Analysis of Delay Due to Railway Level Crossings

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ABSTRACT

Depok City is one of the buffer cities of the nation's capital, because the distance is only about 29 km from DKI Jakarta. With the many vehicles, Depok City has become one of the cities with moderate to high levels of congestion. The congestion is also supported by other highway network system problems, namely delays caused by railroad crossings. The aim is to investigate the delays that arise due to the intersection between the road and the railroad on Jl. Raya Citayam, Depok City using the shock wave method and looking for a comparison of traffic volume between weekdays and holidays. The method for being able to perform data analysis, then all the data needed must have been obtained. Data collection of flow/volume and travel time is carried out when the crossing gate is open and no trains are crossing. Then the flow/volume data is processed using the Microsoft Excel program. The EKR value is used to convert the vehicle traffic flow unit into Light Vehicle Units (SKR). The next step is to calculate the speed based on the travel time that has been obtained. Next, look for the mathematical relationship between flow, speed, and density in order to obtain the speed when the flow is free (Sff) and density (Dj). The Sff and Dj values are then used to find the VM and DM values. The VM and DM values are then used to calculate the shock wave value. The shock wave value obtained can be used to obtain the delay that occurs. From the results of the analysis and calculation of traffic flow volume, the minimum result is obtained on Monday at 14 pcu/hour and the maximum occurs on Sunday at 68 pcu/hour, the average traffic density is obtained in two days at 27.01 pcu/km, the average traffic flow speed is obtained in two days at 19.01 km/hour, the delay is obtained from the duration of the railroad crossing closing, the delay time is obtained from 2 minutes 96 seconds. The results of the relationship between speed and density on average for two days with the largest value using the greenshield method are 19.05 km/hour and the smallest is 12.84 km/hour, the relationship between volume and speed on average for two days with the largest value using the greenshield method is 210.211 pcu/hour and the smallest is 99.792 pcu/hour. After conducting shock wave analysis at the railroad level crossing, the results of the formed forward shock wave (ωda) were 14.387 km/hour, the formed backward shock wave velocity (ωab) was -1.118 km/hour, the recovery forward shock wave velocity (ωdc) was 7.783 km/hour, the recovery backward shock wave velocity (ωcb) was -7.763 km/hour, and the recovery shock wave velocity (ωac) was 5.500 km/hour.

Keywords: transportation, railroad level crossing, greenshield, shock wave.

INTRODUCTION

Depok City is one of the buffer cities of the nation's capital, because the distance is only about 29 km from DKI Jakarta. With the large number of vehicles, Depok City has become one of the cities with moderate to high levels of congestion. This congestion is also supported by other road network system problems, namely delays caused by railroad crossings. Jalan Raya Citayam is known as a densely populated area. Traffic on this road is often congested, especially during rush hour, causing congestion. Another factor that triggers congestion is the presence of a railroad crossing that crosses the road, so drivers must slow down their vehicles when passing the crossing and speed up again afterwards. This situation can be explained using the shockwave theory. Based on the title of the final project and the previous explanation, the objectives to be achieved through writing this final project are to investigate the delays that arise due to the intersection between the road and the railroad tracks on Jl. Raya Citayam, Depok City using the shockwave method and to find a comparison of traffic volume between weekdays and holidays.

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Railway level crossings are critical points within urban transportation systems where interactions between road vehicles and train operations frequently generate traffic disruptions. One of the most significant phenomena occurring at these crossings is the formation of shockwaves, which describe the propagation of traffic congestion caused by sudden interruptions in vehicle flow during gate closures [1], [9]. Shockwave analysis is widely applied in delay studies because it provides a dynamic representation of queue formation, queue dissipation, and vehicle movement behavior before and after train passage [2], [10]. When a crossing gate closes, vehicle speeds rapidly decrease, creating backward-moving shockwaves that increase queue length and traffic delay. After the train passes and the gate reopens, forward recovery shockwaves emerge as vehicles gradually accelerate and traffic conditions return to normal. Understanding these traffic patterns is essential for evaluating operational performance, estimating delay costs, and improving transportation management strategies at railway crossings [3], [11]. Delay analysis using shockwave theory generally involves parameters such as traffic volume, arrival rate, departure rate, queue length, and wave speed. The approach is particularly effective in urban areas with high traffic density because it can identify congestion severity and predict the impacts of repeated train crossings on surrounding road networks [4-6], [12]. Several studies have shown that shockwave analysis supports more accurate transportation planning by quantifying delay duration and identifying critical operational conditions. Consequently, the integration of shockwave theory into level crossing delay analysis contributes to safer, more efficient, and sustainable traffic management systems while supporting decision-making for infrastructure improvement and congestion mitigation near railway crossings [7-8], [13-15].

