Analysis of The Relationship Between Volume, Speed, And Density On The MT Haryono Road Section Using The Greenshield, Greenberg, And Underwood Models

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Abstract
Traffic congestion frequently occurs on MT Haryono Street in Balikpapan. Changes in travel patterns, population growth, and infrastructure development have a significant impact on the traffic conditions on this road. Effective congestion management requires a thorough understanding of traffic volume, speed, and density to develop appropriate strategies. This study aims to analyze the relationship between traffic volume, speed, and density using the Greenshield, Greenberg, and Underwood models, and to identify the model that best represents the traffic conditions. This quantitative research involved a field survey over a 400–meter segment of the road to determine the traffic volume, speed, and density. The collected data on volume, speed, and density were then analyzed using the Greenshield, Greenberg, and Underwood models. Based on the analysis of the relationship between traffic volume, speed, and density using the Greenshield, Greenberg, and Underwood models, the following primary conclusions are drawn. These models illustrate different relationships: Greenshield as linear, Greenberg as logarithmic, and Underwood as exponential. The analysis reveals a decline in speed with increasing volume and density, with Greenberg's model predicting higher speeds at low densities; however, this is less realistic. In contrast, the Greenshield and Underwood models more closely align with actual conditions. Among the models, Greenshield has the highest coefficient of determination (r^2 = 0.775), making it the most accurate in depicting this relationship.
Keywords: *Volume; Speed; Greenshield; Greenberg and Underwood.*

I. INTRODUCTION

Congestion frequently occurs on arterial roads in Balikpapan City, East Kalimantan, including Jalan MT Haryono. Factors such as changing travel patterns, population growth, and evolving road infrastructure influence traffic dynamics on this stretch. Managing congestion requires a deeper understanding of the relationship between volume, speed, and density to develop effective traffic management strategies.

Previous studies(Abdi et al., 2019; Julianto, 2010; Savitri, 2021; Thalib, 2018; Widodo et al., 2012)has highlighted the importance of analyzing the relationship between traffic volume, speed, and density in the context of managing road congestion. The study used three models, namely Greenshield, Greenberg, and Underwood, which have provided insights into traffic behavior under various road conditions. This study aims to understand the characteristics of traffic on MT Haryono Road by conducting an in-depth analysis of the relationship between these variables using the Greenshield, Greenberg, and Underwood models.

This study uses a combined approach of field surveys and secondary data analysis. The field survey was conducted to collect data on traffic volume, speed, and density at various points along Jalan MT Haryono. The data was then analyzed using three models—Greenshield, Greenberg, and Underwood—to understand the relationships between these variables. Furthermore, statistical analysis was conducted to evaluate the significance of these relationships.

With a better understanding of the relationship between traffic volume, speed, and density on Jalan MT Haryono, it is hoped that more effective strategies can be developed to reduce congestion and improve traffic flow. The results of this study are expected to provide guidance for policymakers in planning road infrastructure improvements and traffic management in the city.

Model of the Relationship between Volume, Velocity, and Density

The relationship model between volume, speed, and density is an important concept in transportation and traffic engineering studies which is the focus of this research.

Greenshield Model

According to Tamin in(Saputra & Savitri, 2021)This model is one of the first models used to understand traffic behavior. Greenshield found that the relationship between speed and density is assumed to be linear. The Greenshield model can be described as follows.(Bruce & Greenshields, 1934; Greenshields et al., 1935).

1. Relationship between Speed and Density

   *Greenshield*states that the relationship between speed and traffic density can be explained by a linear function expressed in the following formula:

   $Us=Uf-.D\left(\frac{U_f}{D_j}\right)$ ....

2. Relationship between Volume and Density

   The relationship between volume and density is a parabolic function which is expressed in the following formula:

   $V=Uf.D-.D2\left(\frac{U_f}{D_j}\right)$ ....

3. Relationship between Volume and Velocity

   The relationship between volume and velocity is also a parabolic function which is expressed in the following formula:

   $V = Dj\ .\ Us -\ .\ Us2\left(\frac{D_j}{U_f}\right)$ ....

   Where:
   V = Volume (junior high school/hour)
   DJ =Density in total traffic jam conditions (smp/km)
   Us =Average space speed (km/h)
   Uf =Speed in free flow conditions (km/h)
   D =Density (smp/km)
   DJ =Density in total traffic jam conditions (smp/km)
   smp = Passenger Car Unit

Greenberg Model

According to Tamin(Tamin, 1992)The Greenberg model is the second model that examines the relationship between speed and density in traffic flow and concludes that the use of a non-linear model is more appropriate, namely the logarithmic function. The Greenberg model is described as follows.(Greenberg, 1959).

