 vehicles per meter.
2) The same maximum speed (speed under free-flow condition) v_{max}, which is 42 km/h, or 700 meters per minute.
3) Density p is calculated by

$$p = \frac{vehicle\ count}{road\ length} \tag{9}$$

Traffic flow q was calculated using the LWR model, explicitly applying the flow-density relationship based on the Greenshields model. This model defines the relationship between vehicle flow and density, as shown in equation (4). Finally, traffic density (blue graph) and traffic flow (green graph) from each road is plotted in Figure 9 - 14.

Figure 9, 11, and 13 show the traffic dynamic on T-junction on off-peak at 09:00 - 10:00. It can be observed that traffic flow and density has a same qualitative pattern, as density increases, the flow also increases and vice versa. At this time, the maximum traffic density in Rawa Belong Road (Figure 9 and 13) is about 0.58, but only 0.37 on Kyai H. Syahdan Road. It can be concluded that the road condition does not experience congestion or has not reached critical density.

Figure 10, 12, and 14 show the traffic dynamic on the T-junction on peak hours, that is, at 17:00 - 18:00. By these figures, it can be observed that the density on T-junction is relatively high and continues to increase. In this situation, the flow pattern does not follow the density pattern. When

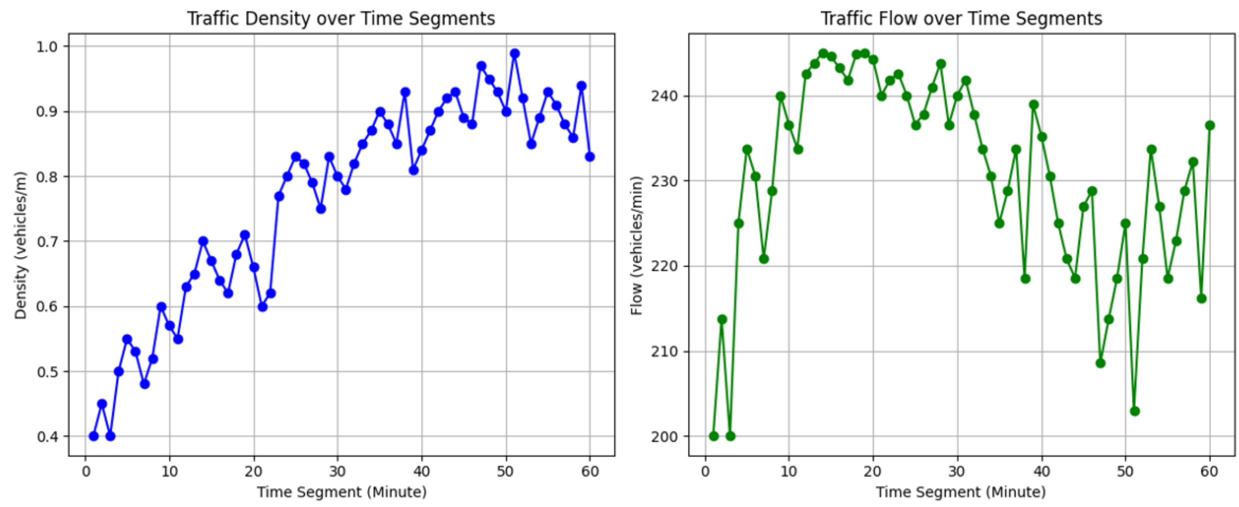

Fig. 10. The traffic density and flow over time on Segments A between 17.00 – 18.00