RESEARCH METHODS

In order to perform data analysis, all required data must have been obtained. Data collection of flow/volume and travel time is carried out when the crossing gate is open and no trains are crossing. Then the flow/volume data is processed using the Microsoft Excel program. The EKR value is used to convert the vehicle traffic flow unit into the Light Vehicle Unit (SKR). The next step is to calculate the speed based on the travel time that has been obtained. Next, find the mathematical relationship between flow, speed, and density in order to obtain the speed when the flow is free (Sff) and density (Dj). The Sff and Dj values are then used to find the VM and DM values. The VM and DM values are then used to calculate the shock wave value. The shock wave value obtained can be used to obtain the delay that occurs.

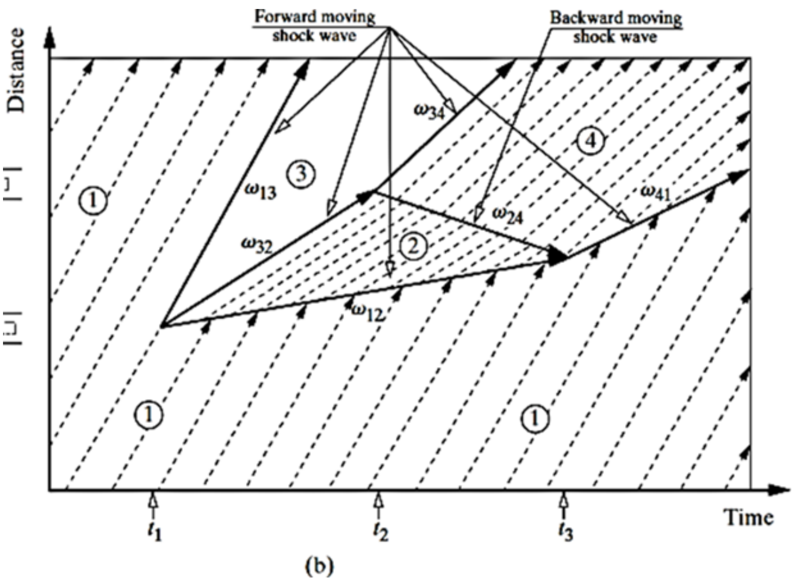

Figure 1. Shock waves at open level crossing gate conditions [10]

At point 0 – t1 is a free flow or free flow where the condition of the vehicle has not passed the level crossing and is traveling at normal speed (part 1). Then, just before passing the level crossing, vehicle A will reduce its speed, and other vehicles behind it will also reduce their speed until they pass the level crossing (part 2). A shock wave is formed that moves at a speed of ω12. Because other vehicles in front of vehicle A will continue to travel at their speed, the section of the highway downstream will not have a flow of vehicles, creating traffic conditions (3). This also produces shock waves with speeds of ω13 and ω32. At time t2, when vehicle A leaves the road, the flow capacity will be increased to a road with traffic conditions (4). This results in the formation of a shock wave moving backward at a speed of ω24 and a shock wave moving forward at a speed of ω34. At time t3, the shock waves with velocities ω12 and ω24 coincide, producing a new shock wave that moves forward with a velocity ω41.

