Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 8, No. 5, 922-939
2024
Publisher: Learning Gate
DOI: 10.55214/25768484.v8i5.1794

Prediction of queue length due to lane closure with shockwave analysis on Jagorawi toll road (Case study: Km 19+600)

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Abstract: This study discusses the prediction of queue length with shockwave analysis through traffic flow characteristics on the Jagorawi toll road KM 19+600. The purpose of this study is to analyze the relationship between traffic characteristics (current, density and speed) on the Jagorawi KM19+600 toll road and evaluate the value of shock waves due to the narrowing of the road on the Jagorawi KM 19+600 toll road when the lane is closed. The method used to achieve the purpose of this study is to use the linear regression method to determine the relationship between traffic variables through the Greenshield model. The data obtained was obtained from CCTV data recording at KM 19 + 600. The results of the current-velocity-density relationship analysis show that the selected model for the relationship is the Greenshield model with a maximum current of 9574 pcu/hour. From the results of the shock wave simulation for the closure of 1 lane, 2 lanes and 3 lanes with the same flow, namely 7200 pcu/hour. It can be known the length of the queue that occurs, where the length of the queue that occurs depends on the volume of traffic, the length of the closure and the number of lanes that are closed.
Keywords: *Characteristics, Jagorawi toll road, Lane closure, Shock wave, Traffic flow.*

1. Introduction

According to the Law of the Republic of Indonesia Number 2 Year 2022, the definition of a Toll Road is a Freeway which is part of the Road Network System and as a national road whose users are required to pay, while a Freeway is a Public Road for traffic with full control of the entrance road and without a level of intersection and equipped with a space fence belonging to the Road. Toll roads are designed based on a minimum planned speed of 80 (eighty) kilometers per hour for intercity toll roads and 60 (sixty) kilometers per hour for toll roads in urban areas (Government Regulation 23 on Toll Roads, 2024).

Reducing congestion and increasing productivity is a typical goal of highway transportation management and control initiatives. Travel time per vehicle, average speed, and total delay are three metrics that can be used to quantify the throughput of any instrumented freeway stretch in real-time (Chen et al., 2001).

According to Dagazo (1995), continuum models of traffic flow are hyperbolic systems that describe how traffic states evolve based only on the initial and boundary conditions. Since they may use fluid-like state variables like density and flow to examine the collective behavior of traffic flow at an aggregate level, these models are also referred to as macroscopic models. Despite its simplicity, the LWR model of traffic flow is an incredibly strong and effective theory, however it is unable to explain significant traffic phenomena like vehicle clustering. In macroscopic traffic theory literature, particularly in higher order model literature (Gupta et al, 2005)

Greenshields, Greenberg and Underwood models are the most commonly used models to state the relationships between flow, density and speed. These models are key factors for traffic engineers to

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explore the characteristic of traffic flow. The Greenshields model is considered as the best that represent the field data (Rompies, 2018)

Shockwave is defined as the movement or journey of a change in traffic flow Shockwave in road traffic is described as a movement in traffic flow due to a change in density and traffic flow values. In the condition of free flow, if the current gets an obstacle (disturbance), there will be a reduction in the current that passes through the location of the obstacle. This reduction in flow results in congestion in the area before the obstacle increases, ultimately resulting in a decrease in speed and queues. (Tamin, 2003).

The implementation of toll roads must meet the Minimum Service Standards (SPM) of Toll Roads as regulated in the Regulation of the Minister of Public Works (PU) Number 16/PRT/M/2014, where the Minimum Service Standard for the average travel speed under normal conditions for intercity toll roads is >60 km/hour. This speed must be maintained so that obstacles that will reduce the speed of the vehicle must be overcome immediately. Obstacles that occur can be in the form of lane closures, accidents, road repairs, and so on.

To find out the prediction of speed decrease due to obstacles on the freeway, it is necessary to study the characteristics of the flow of traffic on the road.

This research was conducted on the JAGORAWI toll road, where the Jakarta-Bogor-Ciawi toll road is a connecting access from the city of Jakarta out of cities such as Bogor and the Puncak area. As a result, the JAGORAWI Toll Road every day demands a high-intensity movement so that it must be guaranteed to move as smoothly as possible. However, it is inevitable that there will be obstacles that occur such as accidents or road repairs that require the closure of part of the closed lane.

2. Literature Review

2.1. Traffic Flow Characteristics

There are three main variables needed in analyzing traffic characteristics on road sections, namely volume, speed and density.

The relationship between velocity, volume and density can be represented as follows:

$$Q = u.k$$

where:
Q =volume (kend/jam)
u = speed (km/hour)
k = density (kend/h)

This relationship can also be illustrated with Figure 1 which shows the general relationship between velocity-density (u-k), volume-density (q-k) and volume-velocity (q-u).

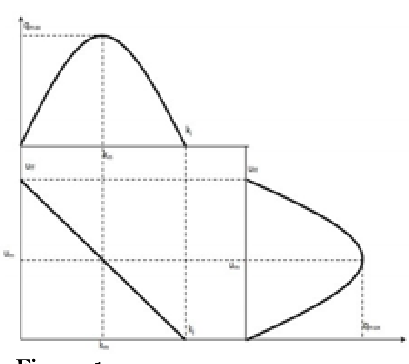

Figure 1.
Fundamental diagram.

In this study, there are 3 types of traffic flow models used to represent the mathematical

ISSN: 2576-8484
Vol. 8, No. 5: 922-939, 2024
DOI: 10.55214/25768484.v8i5.1794

relationship between speed, volume, and density, namely Greenshields, Greenberg and Underwood.

2.2. Model of the Relationship of Volume, Speed And Density

2.2.1. Model Greenshield

This modeling is the earliest model recorded in an effort to observe traffic behavior. Greenshields got the result that the relationship between velocity and density is linear. This model can be described as follows:

$Us = Uf – (Uf / Dj) D$

Where

Us: average speed of space (km/hour)

Uf : speed in free flow conditions (km/hour)

K : Density (pcu/km),

Kj: jammed density (pcu/km)

Q is the traffic flow (pcu/hour).