1. Relationship between Speed and Density

   *Greenberg*put forward a hypothesis that the relationship between speed and density is logarithmic, which is expressed in the following formula:

   $Us = Um\ .\ \ln\left(\frac{D_j}{D}\right)$ ....

2. Relationship between Volume and Density

   The relationship between volume and density uses a formula that can be expressed in the following form:

   $V = Um.D.In\left(\frac{D_j}{D}\right)$ ....

3. Relationship between Volume and Velocity

   The relationship between volume and velocity can be expressed in the following formula:

   $V = Us.DJ.\ e^{\frac{-U_s}{U_m}}$ ....

   Where:
   V = Volume (junior high school/hour)
   Us =Average space speed (km/h)
   DJ =Density in total traffic jam conditions (smp/km)
   D =Density (smp/km)

Um =Speed at maximum volume (km/h)
smp = Passenger Car Unit

Model Underwood

The Underwood model proposes a hypothesis that the relationship between speed and density is an exponential relationship. The Underwood model can be described as follows.(Underwood, 1960).

1. Relationship between Speed and Density
   The formula for the relationship between speed and density is as follows:
   $$Us = Uf.\ e^{\frac{-D}{Dm}} \ldots$$
2. Relationship between Volume and Density
   The formula for the relationship between volume and density can be expressed in the form below:
   $$V = D.Uf.\ e^{\frac{-D}{Dm}} \ldots$$
3. Relationship between Volume and Velocity
   The formula for the relationship between volume and velocity can be expressed in the form below:
   $$V = Us.\ Dm\ .\ \ln\left(\frac{U_f}{U_s}\right) \ldots$$

Where:
V = Volume (junior high school/hour)
Us =Average space speed (km/h)
Uf =Speed in free flow conditions (km/h)
D =Density (smp/km)
Dm =Density at maximum volume (smp/km)
Uf =Speed in free flow conditions (km/h)
smp = Passenger Car Unit

II. METHOD

The research location is on the MT Haryono Road section, which is an urban road with the characteristics of a two-lane, four-lane, and two-way road or 4/2 D. Data regarding the number of vehicles passing a point on the MT Haryono Road section in three two-hour periods with a time interval of 15 minutes, namely at 07.00 to 09.00, 11.00 to 13.00, and 16.00 to 18.00 and carried out on Monday, Saturday, and Sunday. Road geometric data taken in the field can be seen in Figure 1. Speed data in this study was taken by recording the vehicle's travel time with a distance of 400 meters, so that the space mean speed was obtained.

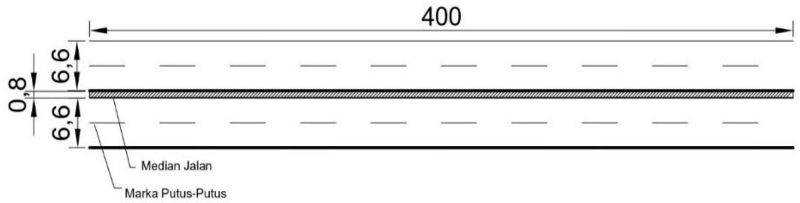

Fig 1. Top View of Road Geometric

Traffic volume data for passenger cars/light vehicles obtained from field observations can be seen in Figure 2.

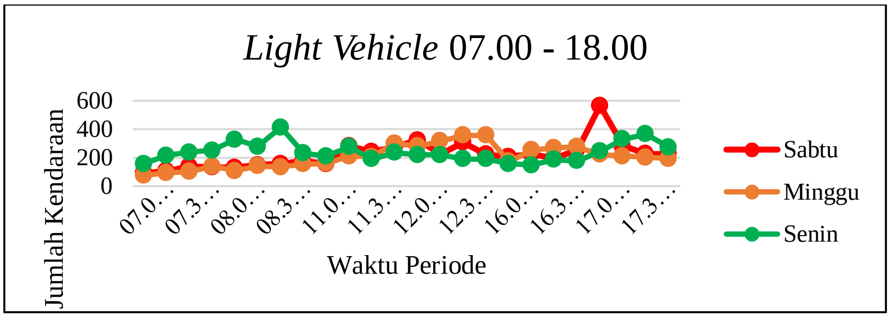

Fig 2. Volume Chart*Light Vehicle (LV) at 07.00 – 18.00*

Overall, it can be seen that traffic patterns on weekdays, namely Mondays, differ significantly from those on weekends, namely Saturdays and Sundays. Mondays show two clear peaks: one in the morning around 8:30–8:45 AM and the other in the afternoon around 5:30–5:45 PM. This morning peak is likely caused by people commuting to work or school, while the afternoon peak reflects the time people return home from work. Between these two peaks, traffic volumes remain relatively stable, with a slight decrease in the middle of the day.

