

# PERFORMANCE OF TRAFFIC CHARACTERISTICS DUE TO BOTTLENECK ON THE MAROS RIVER BRIDGE

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## Abstract

One of the roads in Maros City that often experiences congestion is the narrowing of the road on the Maros River Bridge. For this reason, the purpose of this study is to examine these problems and find out the queues that occur at the Maros River Bridge. Primary data retrieval was carried out for 12 hours with a data collection period of fifteen minutes starting from 06.00 am to 06.00 pm. In the regression analysis, it is known that on normal roads and bottlenecks conditions, the Greenberg method has a better coefficient of determination than the Greenshield and Underwood methods. For the relationship between speed and density, the coefficient of determination ( $R^2$ ) is 0.725 and 0.806 for the Greenshield and Underwood methods and 0.817 for the Greenberd method. Meanwhile, in the relationship between volume and density, the coefficients of determination are 0.738, 0.796 and 0.731 for the Greenshield, Greenberd and Underwood methods. However, in the relationship between volume and velocity, a less significant relationship is obtained for these three methods, it can be seen because the coefficient of determination is only 0.394 and 0.391 and 0.418 for the Greenshield, Greenberg and Underwood methods... By using the Greenshield method, it is also known that there are 6 time periods where Demand exceeds the capacity of the Maros River bridge with a shock wave value in the period of 07.30 – 07.45 of  $w = -38.42$  km/hour, period of 16.15 – 16.30 of  $w = -124.43$  km/hour, period at 16.30 – 16.45 at  $w = -42.82$  km/hour, period at 16.45 – 17.00 at  $w = -39.76$  km/hour, period at 17.00 – 17.15 at  $w = -7, 32$  km/hour and in the period 17.45 – 18.00 at  $w = -21.53$  km/hour. Shock waves due to road narrowing from 3 (three) lanes to 2 (two) lanes with a repeated duration of normal road volume conditions greater than the volume of bottleneck roads, there are three shock waves formed at  $t_1$  on the stop line, namely  $w_{AB}$  of  $-15, 13$  km/hour,  $w_{CB}$  of  $-14.42$  km/hour and  $w_{AC}$  of  $-38.42$  km/hour in the period 07.30 – 07.45.

**Keywords:** Greenshield, Greenberg, Underwood, Traffic Performance, Bottleneck, Shock Wave

## 1. INTRODUCTION

Transportation is a basic need for humans. With transportation, the activities and needs of human life can be achieved. For this reason, transportation plays an important role to ensure that the movement of people, vehicles, or goods can run smoothly, safely in a fast, cheap, comfortable, and environmentally friendly manner, which is a development goal in various sectors. Inequality in transportation systems and management will have an impact on daily human activities. The impacts that will occur include high congestion, pollution, delays, fuel use, and the number of accidents that will increase [1].

On the other hand, Maros Regency is an area directly adjacent to the provincial capital of South Sulawesi, in this case Makassar City, with a distance of about 30 km between the two cities, which is integrated with the development of the Mamminasata Metropolitan Area. In its position, Maros Regency plays an important role in this area because as a crossing area as well

as the gateway to the northern Mamminasata Region which itself provides enormous opportunities for development in Maros Regency [2]. The main road that connects Maros Regency and Makassar City which stretches for 30 km causes changes in surrounding land use along with the development of the city. Of course, this will have a significant impact on the transportation system in the Mamminasata area. This can be seen with changes in traffic characteristics, which will cause an imbalance between traffic volume and the capacity of the road itself. One of the problems that contribute to worsening traffic conditions, which will be used as research material here is the problem of Traffic bottleneck roads on roads with heavy traffic flow.

The Traffic bottleneck is a part of the road with a lower traffic capacity condition downstream than upstream. Road conditions like this can occur for example when entering a bridge, an accident that causes a part of the road width to be closed, during road repairs, or other conditions that cause a change in Uninterrupted Flow to Interrupted Flow resulting in a decrease in speed and an increase in density between vehicles. The effect of the Traffic bottleneck is completely meaningless if the traffic flow (demand) is less than the capacity or supply capacity in the Traffic bottleneck area so that the traffic flow can be easily passed without a hitch [3]. One of the problems of Traffic bottleneck this road occurs on the axis of the Maros Regency - Makassar City road, one of which occurs around the Maros Bridge. Where the road segment initially consisted of two lanes and six divided lanes but changed to two lanes and two undivided lanes when entering the bridge. Reducing lanes on this road segment results in increased traffic density, resulting in queues because the speed will decrease when entering the location of the narrowed road. Information on potential queue lengths is necessary for good traffic management

