

Shock Wave Analysis at Signalized Intersections (Case Study of Cikaret-Cibinong Intersection)

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ABSTRACT

Describe and provide feedback on this manuscript in just 250 words, the signalized intersection of the Cikaret - Cibinong highway is one of the signalized intersections in the Cibinong sub-district, Bogor Regency with a road length of 2.4km causing a shock wave event on the road section due to changes in flow values and density that often experience congestion during rush hour, for that a study was conducted to analyze the characteristics of shock waves at the highway intersection to determine the recovery of the queue length caused by increased traffic flow. This study was conducted for 3 days on Monday, Thursday and Sunday, in the morning (06.00 - 09.00), afternoon (10.00 - 12.00), evening (16.00 - 18.00). The characteristics of the shock waves that occur are current, forward formation, front stop, backward formation, forward recovery, backward recovery, moving forward in one direction, delay, maximum queue length, normalization time. Based on the research results, the results of the mathematical relationship calculation between volume, speed and density in the greenshields model to analyze the queue length value using the shock wave value obtained the maximum volume (VM) 521.2483smp/hour, the maximum density D_m of 28.707smp/km and taken the flow condition $VA = 300.56$ smp/hour which experienced a delay of 116 seconds, the queue length (QM) was 244 meters and the normalization time of 189.550 seconds was higher than the duration of the green light which was 52 seconds. This means that when the light changes from green to red, not all vehicles queuing cross the stop line. According to the results of the processing and analysis, the results of the mathematical relationship between volume, speed and density were obtained from the determination coefficient value (R²) using the greenshields model, which is 0.1774.

Keywords: traffic, signalized intersection, shockwave, greenshiled.

INTRODUCTION

Highways are a means of land transportation used to cross roads and are very important to connect people from one place to another. Road congestion will affect social and economic activities as well as traffic flow. Traffic safety is also very important to prevent accidents caused by humans or other factors including less than optimal intersection performance due to congestion. Intersections are where traffic conflicts occur, traffic flow through a road section can be considered continuous if the flow and density are relatively high, the point at which the vehicle must reduce its speed is marked by the brake lights turning on moving towards the incoming traffic flow. Traffic flow that enters the incident area, then the vehicle will brake which causes the brake lights to be triggered and so on because it creates a queue. With this happening, there will be a change in speed caused by changes in the value of the flow and density of vehicles on the road section both when the incident occurs and after the incident occurs. This change in speed and density will cause a shock wave. The definition of a shock wave is a movement in traffic flow caused by changes in density, speed and traffic flow values on vehicles, this shock wave has several models, one of which is Greenshield, where this model is more efficient in processing its data and also easier in applying data in graphical form.

This research was conducted on One Section of the Cikaret - Cibinong Intersection Road, Cibinong District, Bogor Regency from the direction of Cikaret towards Cibinong, where at this signalized intersection there is often a very long traffic jam that results in many activities every day that require movement, more specifically the performance of the road section at the intersection which has a

fairly large and dense traffic flow becomes very disturbed due to the congestion. Therefore, the road section must operate optimally, this intersection is also a link between Bogor Regency and Jakarta City, which is a strategic access passed by the connecting road between provinces in West Java which is usually used for business access or as mass transportation access which is required to always be smooth and without obstacles.

Road management must view roads as part of a road network system that connects activity centers. Each road network system is grouped according to function, status, type, and class of road that is legally determined. An intersection is a node on a road section where two or more road sections meet or intersect which includes road lane and roadside facilities, where traffic can pass through it. Intersections are an important part of the highway because most of the efficiency, traffic capacity, speed, travel time, and others will depend on the planning at the intersection. Each intersection includes continuous traffic movements and intersecting traffic at one or more of the intersection legs and also includes rotational movements. In general, traffic signals or traffic lights are used for several reasons, including:

1. To prevent congestion at intersections due to traffic flow conflicts, so that a certain capacity can be balanced, even during peak hours;
2. To provide opportunities for pedestrians and vehicle users from (small) intersections to cut through or head towards the main road.
3. To prevent and minimize traffic accidents between vehicles from opposite directions [1].

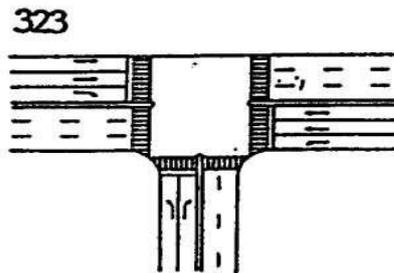


Figure 1. Signal Intersection

Traffic lights are lights that control traffic flow at intersections or highways. They are known as traffic signaling devices or concerning Traffic and Road Transportation. pedestrian crossings, also known as zebra crossings, and other traffic flow locations. These lights function to indicate when vehicles should move and stop turning in various directions. The mathematical relationship between speed and density is monotonic downward, which states that if traffic density increases, speed will decrease. When traffic density is so high that it is no longer possible for vehicles to move, this condition is called a total traffic jam, where there are no vehicles on the road, so that traffic flow becomes 0 (zero) [2].