Weekends exhibit a different pattern. Saturdays have a very high and sharp peak around 5:00 PM – 5:15 PM. This peak is likely due to shopping, recreational, or social events typically held on Saturday afternoons. Before and after this peak, traffic volumes are relatively stable and lower. Sundays exhibit a more even pattern throughout the day, with a gradual increase from morning to afternoon. The highest peak on Sunday occurs around 12:30 PM – 1:00 PM. This difference in patterns demonstrates how people's activity changes between weekdays and weekends. Weekdays have a more structured pattern with a clear peak related to work schedules, while weekends exhibit a more varied pattern, indicating flexibility in social activities. The highest peak on Saturday afternoon indicates the potential for significant congestion at that time, which may require special attention in traffic management.

Traffic volume data for motor vehicles obtained from field observations can be seen in Figure 3.

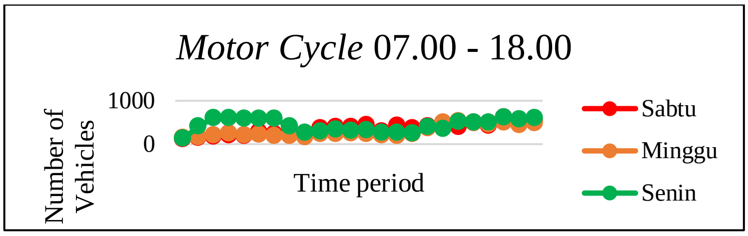

Fig 3. Volume Chart*Motor Cycle (MC) at 07.00 – 18.00*

Mondays display the most striking pattern. There's a sharp increase in motorcycle traffic in the morning, peaking at around 600 between 7:30 and 9:00 a.m. This is likely due to people heading to work or school. Afterward, the number declines and stabilizes throughout the day, before rising again in the afternoon, around 4:00 and 6:00 p.m., indicating the end of work.

Saturdays and Sundays show a more consistent pattern throughout the day, with lower motorcycle traffic than on Monday mornings. However, both days experience a gradual increase from midday to early evening. Peak traffic on Saturdays and Sundays occurs between 4:00 PM and 6:00 PM, likely due to people heading out for weekend activities such as shopping, recreation, or social events.

Furthermore, in the afternoon, around 5:00 PM – 6:00 PM, the number of motorcycles on all three days tended to be close to each other, ranging from 400 to 600 vehicles. This indicates that despite differences in activity between morning and afternoon, afternoon traffic remains a busy time for motorcycle traffic, both on weekdays and weekends. This difference in patterns reflects how people's activity shifts between weekdays and weekends. Mondays have a clear peak associated with work hours, while Saturdays and Sundays show a more even distribution of traffic, indicating flexibility in weekend activity.

The results of observations of travel time on the road section that was the object of the research can be seen in Figure 4.

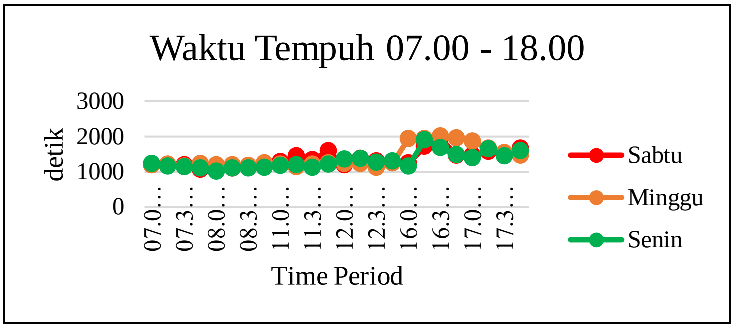

Fig 4. Traffic Speed Graph at 07.00 – 18.00

In general, travel time patterns tended to be stable from morning to afternoon for all three days, ranging between 1,000 and 1,500 seconds. However, significant changes occurred in the afternoon, particularly starting around 4:00 PM. On Saturday, travel times increased around 4:30 PM and 5:00 PM, reaching 1,959 seconds. This is likely due to heavy traffic as people returned from weekend activities such as shopping or recreation. Sunday showed a similar pattern to Saturday, but with a higher and longer peak. Travel times increased dramatically starting around 4:00 PM and remained high until around 5:30 PM, peaking above 2,000 seconds. This could be due to the large number of people returning to the city after weekend travel. Monday had a slightly different pattern. There was a significant but shorter increase in travel times around 4:15 PM, reaching approximately 1,895 seconds. This peak is likely due to the rush hour, when many people are commuting at the same time. However, Monday mornings don't show a drastic increase in travel times, even though they are typically considered rush hour. This is likely because people leave for work or school at more varied times in the morning.

