Modeling Volume-Speed-Density Relationship on the Cibubur Transyogi Road Based on Traffic Behavior During Peak Hours Activity

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Abstract

Transyogi road Cibubur is the main road connecting the activity zone in the city of Bogor. This research models the Volume - speed - density relationship model to determine traffic behavior caused by the activity system in that zone. The research methodology used is quantitative descriptive research modeled using mathematical equations. The inter-city traffic movement that occurs on this section causes the traffic flow situation to become unstable, plus the large rate of increase in traffic and the number of vehicles in the area means it is necessary to carry out planning to anticipate future traffic movement needs. A macroscopic approach can show overall traffic flow. This approach is described by 3 parameters, namely traffic flow (volume), density and speed. The Greenshield, Greenberg, and Underwood models can describe the relationship mathematically between these three parameters. The results of the research show that the flow characteristics at peak hour conditions are shown in the Underwood model with the model significance analysis value on Friday having a value of 0.940. For the model equation between Speed and Density we get S = 54.1 Exp (–D/370.15) Volume and Density get V = 54.1 D Exp (–D/370.15) Volume and Speed get V = 370.15 S Ln (54.1/S). The volume - speed - density relationship model shows that traffic in urban areas has characteristics determined by the zones built from the cover area. So, controlling traffic volume during peak hours in this zone must be controlled by adjusting the activity system on the road corridors that are traversed.

Keywords: *Volume-Speed-Density, Traffic Behavior, Peak Hour Activity.*

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A. INTRODUCTION

Transyogi Road Cibubur is a primary arterial road with six divided two-way lanes connecting Bogor Regency, Bekasi City and Depok City. In this section there are land uses consisting of service centers, government centers, activity centers and shopping centers. These three areas have quite high levels of density among districts/cities in West Java with an average value of 6,458 people/km2 (Open Data Jabar, 2021). The inter-city movement that occurs on the Transyogi Cibubur section causes the traffic flow situation on this section to be unstable. The large rate of increase in traffic and existing land use causes changes and developments in traffic services. This is also influenced by the number of vehicles in the West Java region. The top four cities with the highest number of motorized vehicle ownership in West Java are Depok City (1,139,610 units), Bekasi City (1,502,136 units), and Bogor Regency (1,666,860 units), followed by Bandung City (1,551. 774 units), with an average growth in the number of vehicles from 2013-2022 in these four regions of 4.94% (Open Data West Java, 2023). With this growth potential, it is necessary to plan to anticipate future movement needs. Planning the movement of traffic flows between cities is very

necessary. Because population activity between cities continues to grow every day, causing a rapid increase in traffic flow (Saputra & Savitri, 2021). To help inform traffic flow, a modeling method is used to determine these parameters by describing the relationship graphically and mathematically (Sholahudin & Nurmayadi, 2021). The Greenshield, Greenberg, and Underwood models are models that can graphically and mathematically describe the relationship between traffic flow (volume), speed (speed) and density (density) to estimate actions to resolve problems in traffic flow activities (Akbardin, 2013).

B. LITERATURE REVIEW

1. Model of Relationship Volume-Speed-Density

Traffic flow is a stochastic process, with free variations in vehicle characteristics and driver interactions between them. There are three main approaches to understanding and calculating traffic flow. The first approach is a macroscopic approach by showing the overall traffic flow and explaining it using 3 parameters, namely traffic flow (volume), speed and density. The second approach is microscopic which looks at the response of each individual vehicle separately. The third approach is the human-factors approach. Generally, this approach defines itself against other vehicles on the road or other steering systems (Khisty & Lall, 2005). Traffic flow (volume) can be interpreted as a comparison of the number of vehicles heading to a certain place with the observation time interval. Traffic volume can be calculated using the formula below (Morlok Edward, 1991):

$$q=n/t \quad (1)$$

with:
q = Traffic volume (PCU/Hour)
n = Number of vehicles passing a certain place in the observer's time interval
t = Observation time interval
Space Mean Speed (space average speed) to explain the average speed of a vehicle on a section of road at a certain time (Morlok Edward, 1991):

$$u = \frac{\sum_{i=1}^{n} Si}{\sum_{i=1}^{n} mi} \quad (2)$$

with:
u = Space average speed (m/sec)
Si = Distance traveled by vehicle I on the road (1,2, ….) (m)
mi = Time spent by vehicle I on the road (sec)
n = Number of vehicles observed