Greenshield reveals the relationship between volume and density as follows:

$Q = U_f \times D – (U/Dj) \times D^2$

The relationship between volume and velocity is also a parabolic relationship with the following form of equation:

$Q= D_j \times Us – (D_j / U_f) \times Us^2$

In regression analysis, the correlation coefficient is a measure of the closeness of the relationship between free variables (x) and non-free variables (Q). The Coefficient of Determination (r^2) is used to determine the extent to which the contribution of the free variable in the regression model is able to explain the variation of the bound variable. The coefficient equation of correlation (r) is as follows:

$$r = \frac{n(\sum XY) - (\sum X)(\sum Y)}{\sqrt{(n\sum X^2 - (\sum X)^2)(n\sum Y^2 - (\sum Y)^2)}}$$

2.3. Shock Wave

Shockwave is defined as the movement or journey of a change in traffic flow Shockwave in road traffic is described as a movement in traffic flow due to a change in density and traffic flow values. Tamin, 2003). Shock waves can be described as movements in traffic flow due to changes in the density value of traffic flows when the current and density are relatively high. If an obstacle is given to the current, there will be a reduction in the current that can pass through the location of the obstacle. This reduction in flow results in the density of vehicles in the area before the location of the obstacle becomes high, which in the end the vehicle speed drops or even queues occur. The obstacle to traffic flow can be in the form of lane closure due to accidents, road repairs, or it can also occur due to traffic lights.

In the following Figure 2, it shows the graph of the relationship between k and q. Point A is a traffic condition with a current of VA and a density of D. Point B is a traffic condition after experiencing an obstacle with a current of VB and a density of DB. Point B can be in the form of a closed lane of 1 lane or closed altogether. Point C is the maximum current condition i.e. 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 it takes from the beginning of lane normalization to the end of the queue.

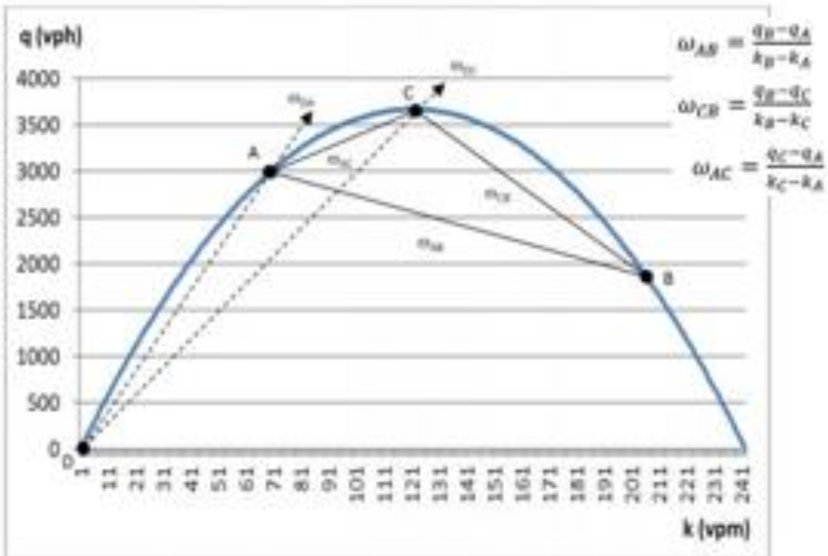

Figure 2.
Shock waves in road narrowing (Current-density).
Source: Tamin (2008).

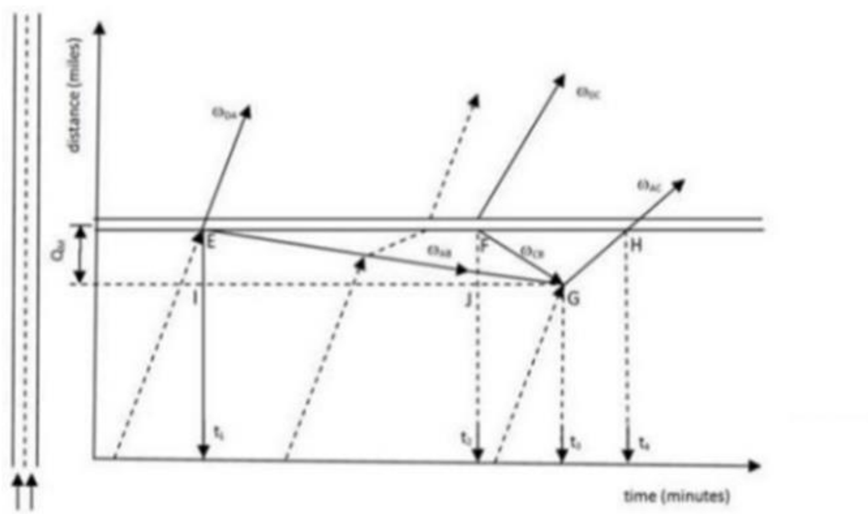

Figure 3.
Shock waves in road narrowing (Time-distance).
Source: Tamin (2008).

($T2$ - $T1$) indicates the duration of the incident,
($T3$ - $T2$) is related to the total time from lane opening to the last time a vehicle joined a long queue. The total delay is the multiplication of the EFG triangle region by the density value associated with it and the FHG triangle multiplication region by the associated density value.

3. Research Methods

The research location is on the Jagorawi Toll Road KM 19+600.

Figure 4.
Research location, Jagorawi toll road KM 19+600.

The primary data obtained in this study was obtained directly from the results of the field survey, namely the Geometry Data of the Jagorawi Toll Road km19 + 600 measured at FO GT Cimanggis. As for the secondary, it was obtained from PT Jasamarga Jagorawi in the form of CCTV at km 19 + 600.