III. RESULTS AND DISCUSSION

From the results of the traffic survey, the number of vehicles obtained was multiplied by the Passenger Car Equivalence (PV), namely Light Vehicles (LV) with a value of 1.3 and Motorcycles (MC) with a value of 0.40 to obtain the rate of flow shown in Figure 5.

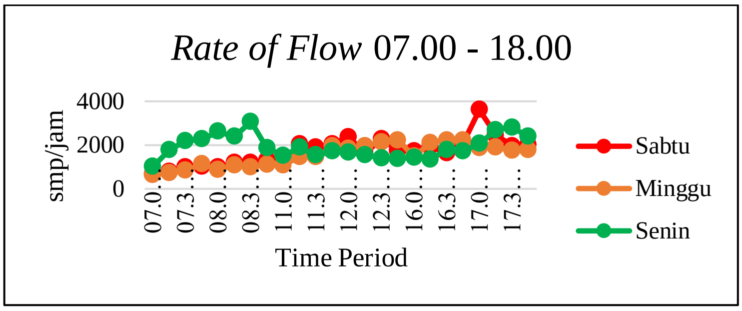

Fig 5. Graph*Rate of Flow at 07.00 – 18.00*

Overall, the three days exhibited distinct patterns. Monday had the most dynamic pattern. There was an increase in traffic in the morning, likely driven by the flow of people going to work and school. After that, volume decreased and became unstable at around 1,500–2,000 smp/hour throughout the afternoon. There was a slight increase again in the afternoon, around 5:30–5:45 PM, due to the employee commute period. Saturday showed relatively stable volume throughout the morning and afternoon, ranging from 1,000–2,500 smp/hour. However, there was a significant increase around 5:00–5:15 PM, reaching 3,607 smp/hour. This was likely due to heavy traffic as people went out for Saturday night activities or returned from weekend activities. Sunday had the most stable pattern of the three. Volume tended to remain consistent between 1,000–2,000 smp/hour throughout the day, with a slight increase in the afternoon. This reflects the more relaxed, spread-out weekend activity. However, despite the different daily patterns, all three days show a trend toward increased traffic volume in the afternoon, particularly after 4:00 p.m. This suggests that, regardless of whether it's a weekday or a weekend, the afternoon remains a busy time for traffic.

Travel time data obtained from field observations was processed to obtain speed data (Figure 6).

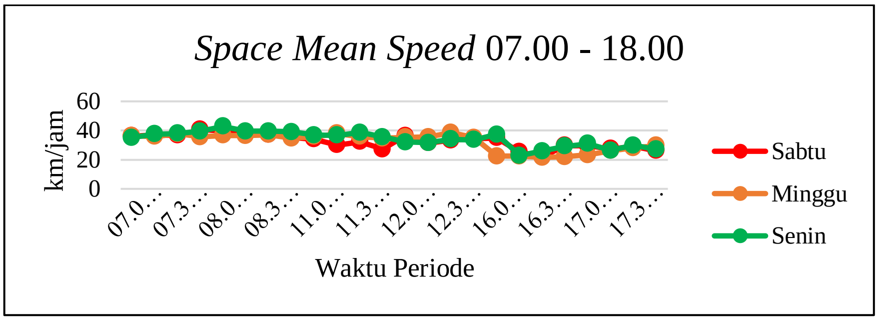

Fig 6. Graph*Space Mean Speed at 07.00 – 18.00*

This graph shows the Space Mean Speed, or the average speed of vehicles in space, from 7:00 AM to 6:00 PM on Saturday, Sunday, and Monday. Speeds are measured in km/h. Overall, average speeds for all three days ranged between 20 and 45 km/h, with some interesting patterns. In the morning, around 7: 00 AM to 9:00 AM, speeds tended to be stable and relatively high for all days, ranging between 35 and 40 km/h. This could be due to smoother traffic in the morning.