### **Road Capacity**

Research on road capacity has been carried out by many researchers. Many variables to estimate a road capacity. Road capacity is the ability of a road segment to accommodate the ideal traffic flow or volume within a certain time unit, expressed in the number of vehicles that pass a certain road section in one hour (vehicles/hour), or by considering various types of vehicles passing through a road, the unit is used. Passenger car as a vehicle unit in the calculation of capacity, the capacity uses passenger cars per hour or (pcu)/hour [4]. So far, traffic performance evaluation in Indonesia uses the traffic code so-called Indonesian Highway Capacity Manual (IHCM, 1997). Indonesian Highway Capacity Manual (IHCM, 1997) provides a static method for examining the capacity of the urban arterial. However, the methodology does not take into consideration of bottleneck activities on arterial roads, such as uncontrolled access points, median opening, and unrestricted on-street parking. This condition could happen simultaneously; mostly repetitive and predictable in the same peak hour demands [5].

Capacity is one measure of traffic performance when the maximum traffic flow can be maintained (fixed) on a part of the road under certain conditions while the basic equation for determining road capacity is as follows [6]:

$$C = C_0 \times FC_w \times FC_{sp} \times FC_{sf} \times FC_{cs} \dots\dots\dots 10$$

Where:

- C = capacity (pcu/hour)
- C<sub>0</sub> = basic capacity (pcu/hour)
- FC<sub>w</sub> = Effective traffic lane width adjustment
- FC<sub>sp</sub> = Directional separation adjustment factor (UD)
- FC<sub>sf</sub> = Adjustment factor for side friction conditions
- FC<sub>cs</sub> = City size adjustment factor

**Degree of Saturation (DS)**

The degree of saturation is defined as the ratio of traffic flow (pcu/hour) to capacity (pcu/hour) on a certain road section, used as the main factor in determining the performance level of intersections and roads. The Degree of Saturation value is the basic quantity that determines traffic performance.

$$DS = \frac{Q}{C} \qquad 11$$

Where:

- DS = Degree of saturation
- Q = Traffic volume (pcu/hour)
- C = Capacity (pcu/hour)

**Bottleneck**

Among Webster's dictionary definitions of "bottleneck" are i) a narrow or obstructed portion of a highway or pipeline, and ii) a hindrance to production or progress or can be defined simply is localized narrowing of traffic flow. Expanded definition: A section of a local highway that suffers from slowdowns and inherent delays due to the effects of repeated operations or non-recurring impact events [7].

**Road Characteristics**

Road loading from traffic will cause changes in road performance and capacity. There are several variables, namely [8], [9] & [10]:

1. Geometry
2. Flow Composition and Separation of Directions
3. Traffic control
4. Side Road Activity (Side Obstacles)
5. Driver Behavior and Vehicle Population

### Characteristics of Traffic Flow

To be able to represent the characteristics of traffic flowwell, there are 3 (three) main parameters that must be known where the three parameters are mathematically related to each other, namely [11], [12] & [13]:

1. Traffic flow or volume
2. Average Space Speed
3. Density

According to Tamin [14], these characteristics can be studied with a mathematical relationship between the three parameters above, namely speed, flow, and traffic density on roads. The mathematical relationship can be expressed as follows:

$$V = D \cdot S \dots\dots\dots 1$$

Where:

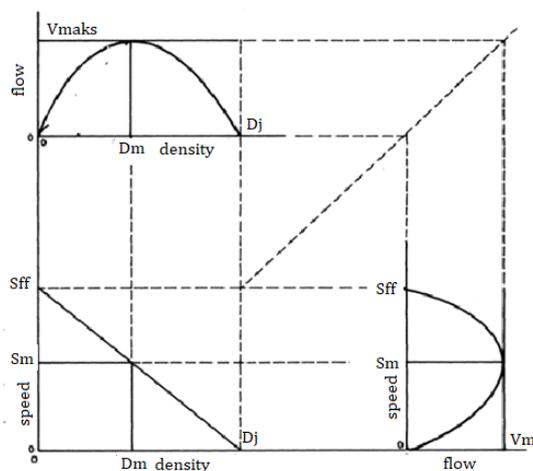
V = Traffic flow or volume

D = Density

S = Speed

The relationship is described in Figure 1 below.