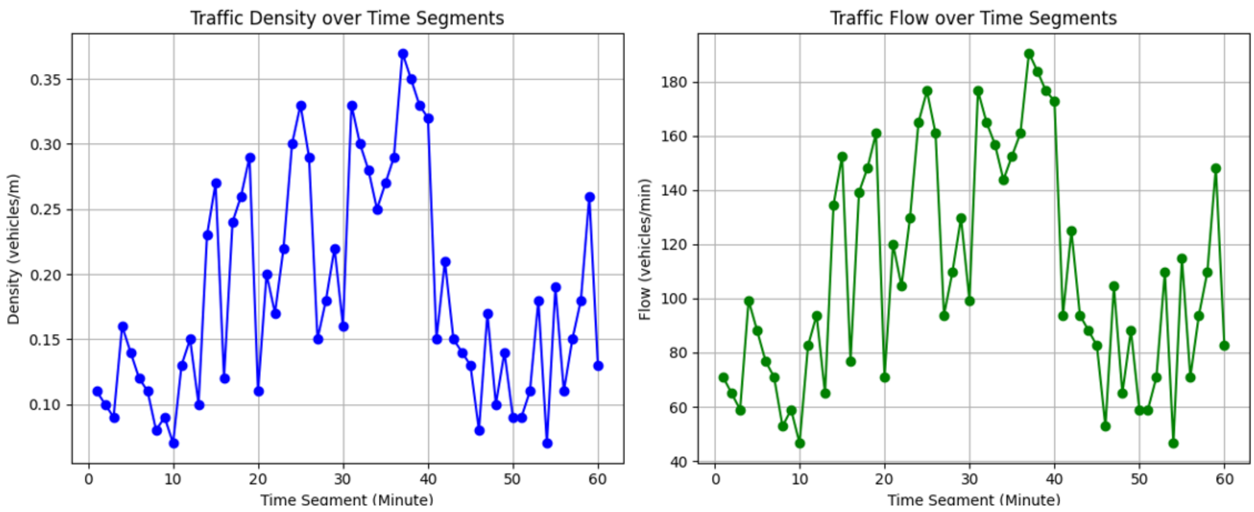

Fig. 11. The traffic density and flow over time on Segment B between 09.00 – 10.00

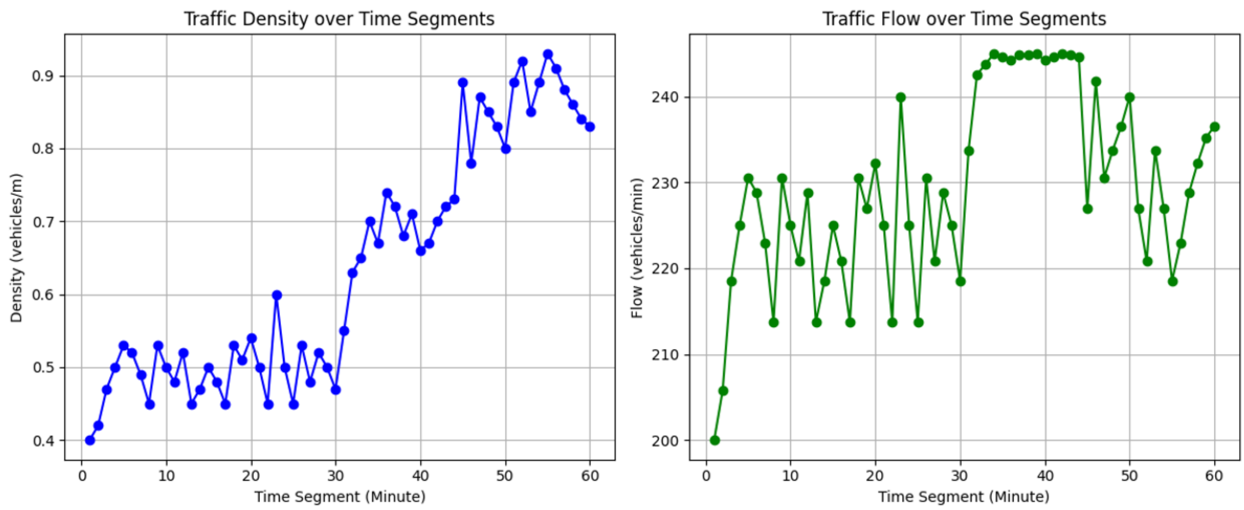

Fig. 12. The traffic density and flow over time on Segment B between 17.00 – 18.00

the density is high, the number of vehicles passing through the road is stuck, so that the traffic flow may decrease.