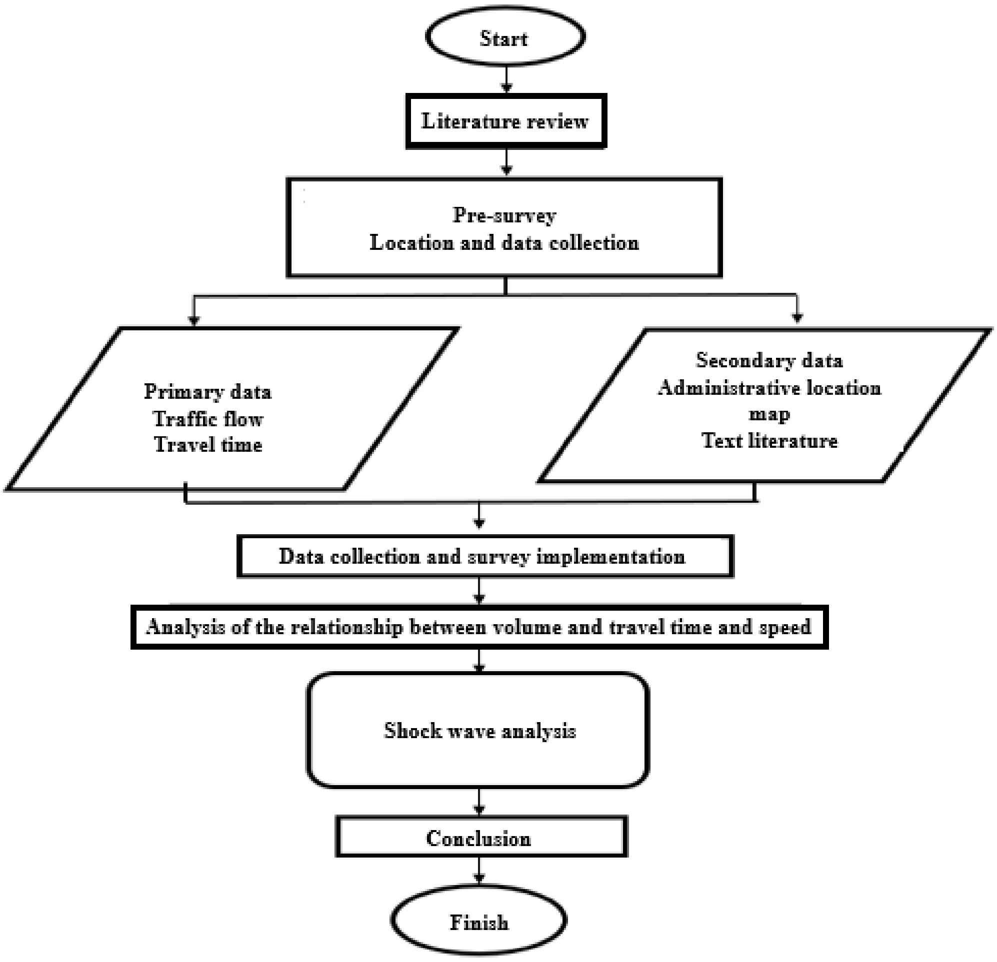

Figure 2. Research flow diagram

Greenshield Method

Greenshields who conducted a study on the outer roads of Ohio, USA proposed a linear model between space mean speed and vehicle density (S – D). From his research, Greenshields modeled the following equation:

Table 1. Equation produced by the Greenshield Model

Relationship	Equation	Relationship	Equation
S-D	$S = S_{ff} - \frac{S_{ff}}{Dj} \times D$	V_M	$V_M = \frac{Dj \cdot S_{ff}}{4}$

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Relationship	Equation	Relationship	Equation
V-D	$V = D \cdot S_{ff} - \frac{S_{ff}}{Dj} \times D^2$	S_M	$S_M = \frac{S_{ff}}{2}$
V-S	$V = Dj \cdot S - \frac{Dj}{S_{ff}} \times S^2$	D_M	$D_M = \frac{Dj}{2}$

RESULTS AND DISCUSSION
Traffic Volume Data Analysis

The survey results are the results carried out by surveyors at certain points that have been determined during the data collection process. Where the traffic volume data for each vehicle in the survey is taken in units of vehicles per 15 minutes, so it is necessary to change the traffic volume units to smp (passenger car units), the traffic volume data (q) that has been obtained in every 15 minutes is multiplied by 60 minutes per 15 minutes, to change the traffic flow (q) in units of smp/hour, the following is Table 2 which is an example of a survey result table.