Traffic density is the number of vehicles that pass a certain place on a road in one or two directions during a certain period of time and certain road and traffic conditions. To calculate traffic density (Morlok Edward, 1991).

$$k=q/u \quad (3)$$

with:
k = Traffic density (SMP/Km)
q = Traffic volume (PCU/Hour)

u = Average traffic speed (Km/Hour)

The Greenshields model is a model that describes flow, density, and density. This model is the first model to look at the flow characteristics on each road. Greenshield obtained the result that the relationship between current, density and density is assumed to be a linear line. Meanwhile, for Greenberg modeling, a model in logarithmic form is used. Greenberg explained that current has similarities to fluid flow. For current, density and density equations in logarithmic form. Meanwhile, the Underwood Model assumes that the relationship between current, density and density follows an exponential form (Akbardin, 2018).

Table 1. Model of Relatianship Volume-Speed-Density

Model	Relationship	Equation	
Greenshield Model	Speed – Density	$S = Sf - \left(\frac{Sf}{Dj}\right) D$	(4)
	Volume – Density	$V = Sf.D - \left(\frac{Sf}{Dj}\right) D^2$	(5)
	Volume – Speed	$V = S.Dj - \left(\frac{Dj}{Sf}\right) S^2$	(6)
Greenberg Model	Speed – Density	$S = So\ .\ln\left(\frac{Dj}{D}\right)$	(7)
	Volume – Density	$V = So\ .D.\ln\left(\frac{Dj}{D}\right)$	(8)
	Volume – Speed	$V = Dj.S.e^{\left(-\frac{S}{So}\right)}$	(9)
Greenberg Model	Speed – Density	$S = Sf.e^{\left(-\frac{D}{Do}\right)}$	(10)
	Volume – Density	$V = Sf.D.e^{\left(-\frac{D}{Do}\right)}$	(11)
	Volume – Speed	$V = Do.S.\ln\left(\frac{Sf}{S}\right)$	(12)

C. METHOD

This research was conducted on the Transyogi Cibubur road section with a spatial observation distance of 25 meters at the yellow box junction ramp on/off Jatikarya. The traffic flow calculation uses the number and speed of vehicles observed via CCTV for one week from 28 May 2023 to 3 June 2023 starting at 06:00 in the morning during rush hour, until 18:00 in the afternoon rush hour.

D. RESULT AND DISCUSSION

1. Analysis of Traffic Volume

By observing the flow volume for one week starting Monday 28 May 2023 to Sunday 03 June 2023, it can be concluded that the peak flow occurred on Monday, namely 8386 pcu/hour at 07:00-07:15. Meanwhile, the average traffic flow for one week is 5669.8 pcu/hour.