**Figure 1. Volume, Speed, Relationship and Density [15]**



Caption:

$V_m$  = Maximum capacity or volume (vehicle/hour)

$S_m$  = Speed at last volume condition maximum traffic (km/h)

$D_m$  = Density at the last volume condition maximum traffic (vehicles/km)

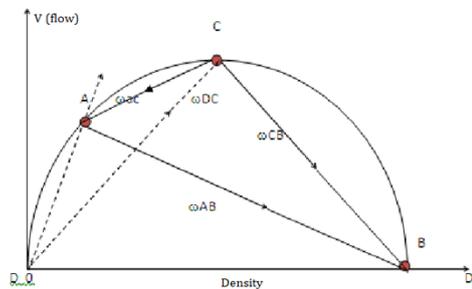
$D_j$  = Density at last volume condition total traffic jam (vehicles/km)

Sff = Speed at last volume condition very low traffic or at density condition close to 0 (zero) or free flow speed (km/hr)

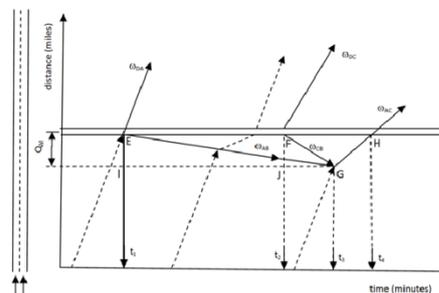
**Shockwave Value**

Shock waves on the road due to the influence of the incident so that the traffic flow becomes disrupted resulting in the closure of part or all of the road lane. Shock waves can be analyzed when the current-density relationship is known. For example: the current-density curve in Figure 2, but the condition in Figure 3 is a current condition with total resistance (all lanes are blocked).

**Figure 2: Shockwave Curve [14]**



**Figure 3: Distance and time chart**



Point A is a traffic condition with a flow of VA and a density of DA. Point B is a traffic condition after experiencing obstacles with a flow of VB and a density of DB. This point B can be in the form of a closed 1 lane or closed all lane condition. Point C is the maximum current condition that is after the resistance is removed. Point D is the point in front of the stop line, which shows VD = 0 and DD = 0. T is the time taken from the start of the lane normalization until the queue ends. In the above case there are 3 shock waves that occur:

$$\omega_{AB} = \frac{V_B + V_A}{D_B + D_A} \dots\dots\dots 2$$

$$\omega_{AC} = \frac{V_C + V_A}{D_C + D_A} \dots\dots\dots 3$$

$$\omega_{CB} = \frac{V_B + V_C}{D_B + D_C} \dots\dots\dots 4$$

Using a shock wave diagram, a distance and time diagram can be shown as in Figure 3. (t2-t1) shows the duration of the incident, (t3-t2) is related to the total time from lane opening to the time the last vehicle joined the long queue. The total delay is the product of the area of the triangle EFG with the density value associated with it and the area of the triangle FHG with the associated density value.

**Total time from lane opening to the time the last vehicle entered the queue**

If r = effective duration of lane closure (t2-t1), then t3-t2 can be calculated as follows see ΔEGI and ΔFGJ

$$t_3 - t_2 = \frac{\omega_{AB} \cdot r}{\omega_{CB} - \omega_{AB}} \dots\dots\dots 5$$

$$t_3 - t_2 = \frac{r}{60} \frac{|\omega_{AB}|}{|\omega_{CB}| - |\omega_{AB}|} \times 60 \dots\dots\dots 6$$

**Queue Length (Qm)**

The queue length is calculated as follows:

$$Q_M = \frac{r}{60} \frac{|\omega_{CB}| \cdot |\omega_{AB}|}{|\omega_{CB}| - |\omega_{AB}|} \dots\dots\dots 7$$

**Total from lane opening to condition normal**

Using t3-t2 and Qm, the total from the lane opening to the normal condition is formulated as follows:

$$t_4 - t_2 = \frac{Q_M}{\omega_{AC}} + (t_3 - t_2) \dots\dots\dots 8$$

**Total Delay**

The total delay is calculated by the formula:

$$T_d = \frac{r \cdot Q_M}{2} (D_B - D_A) + \frac{(t_4 - t_2) \cdot Q_M}{2} + (D_C - D_A) \dots\dots\dots 9$$

**2. RESEARCH METHODS**

**Place and time of research**

Lokasi penelitian dilakukan di Jalan Poros Barru – Makassar (Jembatan Sungai Maros). Sebelum dilakukan pengambilan data primer dilakukan survei pendahuluan untuk menentukan volume kendaraan puncak selama seminggu. Dari hasil survei pendahuluan maka pada hari puncak dilakukan pengambilan data primer baik pada jalan normal maupun pada jalan menyempit akibat jembatan Sungai Maros. Pengambilan data primer dilakukan perlimabelas menit dari jam 06.00 hingga jam 18.00.