In Rawa Belong Road (southbound), peak hours occur between minutes 10-20, as in Figure 10. However, the flow starts to decrease as the density rises from that point. This situation indicates that the road has reached its critical density and is experiencing congestion. In minutes 21-60, the flow decreases as the density increases and vice versa. It is

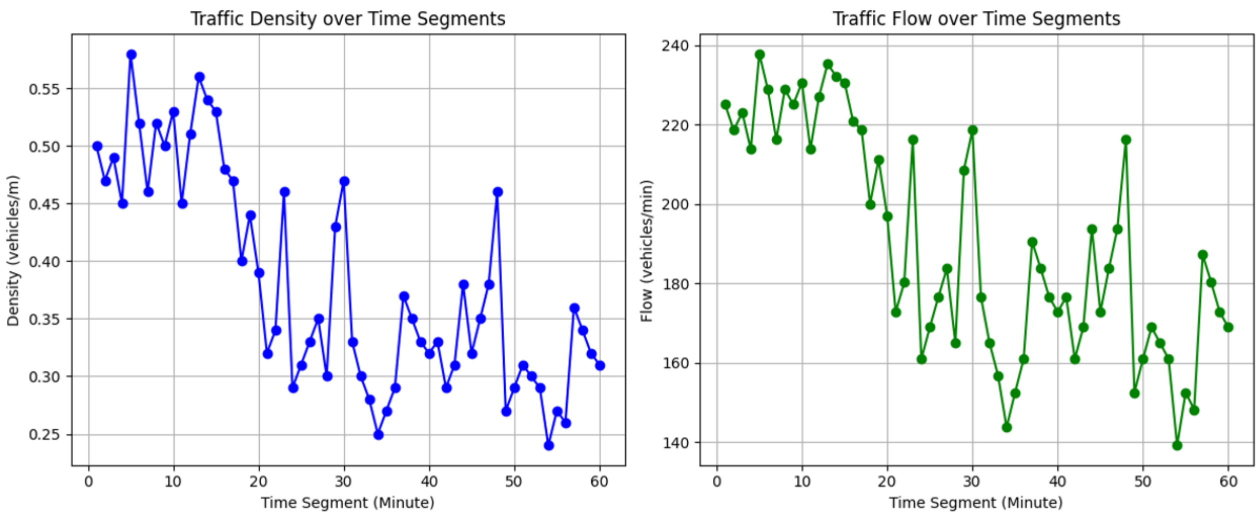

Fig. 13. The traffic density and flow over time on Segment C between 09.00 – 10.00

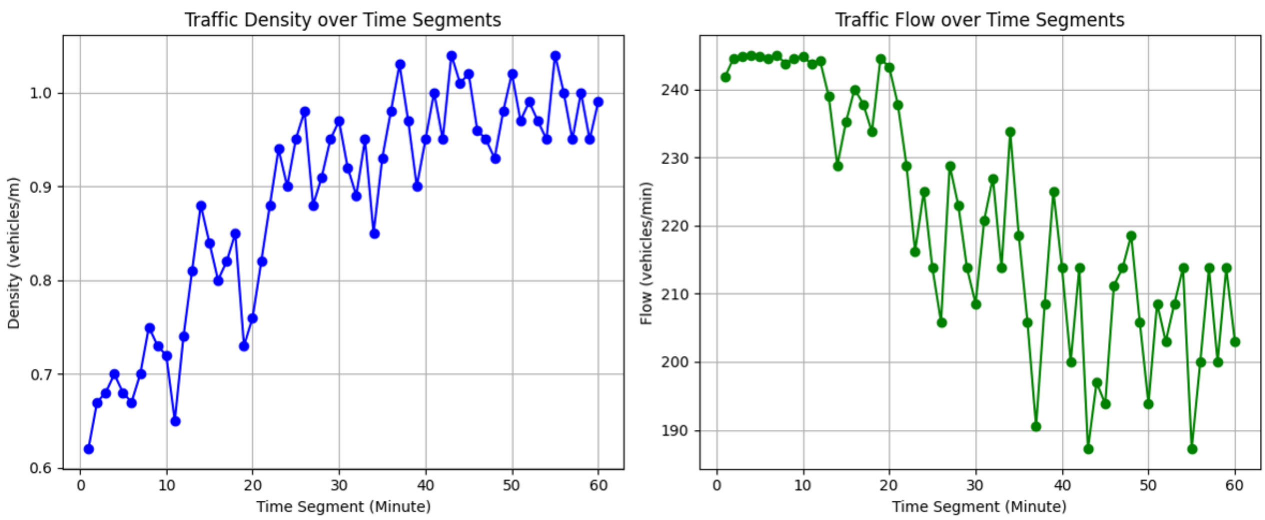

Fig. 14. The traffic density and flow over time on Segment C between 17.00 – 18.00