Table 2. Traffic Volume on Monday

Calculation (smp/hours)	MC	LV	HV	Total
	0,25	1	1,2	
06.00 - 06.15	10	13	4	26
06.15 - 06.30	13	16	1	30
06.30 - 06.45	10	7	4	21
06.45 - 07.00	11	3	0	14
07.00 - 07.15	13	11	1	25
07.15 -07. 30	12	10	4	26
07.30 - 07.45	19	13	5	37
07.45 - 08.00	15	9	5	28
12.00 -12.15	10	6	2	18
12.15 - 12.30	8	3	2	13
12.30 - 12.45	12	6	2	21
12.45 - 13.00	16	15	5	36
13.00 - 13.15	12	7	6	25
13.15 - 13. 30	9	6	0	15
13.30 - 13.45	13	9	2	24
13.45 - 14.00	7	5	2	14
16.00 - 16.15	18	11	1	30
16.15 - 16.30	12	8	6	26
16.30 - 16.45	14	8	2	24
16.45 - 17.00	18	11	5	34
17.00 - 17.15	13	8	4	24
17.15 -17. 30	18	9	5	32
17.30 - 17.45	18	12	2	32
17.45 - 18.00	11	10	2	23

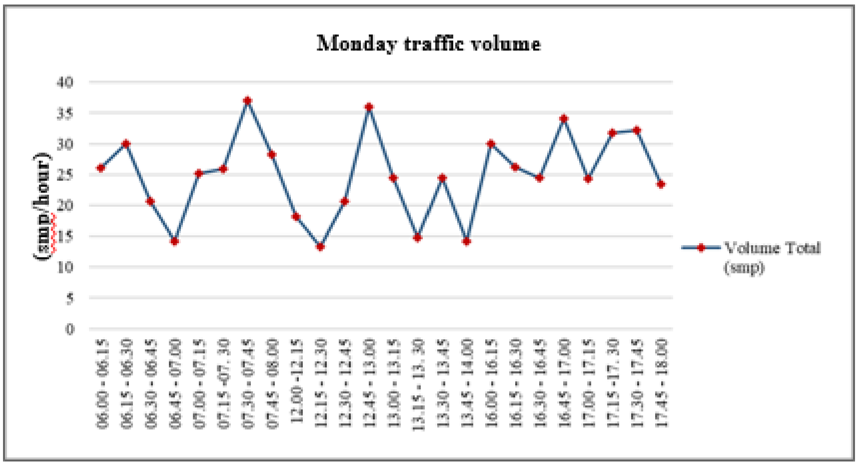

Figure 3. Traffic Volume Graph on Monday

Table 3. Traffic Volume on Sunday

Calculation (smp/hours)	MC	LV	HV	Total
	0,25	1	1,2	
06.00 - 06.15	21	15	5	41
06.15 - 06.30	18	18	4	40
06.30 - 06.45	14	11	5	30
06.45 - 07.00	10	7	0	17
07.00 - 07.15	16	19	7	42
07.15 -07. 30	17	10	6	33
07.30 - 07.45	19	13	6	38
07.45 - 08.00	15	14	6	35
12.00 -12.15	11	6	5	21
12.15 - 12.30	12	7	5	24
12.30 - 12.45	13	10	4	26
12.45 - 13.00	23	15	7	45
13.00 - 13.15	20	15	7	42
13.15 - 13. 30	11	10	2	23
13.30 - 13.45	15	11	4	29
13.45 - 14.00	10	10	4	23
16.00 - 16.15	50	14	4	68
16.15 - 16.30	25	12	7	44
16.30 - 16.45	20	11	8	39
16.45 - 17.00	18	18	8	44
17.00 - 17.15	23	12	7	42
17.15 -17. 30	25	13	6	44
17.30 - 17.45	28	18	10	55
17.45 - 18.00	18	13	7	38