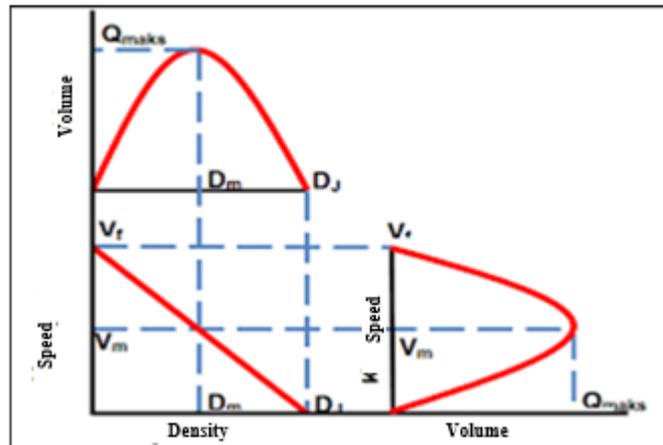


Figure 2. Relationship between volume, speed and density [3]

If density increases from zero, speed will decrease while traffic flow increases. However, if density continues to increase, increasing density will not result in increasing traffic, but will instead decrease it. Flow capacity is a term used to describe the maximum point of traffic flow.

- Sm: maximum capacity or flow (vehicles/hour)
- Sm: Speed at maximum traffic flow conditions (Km/hour)
- Dm: Density at maximum traffic flow conditions (vehicles/Km)
- Dj: density at total traffic jam conditions (vehicles/Km)
- Sff: speed at very low traffic flow conditions or at conditions

Shock waves, also known as (shock waves), are movements or journeys of a change in traffic flow. Vehicles will move at a certain speed in free flow conditions. If the flow is disturbed, the flow will decrease. which has the ability to pass through the place where the obstacle is spread.

If the flow is reduced, the density of vehicles will increase around the obstacle. This will cause speed to decrease and queues. Traffic flow obstructions can be partial or complete closures of lanes, due to accidents or road repairs, for example, or can be in addition, obstructions when red lights at intersections shine for traffic. Shock waves occur when traffic density and flow values change, so that vehicles must reduce when the flow and density are high. The brake lights indicate speed, and the location will move. towards traffic. The brake lights move against the road. Actually shock waves.

The assumption used in shock waves at this traffic light intersection is that the passing traffic is relatively low with a constant flow. If the capacity of the intersection arm is greater than the incoming traffic flow, then no vehicles will be held up when the green light is on. Therefore, at a certain distance before and after the traffic light there is a free-flow condition. However, at a certain distance before the traffic light while the red light is on, there will be a discontinuity in traffic flow, namely when the incoming vehicle joins the vehicle that has stopped queuing and when the vehicle can move again when the green light is on.

The Greenshield model states that the mathematical relationship between velocity and solidity is assumed to be linear, which is shown [4].

$$S = sff - \frac{sff D}{Dj}$$

- Where:
- S: Speed
- Sff: Average speed of free flow space
- Dj: Jam density
- D: Density

Shock waves in traffic flow describe the movement of changes in traffic conditions such as sudden reductions in speed or increases in density along a roadway. These waves occur when there is a disturbance, for example at a signalized intersection where vehicles must stop and then accelerate again. The direction and speed of a shock wave depend on differences in flow, speed, and density between two traffic states [5], [6]. Using the Greenshields method, shock wave analysis is based on the fundamental relationship between speed (v) and density (k), expressed as a linear model: $v = v_f(1 - k/k_j)$, where v_f is free-flow speed and k_j is jam density. From this relationship, traffic flow (q) can be derived as $q = k \cdot v$, producing a parabolic flow–density curve. The maximum flow occurs at half of the jam density ($k = k_j/2$), representing critical conditions [7].

When traffic transitions between two states such as from free flow to congested conditions—a shock wave forms. The speed of the shock wave (w_s) is calculated using the equation:

$$w_s = (q_2 - q_1) / (k_2 - k_1)$$

where q_1 and k_1 represent the initial traffic condition, and q_2 and k_2 represent the new condition. If w_s is negative, the wave moves backward relative to traffic (typical in queue formation). If positive, it moves forward (queue dissipation) [8], [9].

Thus, the Greenshields model provides a mathematical framework to estimate queue growth, maximum queue length, and recovery time at intersections, helping engineers evaluate congestion and signal performance [10].

When a shock wave occurs at an intersection, it indicates a sudden change in traffic conditions caused by fluctuations in flow, speed, and density. This commonly happens at signalized intersections where traffic must stop during the red phase and restart during the green phase. The most visible condition is the formation of a queue upstream of the stop line. Vehicles decelerate rapidly as they approach the back of the queue, creating a backward-moving shock wave that travels against the direction of traffic flow [11], [12]. During peak hours, high arrival volumes often exceed the intersection's discharge capacity, leading to longer queues and increased delay. If the green time is insufficient to clear all waiting vehicles, residual queues remain into the next signal cycle. This condition is known as oversaturation and results in repeated shock wave formation. Drivers experience stop-and-go movement, lower average speeds, and higher travel times [13].

As the signal turns green, a forward-moving recovery wave forms when vehicles begin to accelerate and the queue gradually dissipates. However, if traffic demand remains high, the dissipation may be incomplete. Overall, the presence of shock waves at an intersection reflects unstable flow conditions, congestion, and inefficient signal performance that require traffic management improvements [14], [15].