demonstrated that congestion occurs between minutes 21-60. Figure 12 shows that the Kyai H. Syahdan Road (westbound) reaches peak hours in minutes 30-40. It indicates that the road has reached its critical density and is experiencing congestion. At Rawa Belong Road, going south, as in Figure 14, starting from minutes 45-60, the flow decreases as the density increases and vice versa. It is demonstrated that congestion occurs between minutes 45-60. Furthermore, the highest traffic density range (0.6 - 1.4) appears in Rawa Belong Road going south, which may be caused by the university here.

In addition, through the box plot in density (Figure 15) and flow (Figure 16), the dynamic traffic can be further analyzed. During peak hours, traffic density in each segment shows greater variations than during off-peak hours. It may be caused by an unpredictable condition during peak hours. In contrast, traffic flow in each segment shows smaller variations during peak hours compared to off-peak hours. During off-peak hours, drivers can set their own speed without being affected by traffic flow, so traffic flow data is spread more widely than during peak hours.

V. Conclusion

This study applied the LWR (Lighthill-Whitham-Richards) model to analyze traffic density at the T-junction of Rawa Belong Road and Kyai H. Syahdan Road during two time periods: 09:00–10:00 and 17:00–18:00, to understand vehicle flow dynamics at the intersection. Based on simulations and data analysis, it was concluded that peak density occurred at 17:51 on Rawa Belong Road (northbound), at 17:55 on Kyai H. Syahdan Road, and 17:43 on Rawa Belong Road (southbound). The findings indicate that when density reaches 0.6–0.7, the traffic flow peaks. Any increase beyond this point results in a decline in flow, signifying congestion or obstruction when density surpasses this threshold. Specifically, congestion began at 17:21 on Rawa Belong Road (northbound), at 17:45 on Kyai H. Syahdan Road, and at 17:11 on Rawa Belong Road (southbound). It can be concluded that when vehicle density reaches its critical value (ρ_{crit}), traffic flow is at its maximum. However, if density exceeds this critical value, the average vehicle speed decreases significantly, reducing traffic flow. The simulation results show that density, speed, and traffic flow have a nonlinear relationship where average speed is the primary