**Research Data and Variables**

- 1) Primary data

Primary data is data obtained from conducting direct surveys in the field which includes traffic volume, speed, side fraction, road geometry.

- 2) Secondary Data

Secondary data is data obtained from related agencies, namely data on the population of Maros City obtained from the Department of Population and Civil Registration of Maros City.

## Data Collection

### 1) Traffic Volume Data

The collection of traffic volume data or the number of vehicles passing on the observation line is done by recording all vehicles that pass a stamping line at the observation post during the observation time, assisted by the use of a manual calculator.

### 2) Speed Data

Vehicle speed data collection in the field is carried out using the local speed method by measuring the moving travel time. Similar to the collection of traffic volume data, the recording of travel time is carried out during peak hours in one day, by dividing each hour of observation into 15-minute intervals.

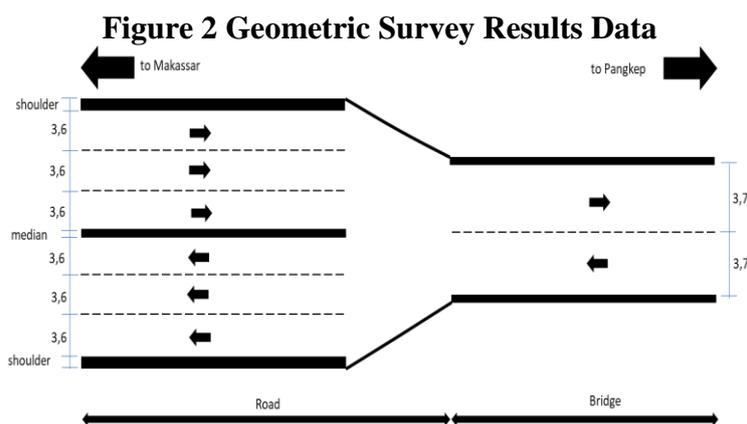
### Side Fraction Data

The data collection of side fraction in the field is carried out by calculating the types of roadside activities at the study location. The procedure for conducting the survey for collecting side obstacle data is the same as the survey when collecting speed data and traffic volume data.

### Road Geometric Data

Geometric data collection of road conditions is carried out at the location of the road to be observed by measuring and observing geometric conditions such as road type, traffic width, width, and condition of (kreb, shoulder, and median), and road alignment.

The geometric survey that has been carried out at the research location includes the geometric conditions of normal roads and traffic bottlenecks. The measurement data can be seen in the following picture.

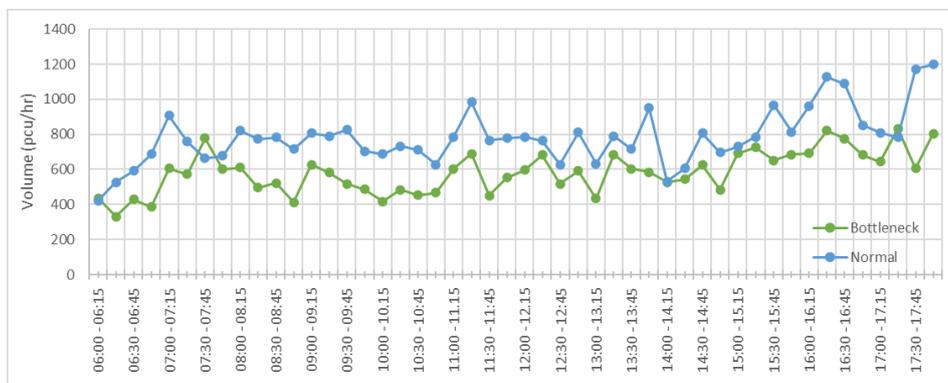


### 3. RESULTS AND DISCUSSION

#### Vehicle Volume

Traffic volume data collection on Jalan Poros Barru – Makassar (The Maros River Bridge) was carried out for 1 day starting from 6.00 am to 06.00 pm on two normal road conditions and bottleneck occurred with an interval of 15-minutes. To get the traffic volume in passenger car units (pcu) analyzed using the MKJI method, the vehicle volume data from the survey results at every 15-minute interval is multiplied by the equivalence factor (emp) and several other variables such as side barriers, city size, etc. The volume of each direction is summed to get one value of vehicle volume per 1 hour. The following are the results of the calculation of vehicle volume as shown in Figure 1 below.