During the day, around 11:00 AM – 1:00 PM, Saturdays saw a decrease in speed, reaching a low of around 30 km/h at 11:45 AM – 12:00 PM. This was due to increased activity in the city center or shopping areas. Sundays were relatively stable with slight fluctuations, while Mondays showed a slight decrease but remained more stable than Saturdays. In the afternoon, from 4:00 PM – 6:00 PM, all days saw a significant decrease in speed. Sundays reached a low of 22 km/h at 4:30 PM – 4:45 PM, then increased again. Saturdays and Mondays also saw a decrease, but not as low as Sundays. The decrease in speed in the afternoon is likely due to increased traffic volume as people return home from work on Monday or end their weekend activities on Saturday and Sunday.

Despite the differences in patterns, all three days showed a trend toward a decrease in speeds in the afternoon. This suggests that, regardless of the day, afternoons tend to be a time of heavier and slower traffic.

Relationship between Speed and Density

From calculations using the Greenshield method, the relationship between speed and density is obtained as Us =45.225 – 0.224.D with a coefficient of determination (r2) obtained of 0.775. Greenberg's method provides a relationship between speed and density in the form ofUs =10,908. $\ln\left(\frac{1056,18}{D}\right)$ with an r2 value of 0.678. The Underwood method provides an equationUs = 48.28. as the relationship between speed and density with an r2 value of 0.762. Figure 7 shows a graph of the relationship between speed and density according to the three methods.$2,712^{\frac{-D}{139,119}}$

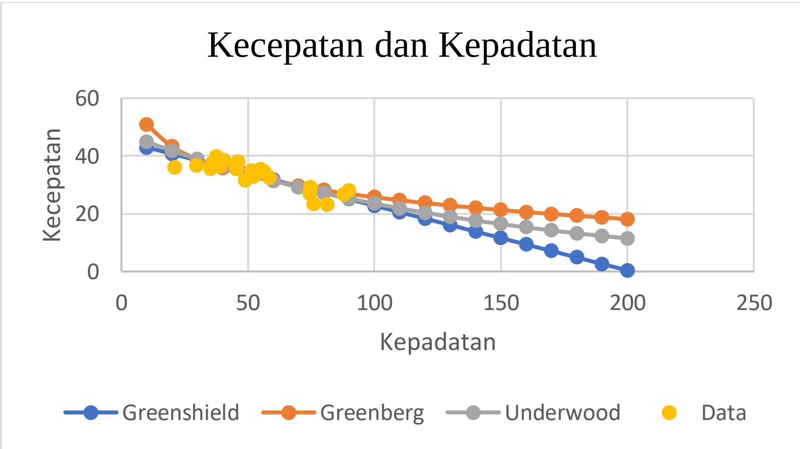

Fig 7. Graph of the Relationship between Speed and Density

A recapitulation of the variables can be seen in Table 1 below:

Table 1. Summary of Variable Calculations

Variables	*Greenshield*	*Greenberg*	*Underwood*
Maximum volume (Vm)	2280.80 smp/hour	4248.24 smp/hour	7120.01 smp/hour
Free flow velocity (Uf)	45.22 km/h	75.94 km/h	48.28 km/h
Maximum Speed (Um)	22.61 km/h	10.91 km/h	17.76 km/h
Maximum Density (Dm)	100.87 smp/km	389.47 smp/km	139.12 smp/km
Coefficient of determinant (r2)	0.775	0.678	0.762

Based on the value of the determinant coefficient, it can be said that the Greenshield model is the one that best approximates field conditions.

Relationship between Volume and Density

The following is the relationship between volume and density according to three methods:

Greenshield :V = 45.225 . D – 0.224 . D2

Greenberg :$V = 10,908 .D.In\left(\frac{1056,18}{D}\right)$

Underwood :$V = D.48.28.\ 2,712^{\frac{-D}{139,119}}$

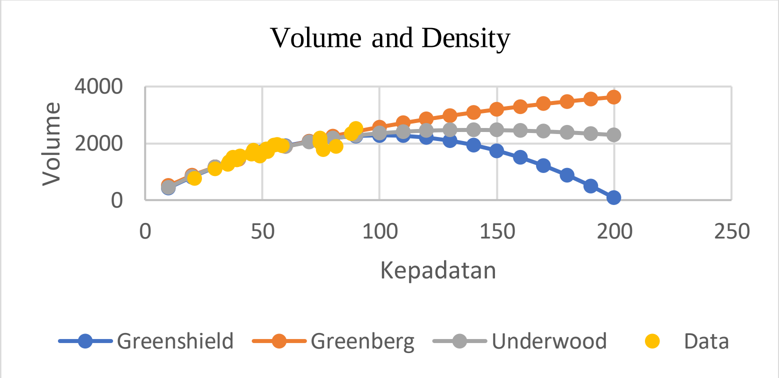

Fig 8. Graph of Volume and Density Relationship

In general, the graph in Figure 8 shows that traffic density increases as density increases up to a certain point, after which volume decreases even as density continues to increase. This reflects a common phenomenon in the field. At low density, increasing the number of vehicles will increase traffic volume. However, after reaching an optimal point, additional vehicles can actually decrease volume due to congestion.