RESEARCH METHOD

The research was conducted on the Cibinong - Cikaret road located in the Cikaret area, Cibinong District, Bogor Regency, this road has been determined by a statement letter from the Regent of Bogor Regency with the Cibinong - Cikaret road section with the section number 22.01.003 and the length of the road is 2.4 km which has a Local Primary 1 (LP1) function which means that according to regional regulation number 4 of 2016, it is explained that the primary local is a road that efficiently connects national activity centers with environmental activity centers.

This research was conducted in the morning and evening to understand the traffic flow conditions or vehicle volume from quiet conditions to peak density hours. The survey was conducted for 3 days at the following times:

Morning at: 06:00 – 09:00 WIB

Afternoon at: 10:00 – 12:00 WIB

Evening at: 16:00 – 18:00 WIB

Considering that the research location is the busiest route passed by many vehicles and has a high intensity volume

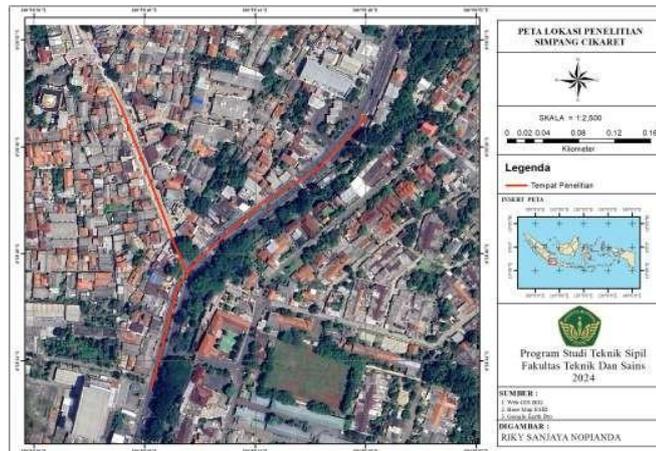


Figure 3. Location map

The research flow diagram can be seen in Figure 2 below.

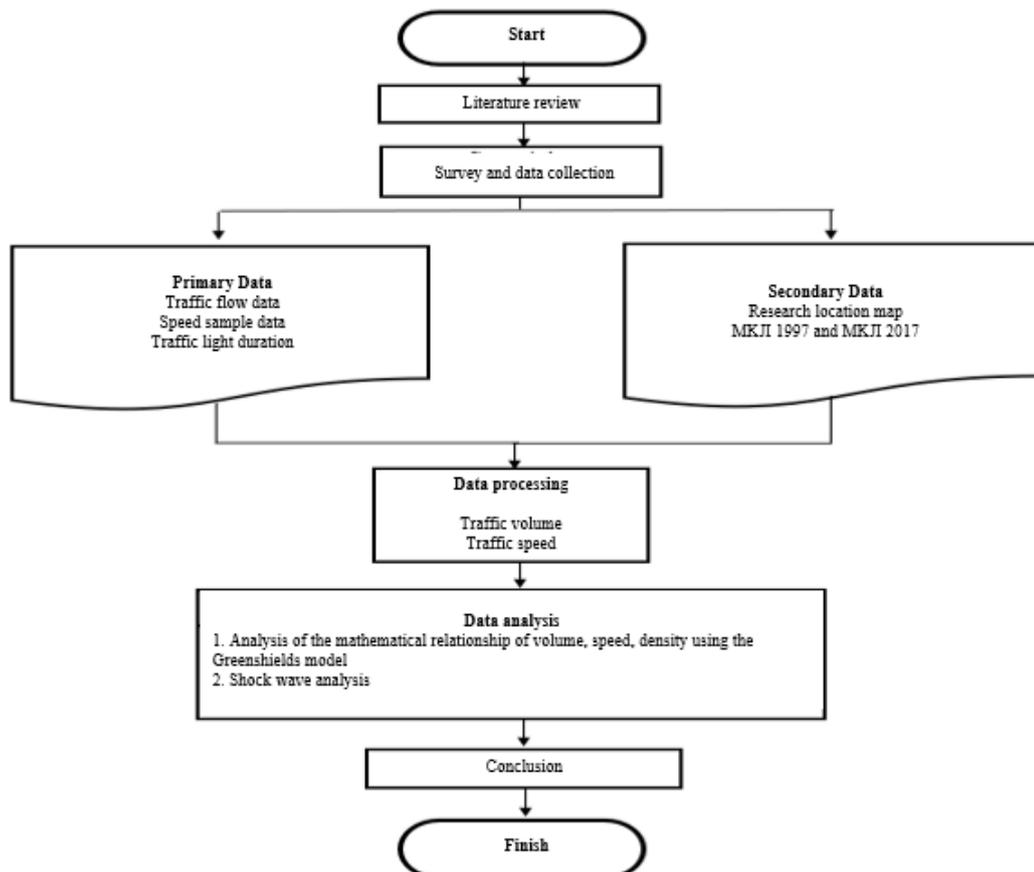


Figure 4. Flowchart [16], [17]

A preliminary survey was conducted to collect information on actual conditions before the main survey was conducted. At this stage, the survey aims to obtain data such as traffic flow patterns and environmental conditions around the intersection. The implementation of this field survey was carried out for 3 days, namely Monday, Thursday and also Sunday, where two days were selected on weekdays or work days and one weekend or holiday with a morning time level representing the hours of going to work or school, afternoon representing work break time or quiet hours and, evening

representing the hours of going home from work or busy time. The equipment used were, cellphones, wheel meters, spray paint, stopwatches, stationery and laptops. For data collection techniques using 2 methods, namely primary data or field data is needed for this study. The main data that must be collected is in the form of traffic surveys (volume), speed surveys (speed) and traffic light duration data. Furthermore, secondary data is obtained from reference sources that are relevant to shock wave analysis. The purpose of collecting secondary data is to obtain information and theories related to the main issue. This data is usually obtained from various sources such as journals, literature, and the internet. From the results of the field survey, the following data or variables were obtained:

1. Traffic flow data (volume), Observers record the number of vehicles every 5-minute interval according to previously determined observation points. The vehicles surveyed are divided into three categories: motorcycles (MC), light vehicles (LV), and heavy vehicles (HV).
2. Speed data, Measuring speed is based on the time required to cover a certain distance. Speed data collection includes all types of vehicles, including light vehicles and heavy vehicles. In certain situations, the appearance of a platoon can interfere with data collection. The sampling procedure involves selecting the first vehicle in the platoon as a sample. The assumption that the second and subsequent vehicles have similar speeds and do not interfere with the measurement is the basis of this procedure.
3. Traffic light duration data, Data processing techniques include the number of vehicles passing, speed and traffic light time ratio. After the data is collected, the initial step is to calculate the total vehicles from the morning, afternoon and evening surveys. From the total number of vehicles, we can calculate the speed of each vehicle. Furthermore, from the speed obtained, we can calculate the density of the vehicle. Then, we will calculate the average speed based on time and the average speed based on space. With this data, we can calculate the Emp of the vehicle and continue the shock wave analysis and linear regression analysis. The graph generated from this regression analysis will show the relationship between vehicle speed, volume, and density. In the end, we will also analyze the shock wave to create a shock wave diagram. Next is the data analysis stage, Data obtained from the survey are collected and then analyzed to obtain accurate results. The validity of the data is determined by the survey method used, namely by taking and determining samples. Samples are selected randomly based on vehicles passing through the Cikaret - Cibinong intersection, then analyzed using vehicle data through shock wave analysis.

RESULTS AND DISCUSSION

1. Traffic light duration
The duration of the traffic light is calculated directly during the data collection process in the field from the direction of Jl. Cikaret towards Jl. Raya Jakarta - Bogor is the red light is on for 116 seconds while the green light is on for 52 seconds, the yellow light is on for only 3 seconds, so the traffic light cycle surveyed is 169 seconds
2. Traffic volume calculation

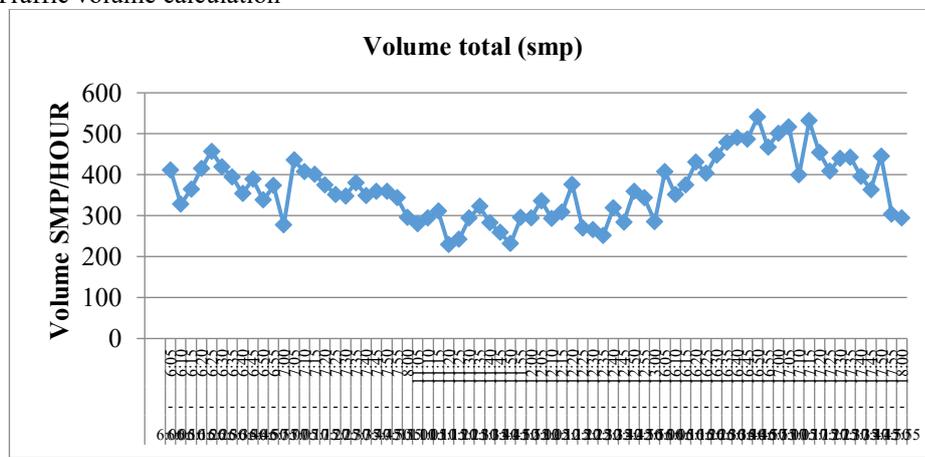


Figure 5. Vehicle Volume Graph Source: Processed data, 2025

From the survey results, it can be seen that the maximum volume on Tuesday occurred in the morning observation from 07:00 to 09:00, at noon from 11:00 to 13:00, and in the afternoon from 16:00 to 18:00