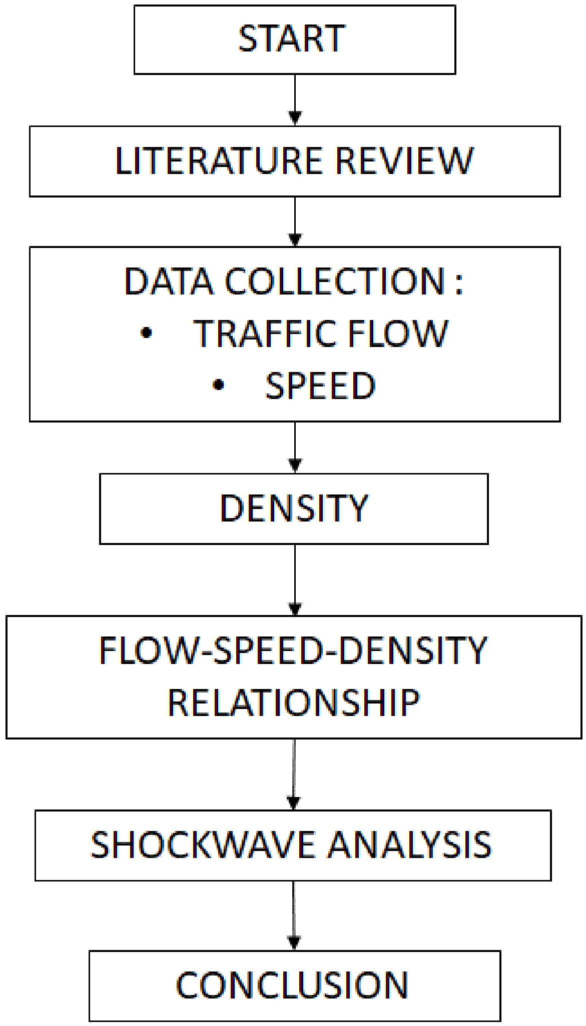

Figure 5.
Flow chart of research methods.

Traffic flow and vehicle speed are calculated with a predetermined distance guide. The density is calculated from the results of the flow analysis divided by the velocity. The analysis of the relationship between volume, velocity and density was carried out using the Greenshield model. After obtaining the flow-speed-density relationship model, shock wave analysis was carried out by simulating the closure of 1,2 and 3 lanes.

4. Results and Discussion

In this study, the enumeration of traffic volume begins by determining a certain point or line on the video data from CCTV (Figure 6), then the enumeration of traffic volume based on the type of vehicle with a duration of 5 minutes.

DOI: 10.55214/25768484.v8i5.1794

Figure 6.
Reference point for data collection of traffic volume and speed.

Furthermore, the traffic volume is recorded and multiplied by the passenger car equivalent (emp). The total number of vehicles with the highest hours in the observation period is:

Bogor Direction : 6821 vehicles
Jakarta Direction :7414 vehicles
Type of linemen : Flat
The passenger car equivalent (pce) values used are:
Passenger car : 1.0
Medium sized vehicle : 1.3
Big Bus : 1.5
Big Truck : 2.0

Based on this value, the traffic volume per 5 minutes can be converted to passenger car units (pcu). An example of the calculation of the results of the conversion from vehicle units per group to pcu in the observation period at 06.00-06.05 is presented in Table 1.

Table 1.
Traffic flow at 06.00-06.05 on Jagorawi toll road km 19+600.

Period	direction	number of vehicle (vehicle)					number of pcu	
		Type I	Type II	Type III	Type IV	Type V	5 minutes	per hour
06.00 - 06.05	Bogor	150	16	15	1	0	195	2344
	Jakarta	303	30	13	3	0	368	4410

Source: Analysis Results, 2024.

Traffic speed is obtained by measuring the travel time of each vehicle according to the type of vehicle so that the speed of each vehicle is obtained. The measurement of travel time begins by determining a 2(two) lines with a distance of 52 m obtained from the results of the field survey on the video data of the CCTV results.

The traffic density value is calculated using the formula for the relationship between volume and traffic speed as follows:

$$K = \frac{Q}{U}$$

Where:
K = Density (Number of vehicles/km)
Q = Traffic volume (pcu/hour)
U = Average speed (Km/hour)

The results of the calculation of speed, volume and traffic density on the Jagorawi toll road km 19 + 600 for each 5-minute period are presented in Table 2 and Table 3, which are as follows:

Table 2.
Speed-volume-density Jl, Jagorawi toll road km 19+600 bogor direction.

no. of data	average speed (u) km/hour	flow rate (Q) pcu/hour	density (k=Q/u) pcu/km
1	76	2344	31
2	101	2132	21
3	81	2236	28
4	83	2118	26
5	77	2928	38
6	68	2570	38
7	68	3211	47
8	58	3698	64
9	73	3162	43
10	75	2989	40
11	75	3340	44
12	70	3409	49
13	75	3990	53
14	71	4228	59
15	72	3193	45
16	77	4213	55
17	77	4571	60
18	74	3758	50
19	88	4115	47
20	81	5100	63
21	71	4145	59
22	67	3955	59
23	64	5185	82
24	86	3623	42
25	79	4085	52
26	80	5758	72
27	75	6076	81

Source: Analysis Results, 2024.

ISSN: 2576-8484
Vol. 8, No. 5: 922-939, 2024
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Table 3.
Speed-volume-density Jl, Jagorawi toll road Km 19+600 Jakarta.

no. of data	average speed (u) km/hour	flow rate (Q) pcu/hour	density (k=Q/u) pcu/km
1	75	4410	59
2	85	4722	55
3	69	3872	56
4	66	4518	69
5	58	5675	98
6	61	5573	92
7	72	5234	72
8	67	6217	93
9	69	6457	94
10	67	6654	99
11	76	5695	75
12	68	4811	71
13	58	6547	113
14	63	5424	86
15	65	5018	78
16	76	4589	60
17	77	5063	66
18	72	4684	65
19	79	4880	62
20	69	4068	59
21	63	4928	78
22	67	4300	65
23	64	7414	117
24	68	4576	67
25	80	4140	51
26	73	5156	70
27	71	4316	60
28	79	4590	58

Source: Analysis Results, 2024.