Of these three methods, it is not possible to determine which is the best method for depicting field conditions because the density values in the field do not exceed 100 vehicles. This results in the branching between the three graphs not being able to be evaluated.

Relationship between Volume and Velocity

The following is the relationship between volume and velocity obtained from three methods:

Greenshield :V =201,730. Us – 4,461. Us2

Greenberg :$V = Us.1056.18.\ 2,712^{\frac{-U_S}{10,908}}$

Underwood :$V = Us.139,119.\ \ln\left(\frac{48,28}{U_S}\right)$

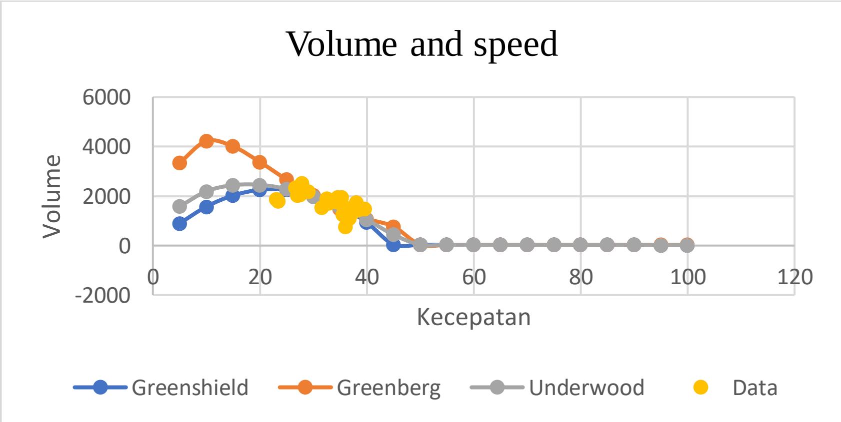

Fig 9. Graph of the Relationship between Volume and Velocity

In general, the graph in Figure 9 shows that as traffic volume increases, there will be an increase at a certain point. After that, vehicle speeds decrease as traffic volume increases. This reflects a common phenomenon on highways.

At low volumes, vehicles can move faster because there's more room on the road. As volume increases, speeds decrease because interactions between vehicles increase.

The actual data (yellow dots) shows a fairly consistent distribution with a decreasing trend in speed as volume increases. Most of the data focuses on volumes of 1,000–2,000 smp/h with speeds between 20–40 km/h, which is during the after-hours period on weekdays, with roads filled with slow-moving vehicles, with workers rushing home or heading to other destinations. Meanwhile, on weekends, many people travel to shopping centers, tourist attractions, or simply spend time outside, causing congestion on several roads.

IV. CONCLUSION

Based on the analysis conducted on the relationship between volume, speed and traffic density using the Greenshield, Greenberg and Underwood models, the following conclusions were obtained:

The relationship between speed and traffic density shows a similar pattern, and the models closely resemble actual conditions in the field. Overall, the models show increasing traffic volumes as density increases up to a point, where volumes then stabilize or decline due to congestion. Actual data supports this trend, with most volumes concentrated at intermediate densities. All three models—Greenshield, Greenberg, and Underwood—represent this relationship with variations at the extremes of density, with volumes nonzero at low densities and decreasing at high densities, suggesting a common phenomenon in the field.

In general, all three models show that vehicle speeds decrease as traffic volume increases, reflecting a common phenomenon on highways. At low volumes, vehicles move faster, while increasing volumes reduce speeds due to interactions between vehicles. Actual data confirms this, with the majority of speeds ranging from 20 to 50 km/h at volumes of 1,000 to 2,500 smp/h, reflecting normal traffic conditions.

Based on the results of the analysis above, it shows that the highest determination correlation coefficient or r2 is found in the Greenshield model with a value of0.775. These results indicate that the Greenshield model is the most appropriate model in describing the relationship between traffic volume, speed, and density.

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