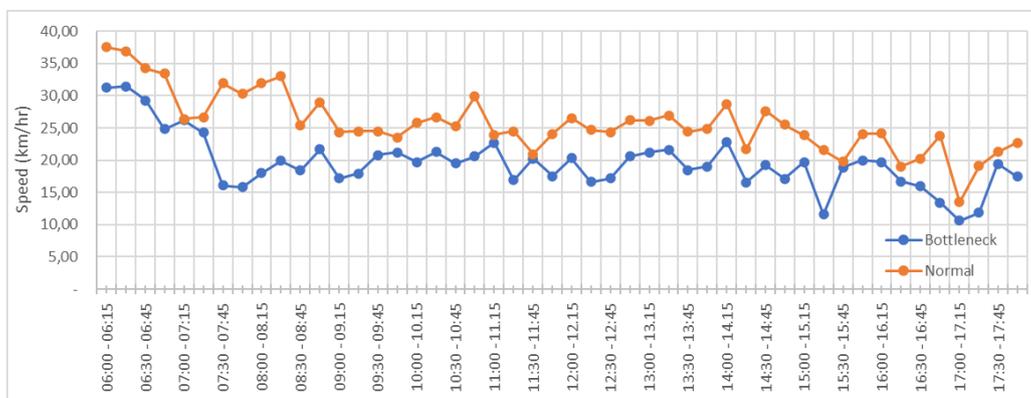
**Figure 1 Traffic Volume in Normal & Bottleneck Conditions**



#### Vehicle Speed.

Speed data is obtained based on a survey conducted in the same way as when calculating vehicle volume. In calculating the speed, the space means speed is used with a distance of 25 meters and a time interval of 15 minutes. Figure 2 is the result of calculating the average speed which shows variations in vehicle speed under normal road conditions and bottleneck condition.

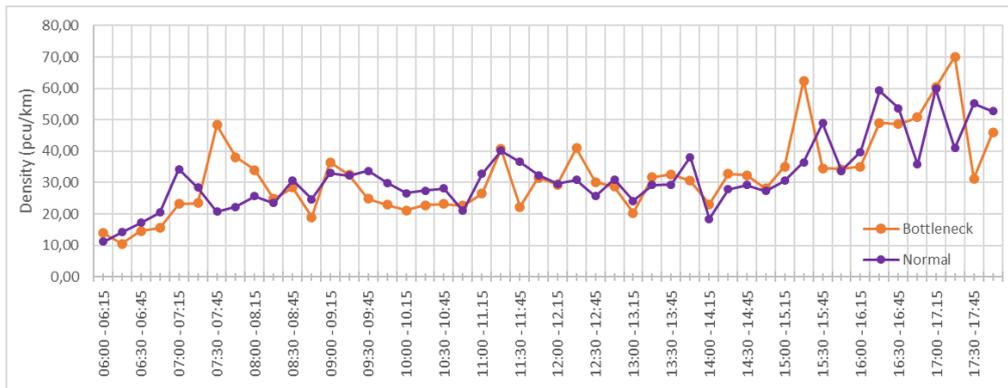
**Figure 2 Average Vehicle Speed in Normal & Bottleneck Conditions**



### Vehicle Density

Density is calculated by dividing the traffic volume by the average speed. From Figure 3 it can be seen that the highest maximum density is 59.85 pcu/km on normal roads and 70.10 pcu/km on bottleneck roads. More as in Figure 3 below.

Figure 3: Density in normal & bottleneck conditions



### Relationship between Volume, Velocity and Density

The relationship between the three variables above is based on data on traffic flow and vehicle speed taken every 15 minutes and arranged in a paired list to get the density value. The relationship between speed (U), density (D) and volume (V), was analyzed using three methods, namely the Greenshield, Greenberg and Underwood methods. Statistical analysis to find the relationship between the speed with density, volume with speed and volume and density with regression method. By using three mathematical models, namely the Greenshield, Greenberg and Underwood models, the relationship model is obtained as shown in Table 1.