4.1. Analysis of Volume, Velocity, and Density Relationship Models

The calculation of the mathematical relationship for the Greenshield model is determined based on the combination of speed, volume and density data in both directions of Bogor and Jakarta to obtain more varied data on high and low traffic volume conditions. Merge is possible due to the same geometric dimensions in both directions

4.1.1. Relationship Between Speed and Density

Greenshield states that the relationship between velocity and density is in the form of a linear function with the equation:

U.s.$= Uf - \left(\frac{Uf}{Dj}\right).D$

Where
U.s. : Speed (km/hour)
Uf : Free flow speed (km/hour)
Dj : jammed density (pcu/km)
D : density (pcu/km)

the equation is changed to a linear equation y = a + bx with Us = y,
Uf = a, b = (-Uf/Dj), x = D. So it is obtained:
a = 83.33, Maka Uf = a = 83.33 km/hour
b = -0.1813, Maka Dj = Uf/b = 459.57pcu/hour
The calculations a and b are presented in the Appendix.
So the regression equation is
Us = 83.33 – (0.1813) x D

Its correlation coefficient (r) $= \frac{n(\sum XY)-\sum X.\sum Y}{\sqrt{(n\sum X^2-(\sum X)^2)(n.\sum Y^2-(\sum Y)^2}}$
= -0.9331

$r^2 \quad = 0.8707$

b. Volume and Speed Relationship

The relationship between volume and velocity is a parabolic relationship with the following form of equation:

$V \quad = Dj \times Us - (Dj / Uf) \times Us^2$

$\quad = 459.57 \times Us - (459.57 / 83.33) \times Us^2$

c. Relationship between volume and density

The relationship between volume and density is also a parabolic relationship with the following form of equation:

$V \quad = Uf \times D - (Uf / Dj) \times D^2$

$\quad = 83.33 \times D - (0.1813) \times D^2$

The maximum Volume calculation can be calculated by using the formula

$Vmaks = Uf \times Dj / 4$

$\quad = 83.33 \times 459.57 / 4$

$\quad = 9574$ smp / jam

Based on the mathematical model of the relationship between velocity, volume and density, the capacity values for each model are presented in Table 4. Namely as follows:

Table 4.
Capacity calculation based on the mathematical model of speed, volume and density of the Jagorawi toll road km 19+600.

	Capacity	
	Pcu/4 lanes/hr	**Pcu/lane/hr**
Model	9574	2393
PKJI	10000	2500

The mathematical model of the relationship between speed, volume and density of the Jagorawi toll road km 19 + 600 is presented in Table 5 and Figures 6, 7 and 8 as follows

Table 5.
Mathematical model of the relationship between speed, volume and density of the jagorawi toll road km 19+600

Relationship	**Equation**
Speed-density	Us= 83.33 – 0.1813D
Flow-speed	Q = 459.57Us-5.52Us2
Flow-density	Q = 83.33D – 0.1813D2

Source: Analysis Results, 2024.

From the calculation results, it appears that all model~~s~~ are suitable for use because the value of r^2 0.87 ~~for all models is 0.87~~>0.8. ~~So for the selection of the model to be used, the Greenshield model is because~~ The maximum capacity value of the model ~~Greenshield~~, which is 2393 pcu/hour/lane, is close to the Indonesia Road Capacity Guidelines (PKJI, 2023) of 2500 pcu/hour/lane.

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 8, No. 5: 922-939, 2024
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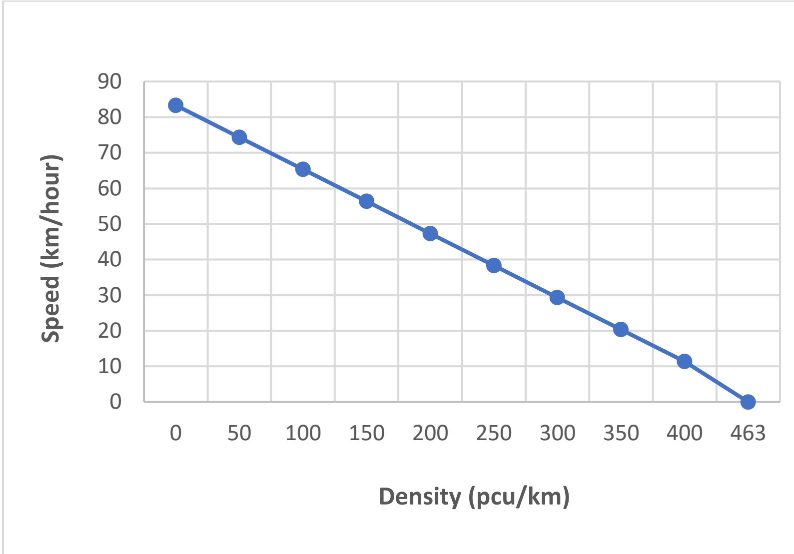

Figure 7.
Graph of the relationship between speed and density.