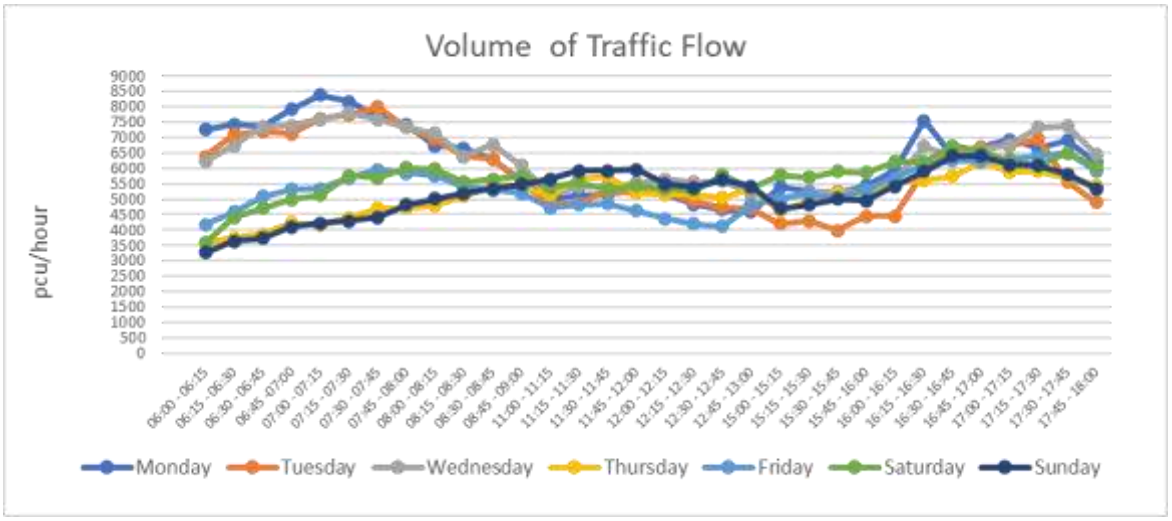

Figure 3. Analysis of traffic volume

2. Analysis of Sapce Mean Speed

The calculation results for the average speed of space for all vehicles, on Thursday is the highest speed with 41.93 km/hour at 06:00-06:15 and the lowest speed on Wednesday at 07:15-07:30 with a value of 30 .66 km/h.

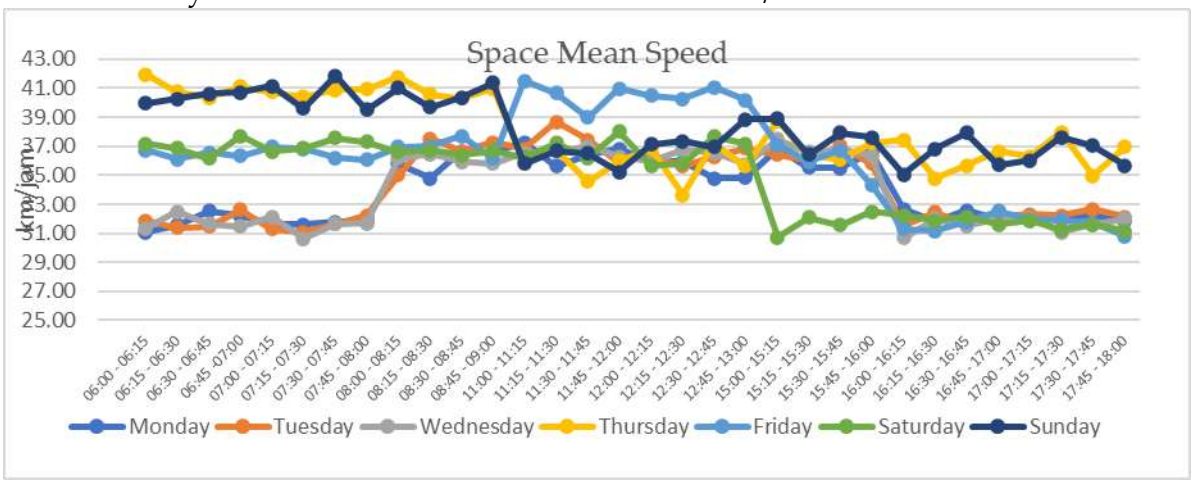

Figure 4. Analysis of Space Mean Speed

3. Analysis of Density

After the volume and velocity data are obtained, we can use the data to carry out density calculations. Density analysis is analyzed based on the mathematical relationship between speed and volume. The density characteristics are shown on the graph in figure 5:

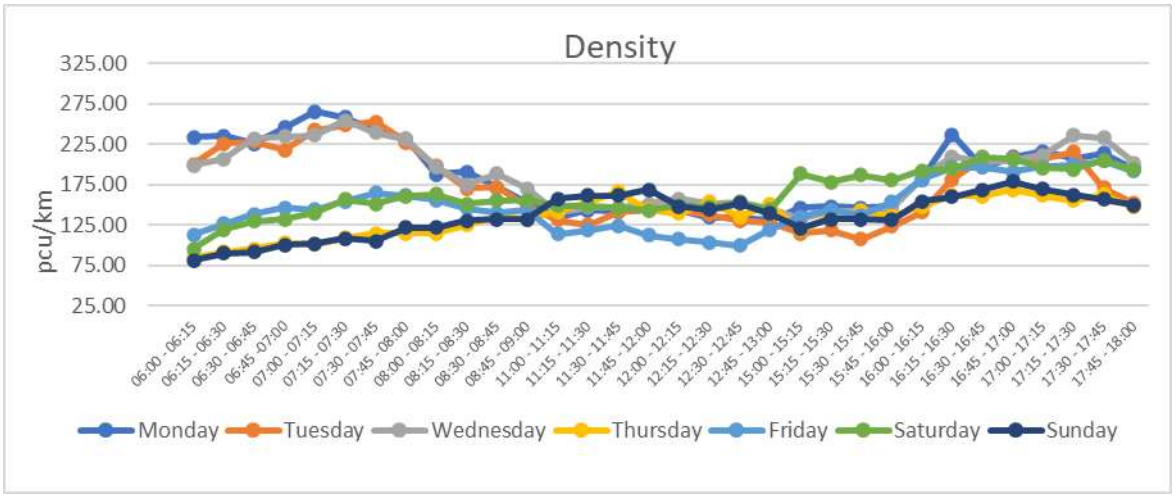

Figure 5. Analysis of Traffic Density

4. Analysis of Relationship Model Volume-Density-Speed

The equation for the Volume Density Speed relationship according to Greenshield, Greenberg and Underwood obtained from the calculation results is presented in the table 2