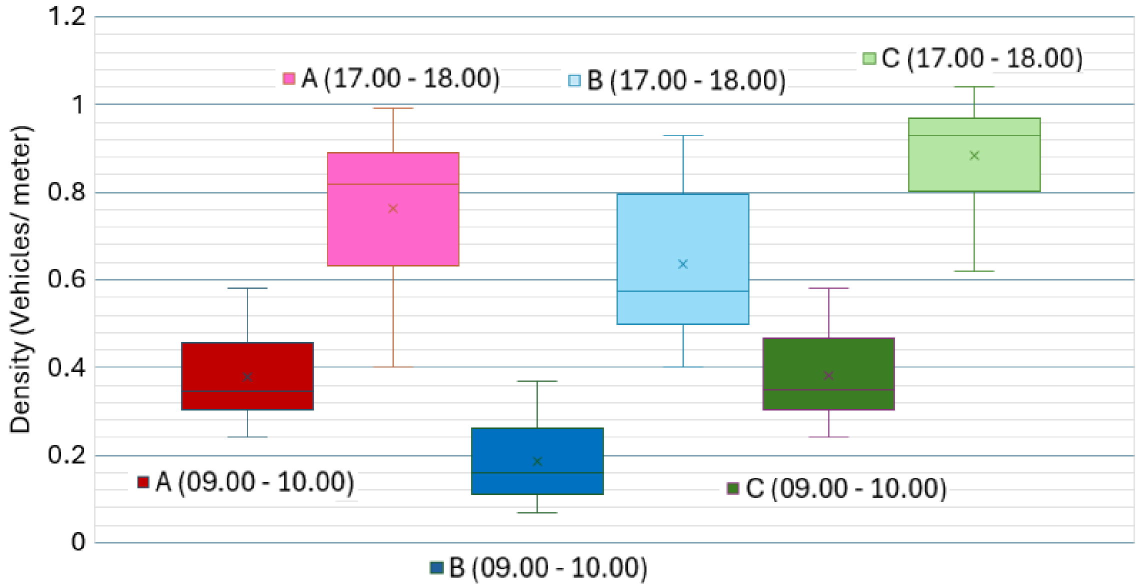

Fig. 15. Box plot for density on each segment during 09.00 - 10.00 and 17.00 - 18.00

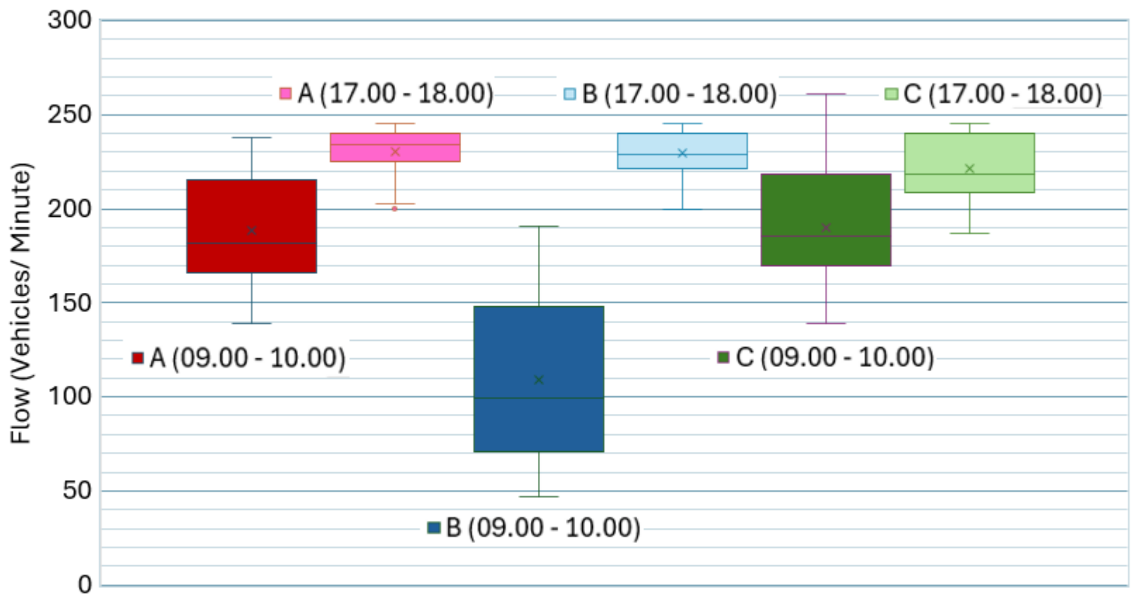

Fig. 16. Box plot for flow on each segment during 09.00 - 10.00 and 17.00 - 18.00

determinant of maximum current capacity.

This study demonstrates that using mass conservation principles and fundamental traffic relationships, the LWR model can effectively analyze traffic density and flow at the studied location. This model can describe vehicle density and flow changes as a function of space and time. In addition, simulation results based on this model can be used to predict traffic dynamics around the campus. In this way, related parties can determine optimal traffic management to minimize congestion.

Data Availability Statement

The authors confirm that the data supporting the findings of this study are available in the article. In detail, it is accessible via https://github.com/viska-noviantri/traffic-flow/blob/main/traffic%20flow.xlsx and may be downloaded free of charge.

CRediT Authorship Contribution Statement

Christianto Herpin: Writing – original draft, Methodology, Investigation, Data Curation. **Margaretha Ohyver**: Methodology, Data Curation, Supervision. **Viska Noviantri**: Writing – review and editing, Investigation, Formal analysis, Conceptualization, Validation, Supervision.

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