Table 1: Calculation results of model parameter values

METHOD	RELATION	MODEL	
		NORMAL	BOTTLENECK
GREENSHIELD	S - D	$S = 37,2603 - 0,36.D$	$S = 28,8313 - 0,2887.D$
	V - D	$V = 37,2603.D - 0,36.D^2$	$V = 28,8313.D - 0,2887.D^2$
	V - S	$V = 103,495.S - 2,778.S^2$	$V = 99,8683.S - 3,4639.S^2$
GREENBERG	S - D	$S = 67,1358 - 12,1394.\ln D$	$S = 53,2361 - 9,9143.\ln D$
	V - D	$V = 67,1358.D - 12,1394.D.\ln D$	$V = 53,2361.D - 9,9143.D.\ln D$
	V - S	$V = 252,2515.S - e^{(-0,0824.S)}$	$V = 214,7844.S - e^{(-0,1009.S)}$
UNDERWOOD	S - D	$\ln S = 3,6954 - 0,0144.D$	$\ln S = 3,4498 - 0,0155.D$
	V - D	$V = 40,2627.D \cdot e^{(-0,0145.D)}$	$V = 31,4931.D \cdot e^{(-0,0155.D)}$
	V - S	$V = 255,1130.S - 69,0348.S.\ln S$	$V = 221,9094.S - 64,3259.S.\ln S$

From Table 1 the relationship model of speed and density characteristics (S-D) for Greenshield, Greenberg and Underwood generally shows that the value of traffic density increases when the value of traffic speed continues to increase when the traffic density approaches zero. For the relationship of V-D traffic characteristics as shown in Table 1, it can be seen that the volume increases up to a certain density value, namely the optimum density. Furthermore, the density

value continues to increase and the volume approaches zero. As for the relationship between V-S traffic characteristics as shown in Table 1, it can be seen that the road section of the study location has a tendency for the volume value to reach its peak at a certain speed value, then the speed value increases and the traffic volume value approaches zero.

### Maximum Value

After obtaining the regression equation for each model, the maximum current from each model will be calculated. The following presents the calculation results for the maximum value based on the data volume (Vm), speed (Sm) and density (Dm).

**Table 2: Maximum Value of Each Parameter**

METHOD	CONDITION	PARAMETER		
		Dm	Vm	Sm
GREENSHIELD	NORMAL	51,75	964,11	18,63
	BOTTLENECK	49,93	719,83	14,42
GREENBERD	NORMAL	92,80	1.126,51	12,14
	BOTTLENECK	79,01	783,37	9,91
UNDERWOOD	NORMAL	69,03	1.022,53	14,81
	BOTTLENECK	64,33	745,26	11,59

### Statistical Test

The variables tested in this study are the values of F and t which are the control tools from the results of statistical analysis in this case linear regression, by comparing the values of F and t obtained from the calculation results with the values of F and t from the table. The test is said to be true if the value of F and t count is greater than the table. The value of R<sup>2</sup> which is the coefficient of determination shows how much influence the independent variable (X) has on the dependent variable (Y). From the results of the analysis, it is known that the F<sub>count</sub> and t<sub>count</sub> values for the entire model have a value greater than the F and t values from the table at a 95% confidence level, so statistically, all models can be used. The results of statistical tests are shown in Table 3 below.

**Table 3: Determination Value and Model Validation Test**

METHOD	RELATION	STATISTICAL PARAMETERS					
		NORMAL CONDITION			BOTTLENECK CONDITION		
		r <sup>2</sup>	t	F	r <sup>2</sup>	t	F
GREENSHIELD	S - D	0,713	-10,698	114,444	0,725	-11,015	121,324
	V - D	0,760	12,064	145,541	0,738	11,387	129,671
	V - S	0,336	-4,821	23,239	0,394	-5,469	29,905
GREENBERD	S - D	0,796	-13,398	179,511	0,817	-14,314	204,878
	V - D	0,768	12,344	152,379	0,796	13,384	179,139
	V - S	0,302	-4,465	19,936	0,391	-5,432	29,508
UNDERWOOD	S - D	0,740	-11,431	130,675	0,806	-13,840	191,555
	V - D	0,738	11,387	129,672	0,711	10,647	113,359
	V - S	0,377	-5,277	27,852	0,418	-5,746	33,021