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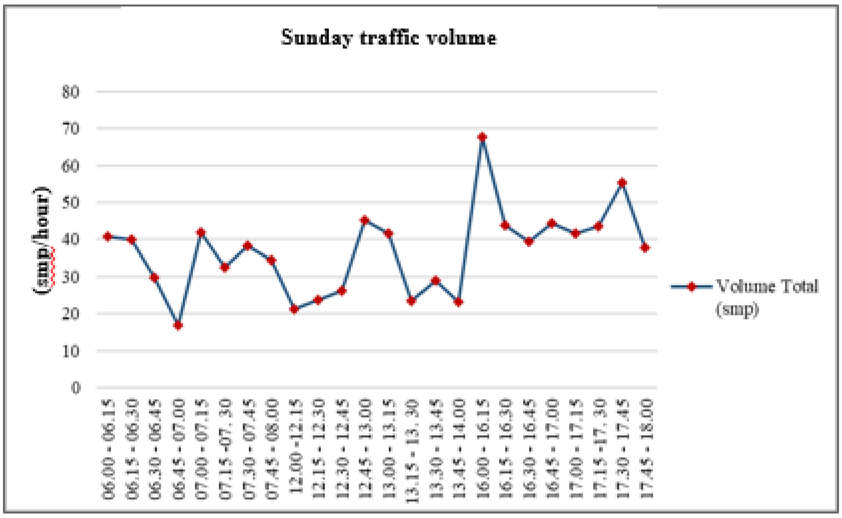

Figure 4. Traffic Volume Graph on Sunday

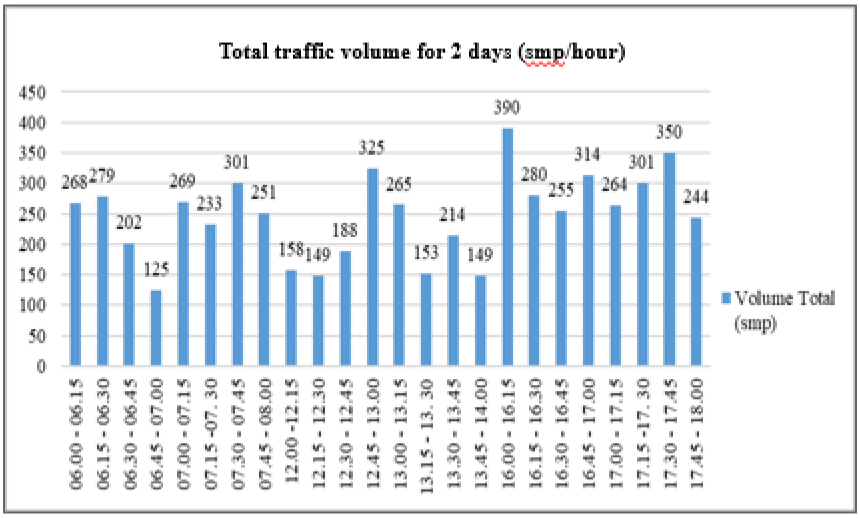

Figure 5. Total Traffic Volume Graph in 2 days

Analysis of Traffic Speed and Density Data

In this study, a survey of vehicle speed and density was conducted on motorcycles, light vehicles, and heavy vehicles. Where the traffic speed data for each vehicle in the survey was taken in kilometers per second, so it is necessary to convert the traffic speed units to kilometers per hour, the traffic speed data (Us) that has been obtained in every 15 minutes is divided by 3600 seconds and multiplied by 1000 to convert meters to kilometers, to convert traffic speed (Us) in km/hour units, and for traffic density where the total traffic density data in smp/km units is obtained by dividing the total traffic volume (q) by the total traffic speed (Us).