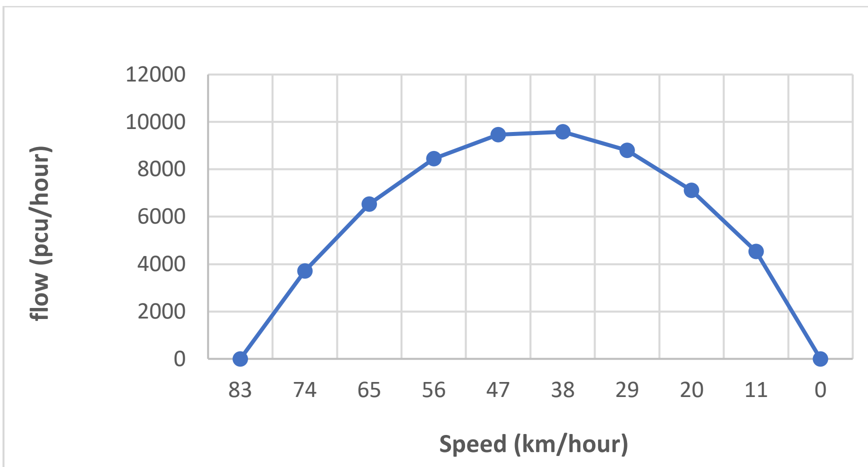

Figure 8.
Volume and speed relationship graph.

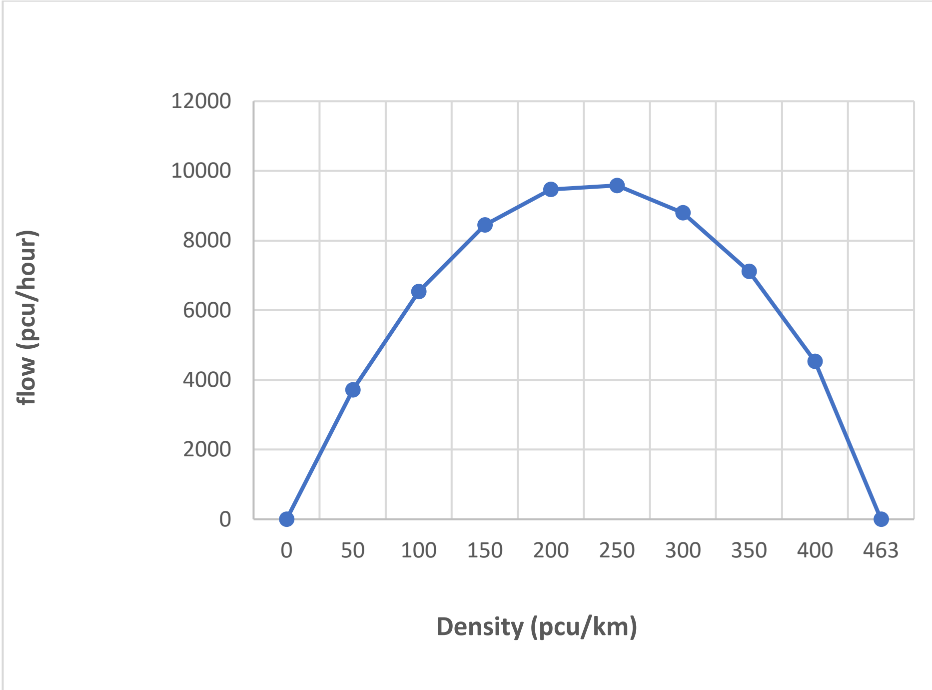

Figure 9.
Volume and density relationship graph.

4.2. Shock Wave

The selection of the Greenshield model on the Jagorawi toll road section is set for the calculation of 3 lanes at once with an observation interval of 5 minutes. The initial calculation is the Capacity Used Due to Lane Closure, which can be seen in Table 6 Table of Capacity Used Due to Lane Closure.

Table 6.
Capacity Used due to lane closure.

closed lane width (m)	effective width (meter)	no of lane	Factor of lane width	base capacity pcu/lane/hou	effective capacity pcu/hr
3.75	11.25	3	1.03	2500	7725
7.5	7.5	2	1.03	2500	5150
11.25	3.75	1	1.03	2500	2575

Source: Analysis Results, 2024.

4.3. Shock Wave Due to the Closure of 1 Lane

The value of shock waves that occur on roads that are disrupted by the closure of 1 lane can be seen in the graph.

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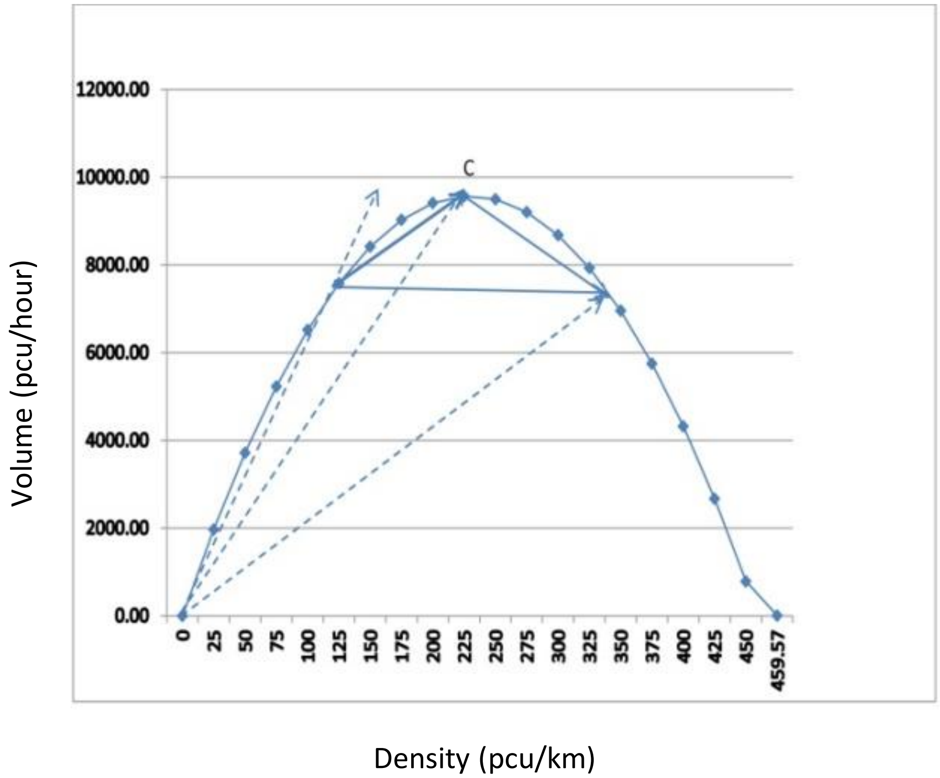

Figure 10.
1 Lane closure chart.