Based on the values presented in Table 3, it can be seen that for the S – D characteristic relationship, the three model approaches almost have the same  $R^2$  value, which is around 0.713 for the Greenshield model and 0.796 for the Greenberg model and 0.740 for the Underwood model. The same thing also happened to the V–D relationship model, where the  $R^2$  parameter values ranged between 0.760 and 0.768 and 0.738, respectively, in the Greenshield model, Greenberg model and Underwood model. However, in this connection, the Greenberg model approach is slightly higher than the other two approaches. For the V–S relationship model, the  $R^2$  parameter values of the Underwood model approach are slightly superior to those of the Greenshield and Greenberg approaches. The statistical test on the t and F tests with a total of 48 data with a significance level of 5% obtained a  $t_{table}$  value of 0.6796 and  $F_{table}$  4.0513, it can be concluded that all models can meet the fit test significantly. The results of the comparison of the three show the advantages and disadvantages of each model for each type of relationship model analyzed. In this context, the Greenberg model approach is slightly better than the Underwood model and the Greenberg model for the S–D, V–D and V–S relationship models. For further analysis in this study, the Greenshield model is used.

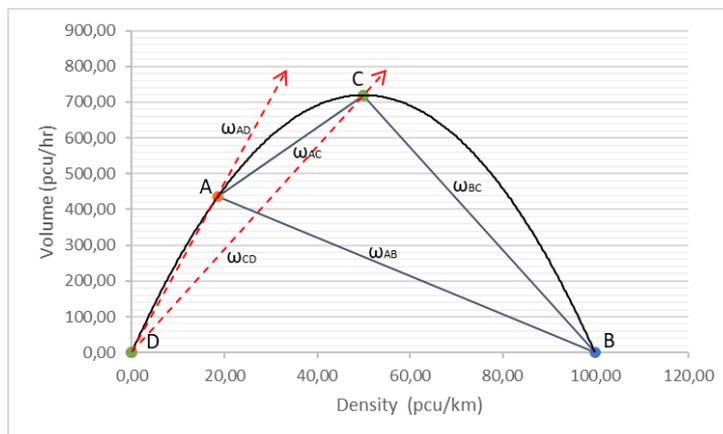
### Shockwave Value Analysis

The calculation of shock waves in road congestion begins by plotting between the inflows (demand) from upstream, namely: combined flows in the middle lane and the edges of normal roads with bottleneck road capacity (supply) based on the maximum current selected from time to time. The analysis begins when demand exceeds capacity. It can be seen that in the Greenshield Model there are six periods where demand exceeds the capacity. This is in line with the fact that the movement of vehicles at that time experienced a peak period where the mobility of human movement was generally in the morning when new activities began. Likewise, the afternoon period starting at 16.30 to 18.00 is the period of return movement which is generally from the activity centre to the house, in full as shown in the table below:

**Table 4: Shockwave analysis results**

Time	qA (pcu/hr)	$U_1$ (km/jam)	kA (pcu/km)	qB (pcu/hr)	kB (pcu/km)	$\omega_{AB}$	N (pcu/jam)	L (second)
07:30 - 07:45	779	16,10	48,39	719,83	49,93	-38,42	1800,34	36,05
16:15 - 16:30	822	16,74	49,11	719,83	49,93	-124,43	6009,17	120,34
16:30 - 16:45	776	15,96	48,62	719,83	49,93	-42,82	2025,68	40,57
16:45 - 17:00	682	13,40	50,89	719,83	49,93	-39,76	2061,00	41,27
17:00 - 17.15	643	10,64	60,43	719,83	49,93	-7,32	519,03	10,39
18:45 - 18:00	804	17,47	46,03	719,83	49,93	-21,53	906,93	18,16

Figure 4: Shockwave



Calculation of shock waves due to road narrowing from 3 (three) lanes to 2 (two) lanes with the repeated duration on normal road volume conditions greater than the maximum volume of road bottleneck. If it is assumed that the bottleneck that occurs in the time range 07.30 – 07.45 is varied ( $r$ ) as shown in Figure 4, it will be seen the slope of the line that describes the speed of the vehicle. At times  $t_0$  to  $t_1$  there are no obstacles so that the traffic flows in the direction of condition A. At time  $t_1$  there is an obstacle due to a bottleneck, the traffic flow condition changes to condition B and a queue of vehicles begins to form, when the traffic flow condition after the bottleneck returns to normal then it changes to condition D. As equations 2, 3 and 4 there are three shock waves that are formed when  $t_1$  at the stop line,  $w_{AB}$  is -15.13 km/hour,  $w_{CB}$  is -14.42 km/hour and  $w_{AC}$  is -38.42 km/hour.