1. Calculation of vehicle speed

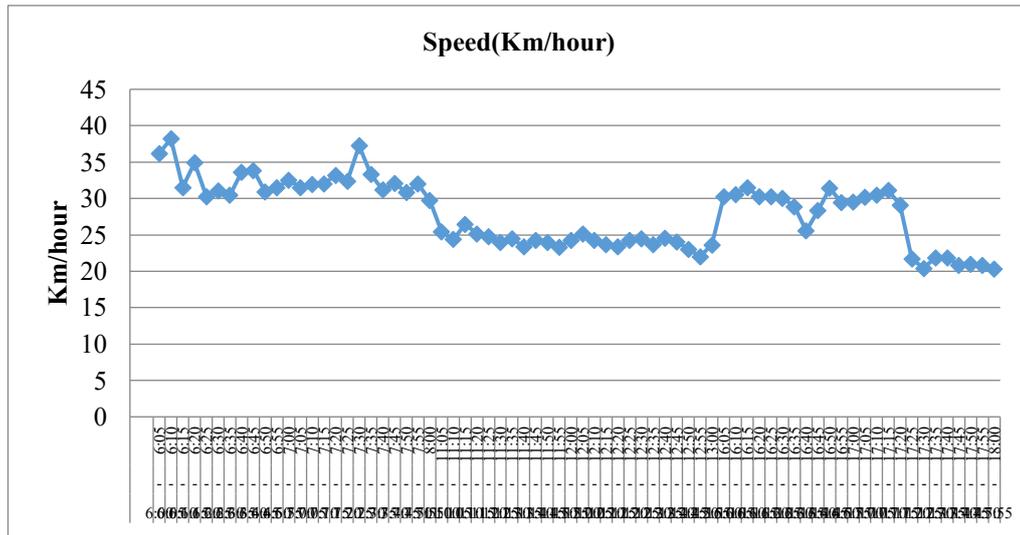


Figure 6. Speed/Density Graph (SMP/KM) Source: Processed data, 2025

From the survey results table in Figure 6, it can be seen in the graph that the vehicle speed on Tuesday per five minutes was taken one sample of HV, LV, and MC vehicles (SMP / KM)

2. Mathematical relationship between volume, speed and traffic density

From Table 1, it can be seen the relationship between the characteristics of speed density, volume density, and volume speed on Thursday, February 27, 2025. While the graph below shows the relationship between Volume capacity, Speed, and Traffic density with Greenshields modeling.

Table 1. Volume capacity, Speed, and Traffic density

Times		Volume (smp/hour)	Us (km/hour)	Density (smp/km)
6:00	- 6:05	462	36.21	12.76
6:05	- 6:10	378	38.21	9.89
6:10	- 6:15	414	31.53	13.13
6:15	- 6:20	474	34.94	13.57
6:20	- 6:25	522	30.30	17.23
6:25	- 6:30	474	31.10	15.24
6:30	- 6:35	456	30.47	14.97
6:35	- 6:40	414	33.63	12.31
6:40	- 6:45	450	33.85	13.29
6:45	- 6:50	384	30.91	12.42
6:50	- 6:55	432	31.48	13.73
6:55	- 7:00	318	32.56	9.77
7:00	- 7:05	504	31.48	16.01
7:05	- 7:10	462	31.98	14.45
7:10	- 7:15	462	32.04	14.42

Times		Volume (smp/hour)	Us (km/hour)	Density (smp/km)
7:15	- 7:20	426	33.17	12.84
7:20	- 7:25	396	32.37	12.23
7:25	- 7:30	390	37.28	10.46
7:30	- 7:35	438	33.33	13.14
7:35	- 7:40	402	31.20	12.89
7:40	- 7:45	408	32.07	12.72
7:45	- 7:50	414	30.86	13.41
7:50	- 7:55	390	32.01	12.19
7:55	- 8:00	336	29.75	11.30
11:00	- 11:05	324	25.42	12.74
11:05	- 11:10	324	24.41	13.27
11:10	- 11:15	354	26.48	13.37
11:15	- 11:20	258	25.11	10.27
11:20	- 11:25	276	24.78	11.14
11:25	- 11:30	324	23.98	13.51
11:30	- 11:35	366	24.51	14.94
11:35	- 11:40	318	23.39	13.60
11:40	- 11:45	288	24.28	11.86
11:45	- 11:50	264	23.95	11.02
11:50	- 11:55	330	23.29	14.17
11:55	- 12:00	330	24.29	13.58
12:00	- 12:05	366	25.12	14.57
12:05	- 12:10	324	24.25	13.36
12:10	- 12:15	336	23.70	14.18
12:15	- 12:20	414	23.36	17.72
12:20	- 12:25	312	24.29	12.85
12:25	- 12:30	300	24.47	12.26
12:30	- 12:35	282	23.71	11.89
12:35	- 12:40	354	24.59	14.40
12:40	- 12:45	312	24.04	12.98
12:45	- 12:50	402	23.05	17.44
12:50	- 12:55	390	22.02	17.71
12:55	- 13:00	318	23.64	13.45
16:00	- 16:05	456	30.24	15.08
16:05	- 16:10	396	30.59	12.95
16:10	- 16:15	414	31.51	13.14
16:15	- 16:20	474	30.24	15.67
16:20	- 16:25	450	30.24	14.88
16:25	- 16:30	498	30.06	16.57
16:30	- 16:35	540	28.89	18.69
16:35	- 16:40	558	25.58	21.81
16:40	- 16:45	546	28.36	19.25
16:45	- 16:50	612	31.41	19.48
16:50	- 16:55	528	29.44	17.93
16:55	- 17:00	570	29.56	19.28
17:00	- 17:05	588	30.16	19.50
17:05	- 17:10	450	30.49	14.76
17:10	- 17:15	594	31.12	19.09
17:15	- 17:20	510	29.11	17.52
17:20	- 17:25	462	21.69	21.30
17:25	- 17:30	486	20.42	23.80
17:30	- 17:35	492	21.88	22.49

Times			Volume (smp/hour)	Us (km/hour)	Density (smp/km)
17:35	-	17:40	456	21.86	20.86
17:40	-	17:45	414	20.83	19.87
17:45	-	17:50	498	21.01	23.70
17:50	-	17:55	342	20.81	16.43
17:55	-	18:00	336	20.31	16.54