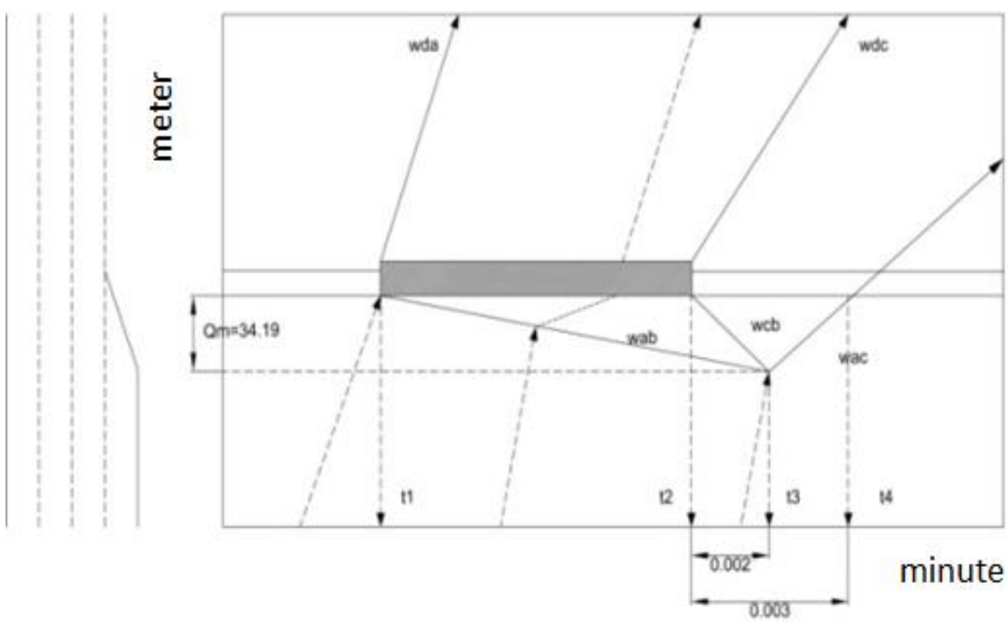

Figure 11.
Shock wave in the condition ~~that the road is closed~~ 1 lane closure for 5 minutes, for the value V = 7200 pcu/hour

Edelweiss Applied Science and Technology
ISSN: 2576-8484
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The state of traffic flow in condition A, is the traffic flow when entering condition B which is the condition of the traffic flow that is experiencing obstacles (1 lane is blocked) during the time between t_0 to t_1, there is no obstacle in the traffic flow moving downstream with the flow of condition A (V_A, DA). VA value is the value of the current that occurs in condition A.

The value of VA = 7200 pcu/hour and the value of D_A is the value of the density that occurs under condition A. The value of density D_A follows the function of the mathematical relationship between current – density of the Greenshield model, which is 115.35 pcu/hour. The value of V_A must be above the usable capacity of 1 lane.

At the time of t_1 (5 minutes), there was an obstacle that caused a narrowing or bottleneck effect and the traffic condition changed to condition B (V_B, DB).

VB is the current value that occurs in condition B. The value is taken from the calculation of the usable capacity for 1 lane in table 4.13, namely $V_{B\ =\ 7107.\ \text{And}\ DB}$ is the density value in condition B. The value of D_B follows the function of the mathematical relationship between current – density of the Greenshield model. D_B = 346.5 pcu/hour.

After the occurrence of a downstream narrowing changes to condition D, Point D is the point in front of the stop line indicating zero current and zero density conditions. $V_{D=\ 0,\ DD}$ = 0. At the start of t 1, the shock wave that occurs is ωAB. ωAB is the wave velocity between 2 (two) conditions A and B.

Traffic flow in conditions A, B and D continues to occur until time t_2 where at that time the traffic flow does not experience obstacles.

In the C condition (V_C, DC), it is the maximum current condition after the resistance is removed. Where the value of V_c is the maximum current value obtained from the mathematical function between current – density of the Greenshield model, namely V_C = 9574 pcu/hour. And the $D_{C\ \text{value}}$ is the density that occurs at the maximum current according to the Greenshiled model, namely D_C = 228 pcu/hour.

At the time of the change of conditions to C, this causes the formation of 2 new shock waves, namely ωDC and ωCB. Traffic flow in conditions D, C, B and A continues until ωAB and ωCD reach t_3. At time t_3 1 (one) new shock wave is formed, namely the forward motion shock wave ωAC, and 2 (two) backward motion shock waves ωAB and ωCB end. And at t_4, the forward motion shock wave ωAC cuts the stop line and the traffic current at the stop line changes from the maximum current Vc to Va.