Table. 2. Result of Modelling Volume-Speed-Density Base on Daily Analysis

Day	Model	Existing Model	Day	Model	Existing Model
Monday	Greenshield	$S = 42{,}19 - (0{,}04)D$ $V = S * 963{,}349 - (22{,}83)S^2$ $V = 42{,}19 * D - (0{,}04)D^2$	Thursday	Greenshield	$S = 50.174 - (0{,}09)D$ $V = S\ x\ 556.153 - (11{,}08)S^2$ $V = 50.174\ x\ D - (0{,}09)D^2$
	Greenberg	$S = 8.151\ x\ \ln(11804.02/D)$ $V = 11804.02\ x\ S\ x\ e^{(-S/8.151)}$ $V = 8.151\ x\ D\ x\ \ln(11804.02/D)$		Greenberg	$S = 11.209\ x\ \ln(3939.98/D)$ $V = 3939.98\ x\ S\ x\ e^{(-S/11.209)}$ $V = 11.209\ x\ D\ x\ \ln(3939.98/D)$
	Underwood	$S = 43.197\ x\ e^{(-D/744.811)}$ $V = 744.811\ x\ S\ x\ \ln(43.197/S)$ $V = 43.197\ x\ D\ x\ e^{(-D/744.811)}$		Underwood	$S = 52.150\ x\ e^{(-D/423.574)}$ $V = 423.574\ x\ S\ x\ \ln(52.150/S)$ $V = 52.150\ x\ D\ x\ e^{(-D/423.574)}$
Tuesday	Greenshield	$S = 42.008 - (0.04)D$ $V = S\ x\ 963.349 - (22.47)S^2$ $V = 42.008\ x\ D - (0.04)D^2$	Friday	Greenshield	$S = 50.658 - (0{,}1)D$ $V = S\ x\ 525.225 - (10{,}37)S^2$ $V = 50.658\ x\ D - (0{,}1)D^2$
	Greenberg	$S = 7.644\ x\ \ln(14902.64/D)$ $V = 14902.64\ x\ S\ x\ e^{(-S/7.644)}$ $V = 7.644\ x\ D\ x\ \ln(14902.64/D)$		Greenberg	$S = 14.369\ x\ \ln(1821.60/D)$ $V = 1821.60\ x\ S\ x\ e^{(-S/14.369)}$ $V = 14.369\ x\ D\ x\ \ln(1821.60/D)$
	Underwood	$S = 42.860\ x\ e^{(-D/768.660)}$ $V = 768.660\ x\ S\ x\ \ln(42.860/S)$ $V = 42.860\ x\ D\ x\ e^{(-D/768.660)}$		Underwood	$S = 54.056\ x\ e^{(-D/370.148)}$ $V = 370.148\ x\ S\ x\ \ln(54.056/S)$ $V = 54.056\ x\ D\ x\ e^{(-D/370.148)}$
Wednesday	Greenshield	$S = 45.067 - (0.06)D$ $V = S\ x\ 766.590 - (17{,}01)S^2$ $V = 45.067\ x\ D - (0.06)D^2$	Friday	Greenshield	$S = 48.032 - (0{,}08)D$ $V = S\ x\ 597.711 - (12{,}44)S^2$ $V = 48.032\ x\ D - (0{,}08)D^2$
	Greenberg	$S = 10.943\ x\ \ln(4126.03/D)$ $V = 4126.027\ x\ S\ x\ e^{(-S/10.943)}$ $V = 10.943\ x\ D\ x\ \ln(4126.03/D)$		Greenberg	$S = 11.209\ x\ \ln(3939.98/D)$ $V = 3939.98\ x\ S\ x\ e^{(-S/11.209)}$ $V = 11.209\ x\ D\ x\ \ln(3939.98/D)$
	Underwood	$S = 46.954\ x\ e^{(-D/578.493)}$ $V = 578.493\ x\ S\ x\ \ln(46.954/S)$ $V = 46.954\ x\ D\ x\ e^{(-D/578.493)}$		Underwood	$S = 51.077\ x\ e^{(-D/426.039)}$ $V = 426.039\ x\ S\ x\ \ln(51.077/S)$ $V = 51.077\ x\ D\ x\ e^{(-D/426.039)}$
Sunday	Greenshield	$S = 46.808 - (0{,}06)D$ $V = S\ x\ 745.760 - (15{,}93)S^2$ $V = 46.808\ x\ D - (0{,}06)D^2$			
	Greenberg	$S = 7.775\ x\ \ln(18307.66/D)$ $V = 18307.66\ x\ S\ x\ e^{(-S/7.775)}$ $V = 7.775\ x\ D\ x\ \ln(18307.66/D)$			
	Underwood	$S = 47.750\ x\ e^{(-D/610.865)}$ $V = 610.865\ x\ S\ x\ \ln(47.750/S)$ $V = 47.750\ x\ D\ x\ e^{(-D/610.865)}$			

Based on analysis using the Greenshield, Greenberg, and Underwood models, the best selection analysis uses correlation analysis, where the closer the value is to 1, the better the correlation between the modeled variables. Friday was the best modeling result with a value close to 1 with Underwood as the best modeling to describe overall traffic flow:

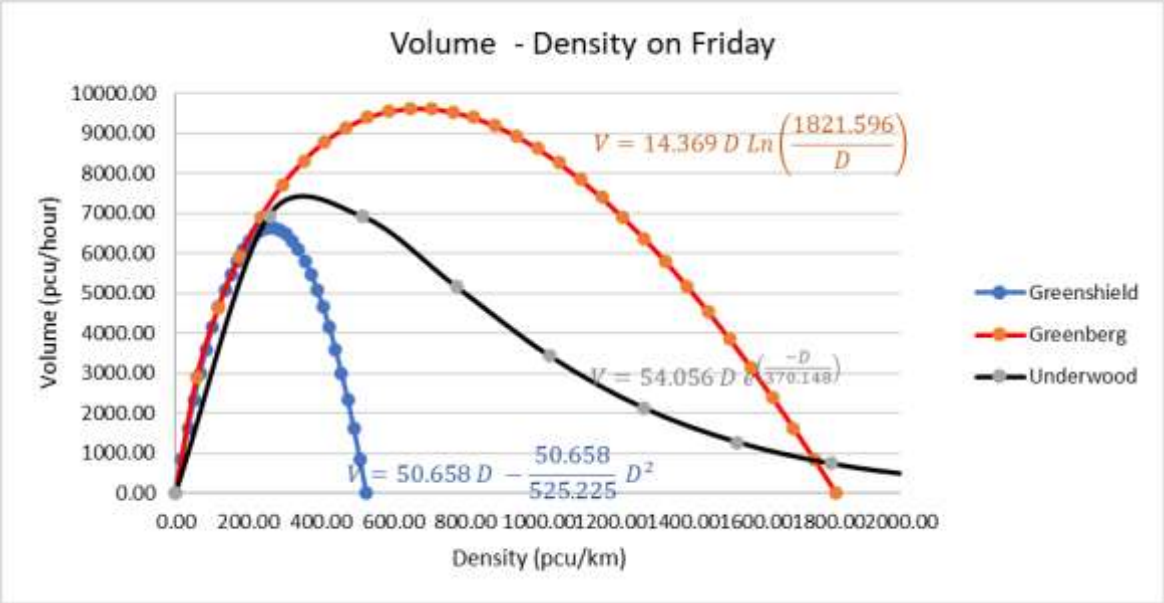

Figure 6. Relationship Volume-Density on Peak hour Friday

Base on the Greenshield, Greenberg, and Underwood Model can be explained for the first graph between the relationship of volume (Y) and density (X). If density (X) continues to increase, a situation will be reached where increasing density does not increase traffic volume (Y), but instead decreases traffic volume (Y). This condition is called the maximum current peak point, or expressed as current capacity (V max) and at this point is also known as critical density (Dm). If the density value (X) has passed the critical density (the center line of the peak flow in the image) then the number of vehicles that will pass through that section will reduce the traffic volume (Y), because there is already a queue of vehicles that has occurred and is called an unstable flow. Until there is a time when the flow reaches point 0, meaning there are no more vehicles that cannot be counted and can be said to be maximum density

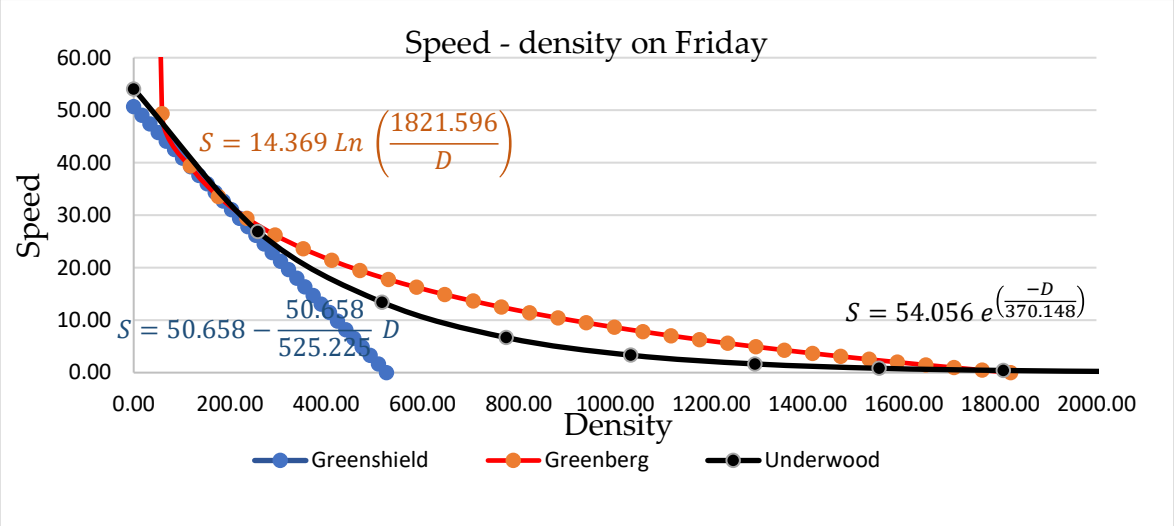

Figure 7. Relationship Speed – Density on Peak hour Friday

The characteristics of traffic behavior in urban systems show that the Underwood model is shown by a logarithmic model. Based on the results of the calculations above, from the equations that have been formed according to the Greenshield, Greenberg and Underwood models, it can be depicted in the form of a graph to make it easier to read macroscopic information from traffic flow activities between volume, speed and density.