Figure 5: Shockwave Analysis

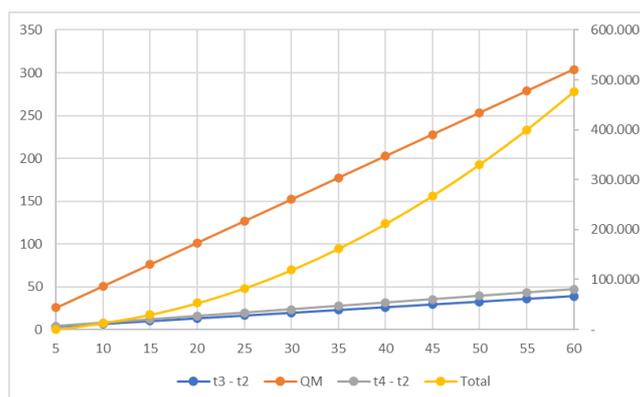


Figure 5 shows that the traffic flow in conditions D, C, B and A occurs continuously until  $w_{AB}$  and  $w_{CB}$  reach  $t_3$ , the time interval  $t_2$  to  $t_3$  can be calculated using equation 5, the resulting value of  $t_3 - t_2$  is 3.25 minutes.  $t_3 - t_2$  is the time interval between the first vehicles queued to enter the bottleneck road to the last vehicle joining the queue.  $r$  is the effective duration (minutes) of the occurrence of obstacles where the length of the normal road volume condition is greater than the maximum volume of the bottleneck road. At time  $t_3$  the maximum queue length (QM)

is calculated using equation 7 where the QM value is 25.32 meters. At time  $t_3$ , one new shock wave is formed, namely the forward-moving shock wave AC while the backward moving shock wave  $w_{AB}$  and  $w_{CB}$  ending. In the time span from before the obstacle occurs to the stop line is the maximum value  $t_4 - t_2$ . The value of  $t_4 - t_2 = T$  or normalization time and calculated by equation 8, the resulting value is 3.91 minutes. The details are shown in Figure 5 below.

## CONCLUSIONS

From the entire process of observing, calculating and analyzing the traffic flow that occurs in the bottleneck of the road on Jalan Poros Barru – Makassar (The Maros River Bridge) it can be concluded as follows:

1. There is a fairly basic difference in travel speed in the three road conditions, which is due to differences in the geometric characteristics of the road, such as from a 3 lane road to a 2 lane road, in normal road conditions the speed is greater than the bottleneck road condition.
2. In the bottleneck condition of the regression analysis in general the coefficient of determination in the Greenberg method is better than the Greenshield method and the Underwood method, this can be seen from the  $R^2$  value which is 0.817 respectively compared to 0.725 and 0.806 in the relationship between Speed and Density. In the relationship between volume and density, the coefficient of determination for the Greenberg method is better than the Greenshield method and the Underwood method with a coefficient of determination ( $R^2$ ) of 0.796 respectively compared to values of 0.738 and 0.731. Meanwhile, the relationship between volume and velocity obtained a less significant relationship for the three methods, it can be seen because the coefficient of determination is only 0.394, 0.391 and 0.418 for the Greenshield, Greenberg and Underwood methods.
3. From the statistical analysis for the three models on normal road conditions and on narrow roads with a significance level of 5%, the values of  $t_{table}$  and  $F_{table}$  are 0.6796 and 4.0513, respectively, this shows that the  $t_{table}$  and  $F_{table}$  values are smaller than the value of  $t_{count}$  and  $F_{count}$ . The results of this analysis can be concluded that all models can meet the suitability test significantly.
4. From the analysis and calculation of shock waves, it can be seen that in the Greenshield Model, shock waves will occur in six time periods, namely at 07.30 – 07.45, 16.15 – 16.30, 16.30 – 16.45, 16.45 – 17.00, 17.00. – 17.15 and in the period 17.45 – 18.00. The shock wave values that occurred in each of these periods were -38.42 km/hour, -124.43 km/hour, -42.82 km/hour, -39.76 km/hour, -7.32 km/h and -21.53 km/h.

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