Example of a shock wave calculation on a toll road section that is closed 1 (one) lane for 5 minutes
VA = 7200 pcu/hour, DA = 115,35 pcu/hour,
VB = 7107 pcu/hour, DB = 346.5 pcu/hour, Value taken from capacity calculation Applies to 1 column on Table 6.

$$\boldsymbol{\omega AB = \frac{VB - VA}{DB - DA} = \frac{7107 - 7200}{346,5 - 115,35} = -0,402\ km/hour}$$

A negative value indicates a backward movement. When there is no obstacle, the current changes to condition C. Backward moving shock wave is moving in the opposite direction to the movement of traffic flow (queue speed)
VC = 9574pcu/hour, DC = 228 pcu/hour

$$\boldsymbol{\omega CB = \frac{VB - VC}{DB - DC} = \frac{7107 - 9574}{346,5 - 228} = -20.819\ km/hour}$$

A negative sign means that the shock wave is moving backwards

$$\boldsymbol{\omega DC = \frac{VC - VD}{DC - DD} = \frac{9574 - 0}{228 - 0} = 41.991\ km/hour}$$

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A positive sign means that the shock wave is moving forward (forward moving shock wave), which is moving in the same direction as the movement of traffic flow. With r = 5 minutes, then:

$$\mathbf{t3 - t2} = \frac{\boldsymbol{r}}{\mathbf{60}}\ \boldsymbol{x}\ \left(\frac{\boldsymbol{\omega AB}}{\boldsymbol{\omega BC - \ \omega AB}}\right) = \frac{\mathbf{5}}{\mathbf{60}}\boldsymbol{x}\left(\frac{\mathbf{0,402}}{\mathbf{20,819 - 0,402}}\right) = \mathbf{0,002}\ \boldsymbol{minute}$$

$$\mathbf{QM} = \frac{\boldsymbol{r}}{\mathbf{60}}\ \boldsymbol{x}\ \left(\frac{\boldsymbol{\omega CB\ x\ \omega AB}}{\boldsymbol{\omega CB - \ \omega AB}}\right) = \frac{\mathbf{5}}{\mathbf{60}}\boldsymbol{x}\left(\frac{\mathbf{20,819}\ \boldsymbol{x}\ \mathbf{0,402}}{\mathbf{20,819 - \ 0,402}}\right)\boldsymbol{x}\ \mathbf{1000} = \mathbf{34,19}\ \boldsymbol{meter}$$

$$\mathbf{\omega AC} = \frac{\boldsymbol{VC - VA}}{\boldsymbol{DC - DA}} = \frac{\mathbf{9574 - 7200}}{\mathbf{228 - 115,35}} = \mathbf{21,074}\ \boldsymbol{km/hour}$$

$$\mathbf{t4 - t2} = \frac{\boldsymbol{r}}{\mathbf{60}}\ \boldsymbol{x}\ \left(\frac{\boldsymbol{\omega AB}}{\boldsymbol{\omega CB - \ \omega AB}}\right)\boldsymbol{x}\ \left(\frac{\boldsymbol{\omega CB}}{\boldsymbol{\omega AC}} + \mathbf{1}\right) = \frac{\mathbf{5}}{\mathbf{60}}\boldsymbol{x}\left(\frac{\mathbf{0,402}}{\mathbf{20,819 - 0,402}}\right)\boldsymbol{x}\left(\frac{\mathbf{20,819}}{\mathbf{21,074}} + \mathbf{1}\right)$$
$$= \mathbf{0,003}\ \boldsymbol{menit}$$

(t4 – t2) = T, called normalization time, which is the total time from the normalization of the lane to the end of the queue.

Shock Wave Due to the Closure of 2 Lanes

Example of a shock wave calculation on a toll road section that is closed 2 (two) lanes for 5 minutes with a value of V_A which is 7200 PCU/hour.

VA = 7200 pcu/hour, D_A = 115.35 pcu/hour

VB = 4738 pcu/hour, D_B = 393.15 pcu/hour, The value is taken from the capacity calculation applicable to 2 columns on Table 6.

$$\omega\text{AB} = \frac{VB - VA}{DB - DA} = \frac{4738 - 7200}{393{,}15 - 115{,}35} = -8{,}862\ km/hour$$

A negative value indicates a backward movement. When there is no resistance, the current changes to condition C.

VC = 9574pcu/hour, DC = 228 pcu/hour

$$\omega\text{CB} = \frac{VB - VC}{DB - DC} = \frac{4738 - 9574}{393{,}15 - 228} = -29{,}282\ km/hour$$

A negative sign means that the shock wave is moving backwards

$$\omega\text{DC} = \frac{VC - VD}{DC - DD} = \frac{9574 - 0}{228 - 0} = 41.991\ km/hour$$

A positive sign means that the shock wave is moving forward, with r = 5 minutes, then:

$$\text{t3} - \text{t2} = \frac{r}{60}\ x\ \left(\frac{\omega AB}{\omega BC - \ \omega AB}\right) = \frac{5}{60}x\left(\frac{8{,}862}{29{,}282 - 8{,}862}\right) = 0{,}036\ menit$$

$$\text{QM} = \frac{r}{60}\ x\ \left(\frac{\omega CB\ x\ \omega AB}{\omega CB -\ \omega AB}\right) = \frac{5}{60} x \left(\frac{29{,}282\ x\ 8{,}862}{29{,}282 -\ 8{,}862}\right) x\ 1000 = 1059{,}08\ meter$$

$$\omega\text{AC} = \frac{VC - VA}{DC - DA} = \frac{9574 - 7200}{228 - 115{,}35} = 21{,}074\ km/hour$$

$$\text{t4} - \text{t2} = \frac{r}{60}\ x\ \left(\frac{\omega AB}{\omega CB -\ \omega AB}\right) x\ \left(\frac{\omega CB}{\omega AC} + 1\right) = \frac{5}{60} x \left(\frac{8{,}862}{29{,}282 - 8{,}862}\right) x (\frac{29{,}282}{21{,}074} + 1)$$
$$= 0{,}086\ menit$$

(t4 – t2) = T, called normalization time, which is the total time from the lane normalization to the end of the queue

Shock Wave Due to 3-Lane Closure

Example of a shock wave calculation on a toll road section that is closed 3 (three) lanes for 5 minutes with a value of V_A which is 7200 PCU/hour.