3. Model Greenshields

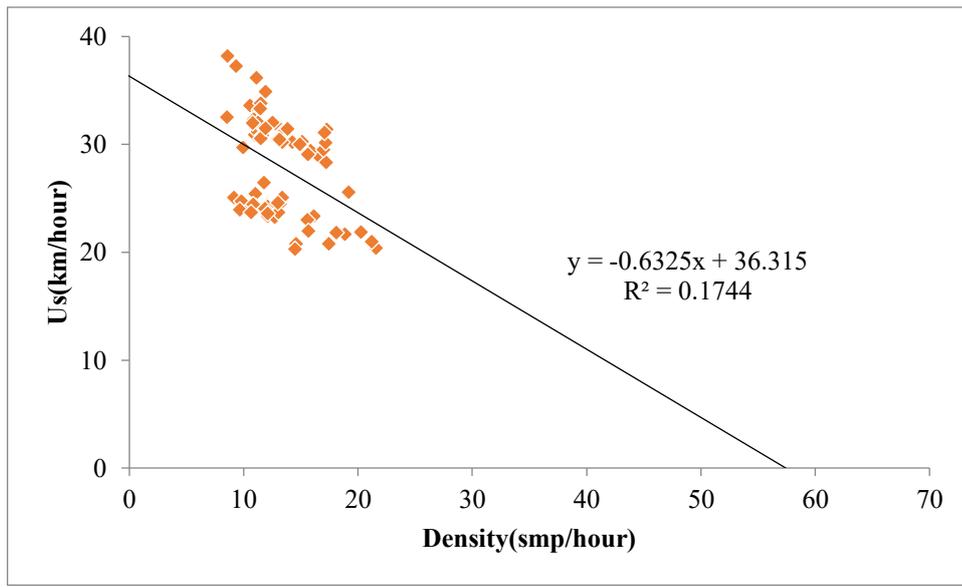


Figure 7. Velocity-Density relationship graph of the Greenshields model Source: Processed data, 2025

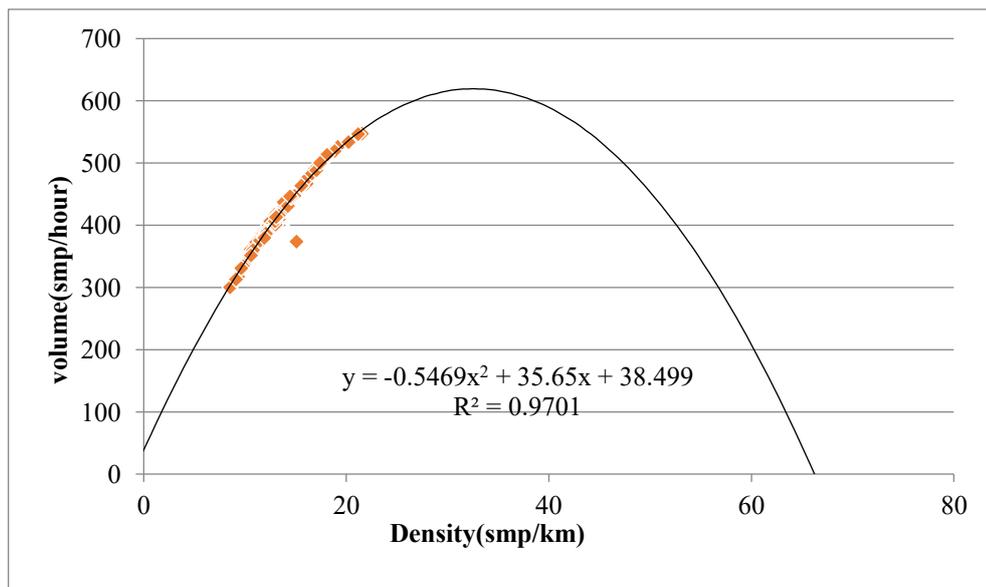


Figure 8. Volume-Density relationship graph of the Greenshields model Source: Processed data, 2025

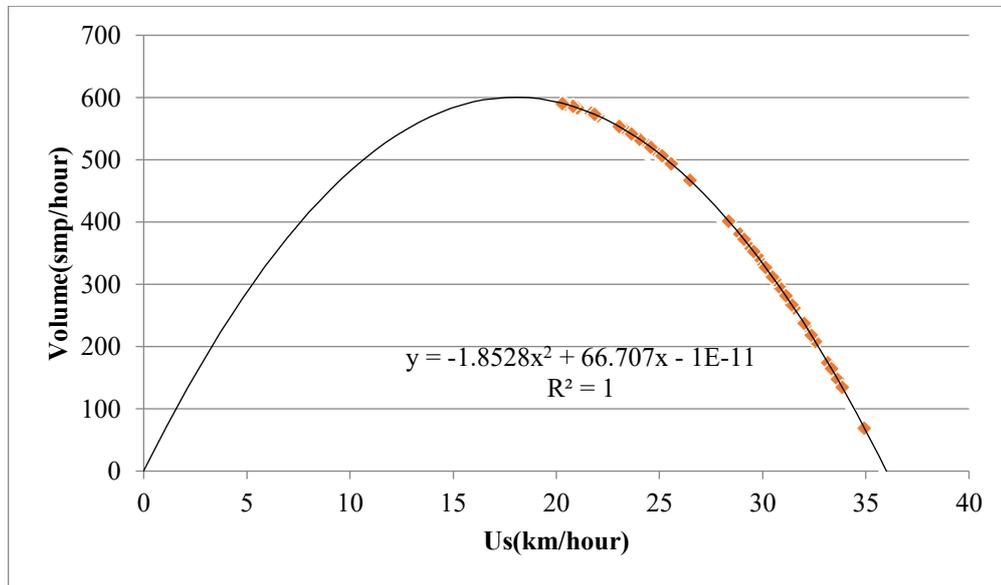


Figure 9. Graph of the relationship between Volume and speed of the Greenshields model Source: Processed data, 2025