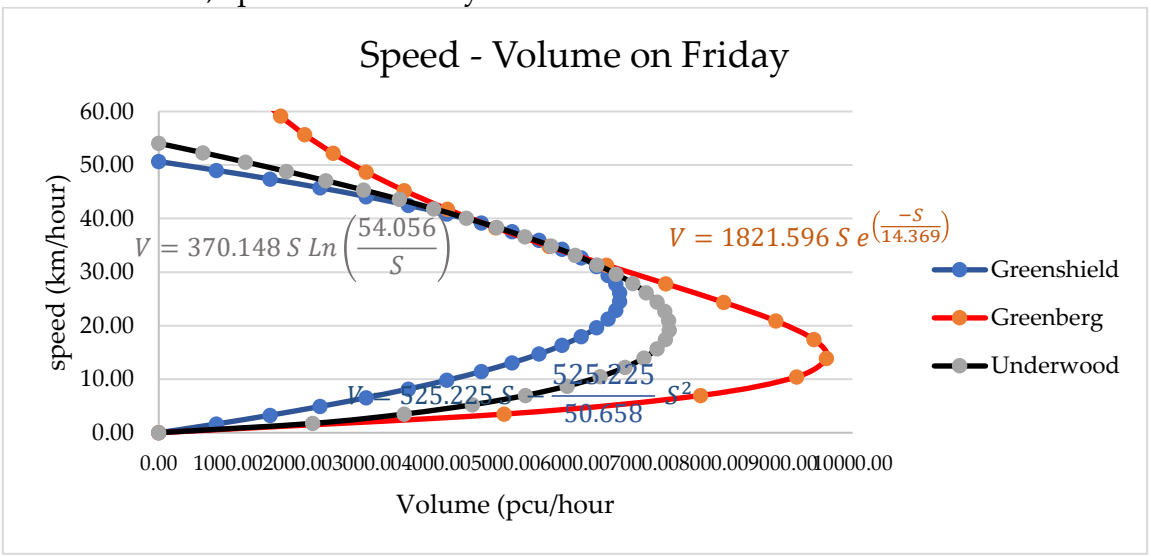

Figure 8. Relationship Speed-Volume on Peak hour Friday

E. CONCLUSION

From the results of data analysis obtained for Monday, the best modeling is Greenberg modeling, Tuesday Underwood modeling, Wednesday Greenberg modeling, Thursday Greenshield modeling, Friday, Saturday and Sunday modeling is Underwood. So, it can be concluded that the traffic flow characteristics that can describe the current that occur are obtained from the analysis of the Transyogi Cibubur road section model with actual conditions in the field, namely Underwood modeling. From the correlation analysis values, it can be seen that Friday's correlation value with Underwood modeling was 0.940, close to 1, with a maximum volume (Q

max) of 7360.76 pcu/hour, free flow speed of 54.06 km/hour and a density value of 370.15 pcu /km. For Underwood's modeling on Friday between Speed and Density we get S = 54.1 Exp (–D/370.15) Volume and Density get V = 54.1 D Exp (–D/370.15) Volume and Speed get V = 370.15 S Ln (54.1/S). For Greenshield modeling on Friday between Speed and Density, we get S = 50.66 – (0.1 D) Volume and Density get V = 50.66 D – (0.1) D2 Volume and Speed get V = 525.225 S – (10.37) S2. For Greenberg modeling on Friday between Speed and Density we get S = 14.37 Ln (1821.60/D) Volume and Density get V = 114.37 D Ln (1821.60/D) Volume and Speed get V = 1821, 60 S Exp (–S/14.37).

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