VA = 7200 pcu/hour, D_A = 115.35 pcu/hour

VB = 2369 pcu/hour, D_B = 429.18 pcu/hour. The value is taken from the capacity calculation Applicable to 3 columns on Table 4.13

$$\omega\text{AB} = \frac{VB - VA}{DB - DA} = \frac{2369 - 7200}{429{,}18 - 115{,}35} = -15{,}394\ km/hour$$

A negative value indicates a backward movement. When there is no resistance, the current changes to condition C.

VC = 9574pcu/hour, DC = 228 pcu/hour

$$\omega\text{CB} = \frac{VB - VC}{DB - DC} = \frac{2369 - 9574}{429{,}18 - 228} = -35{,}814\ km/hour$$

A negative sign means that the shock wave is moving backwards

$$\omega\text{DC} = \frac{VC - VD}{DC - DD} = \frac{9574 - 0}{228 - 0} = 41.991\ km/hour$$

A positive sign means that the shock wave is moving forward, with r = 5 minutes, then:

$$\text{t3} - \text{t2} = \frac{r}{60}\ x\ \left(\frac{\omega AB}{\omega BC -\ \omega AB}\right) = \frac{5}{60} x \left(\frac{15{,}394}{35{,}814 - 15{,}394}\right) = 0{,}063\ minute$$

$$\text{QM} = \frac{r}{60}\ x\ \left(\frac{\omega CB\ x\ \omega AB}{\omega CB -\ \omega AB}\right) = \frac{5}{60} x \left(\frac{35{,}814\ x\ 15{,}394}{35{,}814 -\ 15{,}394}\right) x\ 1000 = 2249{,}85\ meter$$

$$\omega\text{AC} = \frac{VC - VA}{DC - DA} = \frac{9574 - 7200}{228 - 115{,}35} = 21{,}074\ km/hour$$

$$t4 - t2 = \frac{r}{60}\ x\ \left(\frac{\omega AB}{\omega CB - \ \omega AB}\right) x\ \left(\frac{\omega CB}{\omega AC} + 1\right) = \frac{5}{60} x \left(\frac{15{,}394}{35{,}814 - 15{,}394}\right) x (\frac{35{,}814}{21{,}074} + 1)$$
$$= 0{,}17\ menit$$

(t4 – t2) = T, called normalization time, which is the total time from the normalization of the lane to the end of the queue.

Relationship between queue length and closing time with V=7200 pcu/hour due to 1, 2 and 3 lanes closure is shown on Figure 12.

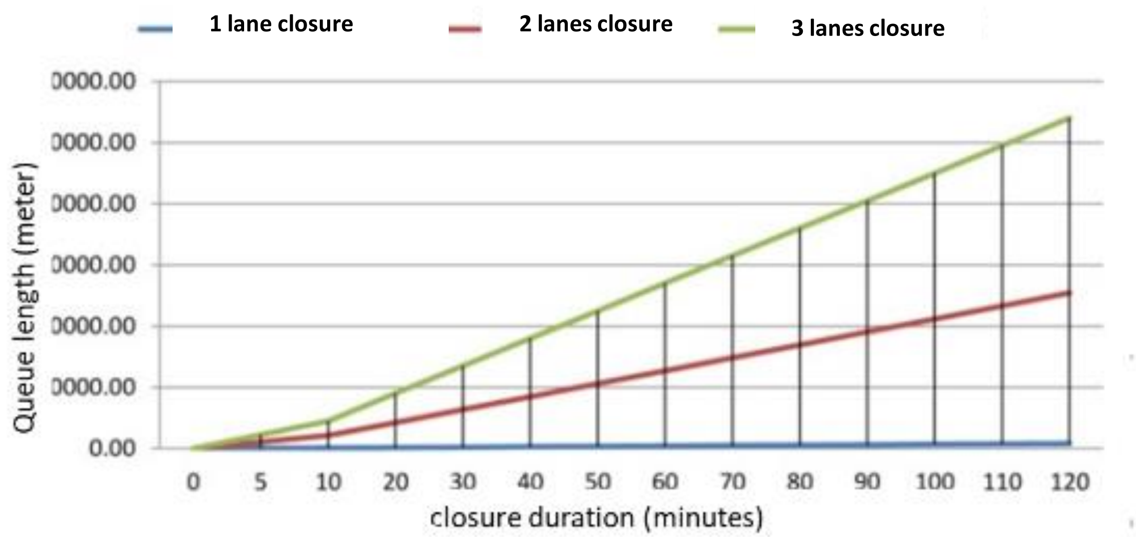

Figure 12.
Relationship between queue length and closing time with V=7200 pcu/hour.

5. Discussion

1. On the Jagorawi toll road (8 lanes, 2 directions) KM 19 + 600, the flow-speed-density relationship equation with a very strong relationship was obtained, a capacity value of 9574 pcu/hour/4 lanes was obtained
2. If 1 lane is closed on the Jagorawi toll road at traffic flow q = 7200 pcu/hour, the length of the queue that occurs during the 5-minute closure period is 34.19 meters. If it is closed for 120 minutes, there will be a queue length of 820.53 meters.
3. If the closure of 2 lanes on the Jagorawi toll road is carried out at traffic flow q = 7200 pcu/hour, the length of the queue that occurs during the 5-minute closure period is 1059.08 meters. If it is closed for 120 minutes, there will be a queue length of 25417.82 meters.
4. If the closure of 3 lanes on the Jagorawi toll road is carried out at traffic flow q = 7200 pcu/hour, the length of the queue that occurs during the 5-minute closure period is 2249.85 meters. If it is closed for 120 minutes, there will be a queue length of 53996.51 meters.

6. Conclusion

The relationship between speed – density, flow relationship – density, and the relationship between flow and speed on the Jagorawi KM 19+600 toll road from the Greenshield model has a strong coefficient of determination.

From the results of the shock wave simulation for the closure of 1 lane, 2 lanes and 3 lanes with the same flow, it can be known the length of the queue that occurs, where the length of the queue that occurs depends on the traffic volume, the length of the closure and the number of lanes closed.

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