From the results of the graph above, it is obtained from the appendix IV table. So, the result of the B value obtained from the graph above is -0.6325, while the result of the A value from the graph above is 36.315. Then the Sff value is produced = 36.315 km/hour and $D_j = -((36.315)) / ((-0.6325)) = 57.41501 \text{ smp/km}$ With the resulting b value = $1/(-0.6325) = -1581$ By using the sff and D_j values, the mathematical relationship between the following parameters can be determined:

Speed - Density Relationship: $S = 36.315 - 0.6325D$

Volume - Density Relationship: $V = 36.315D - 0.6325D^2$

Volume - speed relationship: $V = 57.41501S - 15812$

Then the maximum volume can be calculated using the equation $V = 36.315D - 0.6325D^2$ dan $V = 57.41501s - 1581^2$

$$\frac{\partial V}{\partial D} = 0 \text{ obtained } D_m = \frac{57.41501}{2} = 28.70750 \text{ smp/km}$$

$$\frac{\partial V}{\partial S} = 0 \text{ obtained } S_m = \frac{36.315}{2} = 18.1575 \text{ km/hour}$$

By entering the value of $D_m = 28.70750 \text{ smp/hour}$ into the equation $V = 36.315D - 0.6325D^2$ or the value of $S_m = 18.1575 \text{ km/hour}$ into the equation $V = 57.41501 - 1581$, the value of $v_m = D_m \times S_m = 0$ is obtained $V_m = 28.70750 \times 18.15775 = 521.26360 \text{ smp/hour}$. It can be concluded that the maximum volume occurs at conditions $D = 28.70750 \text{ smp/km}$ moving at a speed of $S = 18.15775 \text{ km/hour}$

4. Coefficient of determination

This coefficient has a limit of one (perfect explanation and no (no explanation). The value between these two limits is stated as the percentage of total variation explained by the linear regression analysis.

starting from t_1 at the stop line are ω_{DA} , ω_{DB} and ω_{AB} are $(r) = 116$ seconds and the volume value $(V) = 521.2483$ smp/hour.

$$\omega_{DA} = \frac{VA - VD}{DA - DD} = \frac{(300.56 - 0)}{(9.77 - 0)} = 30.76356$$

A positive value means a forward shock wave that is directed in the direction of traffic movement. ω_{DA} is a forward shock wave that occurs in front of the stop line. ω_{DB} is a front stationary shock wave that occurs at the stop line.

$$\omega_{DB} = \frac{VA - VD}{DA - DD} = \frac{(0 - 0)}{(0 - 0)} = 0 \quad \omega_{AB} = \frac{VB - VA}{DB - DA} = \frac{(0 - 300.56)}{(66.707 - 0)} = -5.278 \text{ km/hours}$$

The negative sign in the shock wave calculation above indicates that the shock wave moves backwards in the opposite direction to the movement of the traffic flow. ω_{AB} is a backward shock wave formed behind the stop line. When the t_2 light changes from red to green, a traffic flow will form a new condition, namely the traffic flow condition C where the traffic flow at the stop line will increase from 0 (zero) to saturated. Thus causing 2 (two) new shock waves, namely ω_{DC} and ω_{CB} .

$$\omega_{DC} = \frac{VC - VD}{DC - DD} = \frac{0 - 521.5}{0 - 28.707} = 18.1575$$

ω_{DC} is a forward-moving shock wave that occurs in front of the stopping line

$$\omega_{CB} = \frac{VB - VC}{DB - DC} = \frac{0 - 521.24}{66.707 - 28.707} = -13.7171$$

ω_{CB} is the recovery backward shock wave that occurs at the stop line. Traffic flow with conditions D, C, B, and S continues to occur until ω_{AB} and ω_{CB} reach t_3 . The time interval between t_2 and t_3 can be calculated using the following equation:

$$t_3 - t_2 = r \cdot \frac{\omega_{AB}}{\omega_{CB} - \omega_{AB}} = 116 \cdot \frac{-5.278}{-13.7171 - (-5.278)} = 5.662775 \text{ second}$$

The maximum queue length (ASAM) can occur when time is t_3 and can be calculated using the following equation where r is the effective duration of the red light (seconds).

$$QM = \frac{r}{3600} \times \frac{\omega_{CB} \cdot \omega_{AB}}{\omega_{CB} - \omega_{AB}} \cdot \frac{116}{3600} \times \frac{-13.7171 \cdot (-5.278)}{-13.7171 - (-5.278)} = -0,244 \text{ km} = 244 \text{ meter}$$

At time t_3 , 1 (one) new shock wave is formed, namely the forward shock wave (ω_{AC}) while 2 (two) backward shock waves ω_{AB} and ω_{CB} end. The shock wave ω_{AC} can be calculated using the following equation.

$$\omega_{AC} = \frac{VC - VA}{DC - DA} = \frac{521.2483 - 300.56}{28.707 - 9.77} = 11.653 \text{ km/hour}$$

The positive sign indicates that the shock wave is moving forward. Traffic flow in conditions D, C and A will continue to occur until t_5 , which is when the red light is on. At time t_4 , the forward shock wave (ω_{AC}) intersects the stop line and the traffic flow at the stop line changes from the maximum traffic flow VC to VA . The time from the start of the green light to (t_2) to (t_4) can be calculated by the equation.

$$t_4 - t_2 = \frac{r \cdot \omega_{AB}}{\omega_{CB} - \omega_{AB}} \cdot \frac{\omega_{CB}}{\omega_{AB}} + 1$$

$$t_4 - t_2 = \frac{116 \cdot (-5.278)}{-13.7171 - (-5.278)} \cdot \frac{-13.7171}{-5.278} + 1 = 189.550 \text{ second}$$

CONCLUSION

From the results of the calculation of the mathematical relationship between volume, speed and density in the Greenshields model to analyze the queue length value using the shock wave value, the maximum volume (VM) is 521.2483 smp/hour, the maximum density D_m is 28.707 smp/km and the current condition is taken $VA = 300.56$ smp/hour which is delayed for 116 seconds, the queue length (QM) is 244 meters and the normalization time is 189.550 seconds higher than the duration of the green light, which is 52 seconds. This means that when the light changes from green to red, not all vehicles queuing cross the stop line. According to the results of processing and analysis, the results of the mathematical relationship between volume, speed and density are obtained, obtained from the determination coefficient value (R^2) using the Greenshields model, which is 0.1774.

REFERENCES

- [1] Government Law. (2006). Number 34 of 2006.
- [2] APILL. (2009). Law Number 22 of 2009.
- [3] Tamin, O.Z. (2020). Hubungan Volume, Jurnal Teknik Sipil, Jurusan Teknik Sipil ITB, (5), pp. 1–11.
- [4] Tamin, O.Z. (2000). Perencanaan dan Pemodelan Transportasi.
- [5] Abia Appu Sirendena, Audie L. E Rumayarb, M.M.K. (2023). Analisis Gelombang Kejut Pada Lengan Persimpangan Bersinyal (Studi Kasus: Jl. Yos Sudarso – Jl. Maesa), T E K N O, Volume 21, (88), pp. 1–1.
- [6] Adam, O.L., Timboeleng, J.A. and Jansen, F. (2013). Arus Lalu Lintas Di Jalan Walanda Maramis Bitung, Jurnal Ilmiah MEDIA ENGINEERING, 3(2), pp. 94– 98.
- [7] Hulu, V. (2022). Analisis Gelombang Kejut Terhadap karakteristik Arus Lalu Lintas di Jalan H. Adam Malik Medan, Universitas Medan Area [Preprint].
- [8] Iqbal, M.Z. et al. (2023). Metode Greenshields, 1(3), pp. 30–47.
- [9] Margetty R. C. Siongke#a, S.Y.R.R., A.L.E.R. (2023). Analisa Karakteristik Gelombang Kejut Pada Simpang Bersinyal (Studi Kasus: Jl. Yos Sudarso, Paal Dua, Manado), T E K N O, Volume 21, (84), pp. 1–1.
- [10] Sahusilawane, G., Y. R. Rompis, S. and I. R. Lefrandt, L. (2024). Analisis Kinerja Simpang Bersinyal di Jalan Bethesda – Jalan Santo Yoseph Kota Manado“, Syntax Idea, 6(5), pp. 2152–2164. Available at: <https://doi.org/10.46799/syntax-idea.v6i5.3261> September, E. (2023) ,,1) 2) 2) 2), 11(3), pp. 505–512.
- [11] Syaiful S, Muhammad NP, Rulhendri R, Puri AL, Asri KW. (2025). An Urban Modeling Analysis of the Transport Network in the City of Bogor to Observe the Best Choice of a Transport Model. International Journal of Transport Development and Integration 9 (1), 143-150.
- [12] S Syaiful, D Hariyadi. (2019). Case Study on Sustainable T-Jungtion Cibinong City Mall (CCM) in Bogor Indonesia. ARPN Journal of Engineering and Applied Sciences 14 (17), 2960-2971.
- [13] Syaiful, S., Siregar, H., Rustiadi, E., & Hariyadi, E. S. (2022). PERFORMANCE OF THREE ARMS SIGNALIZED INTERSECTION AT SALABENDA IN BOGOR REGENCY. ASTONJADRO, 11(1), 13–29. <https://doi.org/10.32832/astonjadro.v11i1.4955>
- [14] S Syaiful, H Siregar, E Rustiadi, ES Hariyadi. (2021). Traffic Improvement Strategy in Transportation System Using AHP Method. ARPN Journal of Engineering and Applied Sciences 16 (22), 2431-2439.
- [15] S Syaiful, H Siregar, E Rustiadi, ES Hariyadi, E Sutoyo, B Hartono. (2022). Formulate and Evaluate Transportation Infrastructure Facilities and Traffic Signs at Intersections. ARPN Journal of Engineering and Applied Sciences 17 (4), 475-490.
- [16] MKJI (2017). Kapasitas jalan Luar Kota, *Pedoman Bahan Kontruksi bangunan dan rekayasa sipil*, (2017), pp. 28–29.
- [17] MKJI, 1997 (1997). Manual Kapasitas Jalan (MKJI), *Manual Kapasitas Jalan Indonesia (MKJI)*, 1(I), pp. 1–564.