Table 4. Average Traffic Speed

Times	MC	LV	HV	Yi	Xi	Speed (km/hours)
	[1]	[2]	[3]	[4]	[5] = [4]/3600	[6] = [5]*1000
06.00 - 06.15	23,11	19,17	16,33	58,61	0,016	16,28
06.15 - 06.30	20,12	18,54	16,58	55,24	0,015	15,34
06.30 - 06.45	19,23	12,55	15,24	47,02	0,013	13,06
06.45 - 07.00	25,14	19,58	20,16	64,88	0,018	18,02
07.00 - 07.15	26,15	20,16	15,13	61,44	0,017	17,07

Times	MC	LV	HV	Yi	Xi	Speed (km/hours)
	[1]	[2]	[3]	[4]	[5] = [4]/3600	[6] = [5]*1000
07.15 -07. 30	20,31	21,48	18,06	59,85	0,017	16,63
07.30 - 07.45	19,12	16,25	19,30	54,67	0,015	15,19
07.45 - 08.00	18,17	18,35	20,15	56,67	0,016	15,74
12.00 -12.15	16,15	20,17	15,44	51,76	0,014	14,38
12.15 - 12.30	24,15	19,52	16,25	59,92	0,017	16,64
12.30 - 12.45	23,24	18,46	18,34	60,04	0,017	16,68
12.45 - 13.00	29,12	20,19	19,27	68,58	0,019	19,05
13.00 - 13.15	23,58	22,16	18,13	63,87	0,018	17,74
13.15 - 13. 30	14,56	19,25	19,58	53,39	0,015	14,83
13.30 - 13.45	19,28	18,19	19,34	56,81	0,016	15,78
13.45 - 14.00	18,55	12,33	15,35	46,23	0,013	12,84
16.00 - 16.15	20,12	18,35	13,54	52,01	0,014	14,45
16.15 - 16.30	23,25	17,34	12,57	53,16	0,015	14,77
16.30 - 16.45	22,54	18,44	19,58	60,56	0,017	16,82
16.45 - 17.00	19,58	19,12	19,34	58,04	0,016	16,12
17.00 - 17.15	16,57	19,48	18,25	54,30	0,015	15,08
17.15 -17. 30	23,18	20,16	17,36	60,70	0,017	16,86
17.30 - 17.45	23,45	21,15	18,49	63,09	0,018	17,53
17.45 - 18.00	24,15	20,13	19,35	63,63	0,018	17,68

Table 5. Traffic Volume, Speed, and Density

No	Volume (smp/hours)	Us (km/hours)	Density (smp/km)
1	268	16,28	16,44
2	279	15,34	18,20
3	202	13,06	15,44
4	125	18,02	6,94
5	269	17,07	15,74
6	233	16,63	14,04
7	301	15,19	19,83
8	251	15,74	15,96
9	158	14,38	10,98
10	149	16,64	8,94
11	188	16,68	11,27
12	325	19,05	17,06
13	265	17,74	14,93
14	153	14,83	10,29
15	214	15,78	13,56
16	149	12,84	11,60
17	390	14,45	27,01
18	280	14,77	18,95
19	255	16,82	15,17
20	314	16,12	19,46
21	264	15,08	17,52
22	301	16,86	17,86
23	350	17,53	19,97
24	244	17,68	13,83

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Mathematical Relationship Between Volume, Velocity, and Density

The mathematical relationship between volume, velocity, and density can be expressed through the greenshield approach using Microsoft Excel, then obtained Uf 16.670 smp/hour, (Uf)/Dj 0.329 smp/hour, Dj 50.66 smp/hour, and R2 0.014 mathematical relationship as follows:

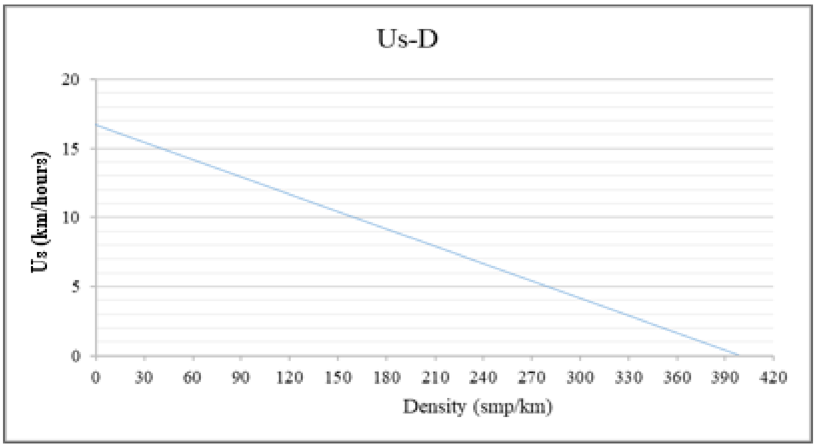

Figure 6. Graph of Mathematical Relationship between Speed and Density

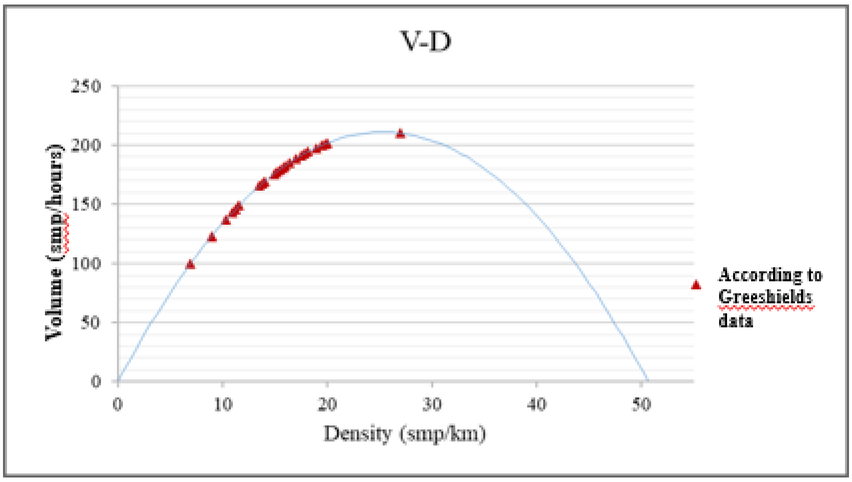

Figure 7. Graph of Mathematical Relationship between Volume and Density

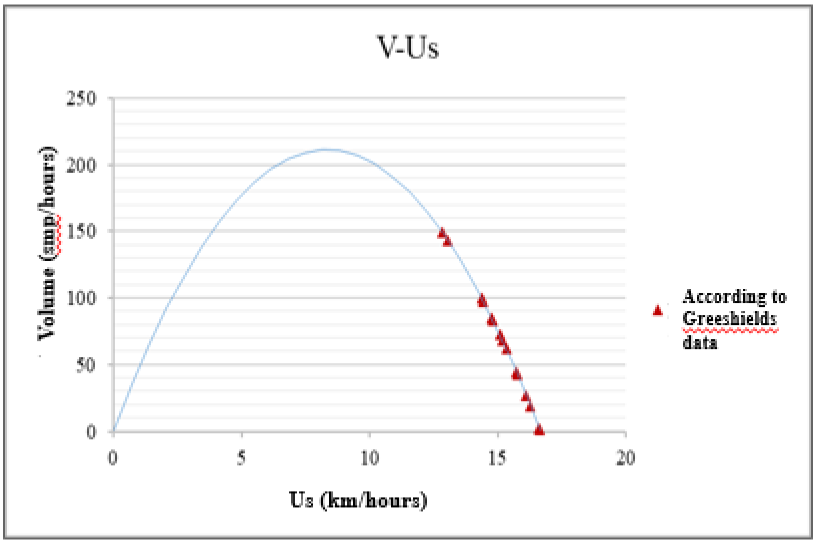

Figure 8. Mathematical Relationship Graph between Volume and Velocity

Shock Waves

To show the nature of shock waves caused by different durations of closed railroad crossings, the value of r is changed. Figure 9 shows that the larger the duration of the closed railroad crossing (r), the longer the time required to reach the maximum queue length (t3-t2), the maximum queue length (QM), and the time for vehicle normalization (t4-t2).

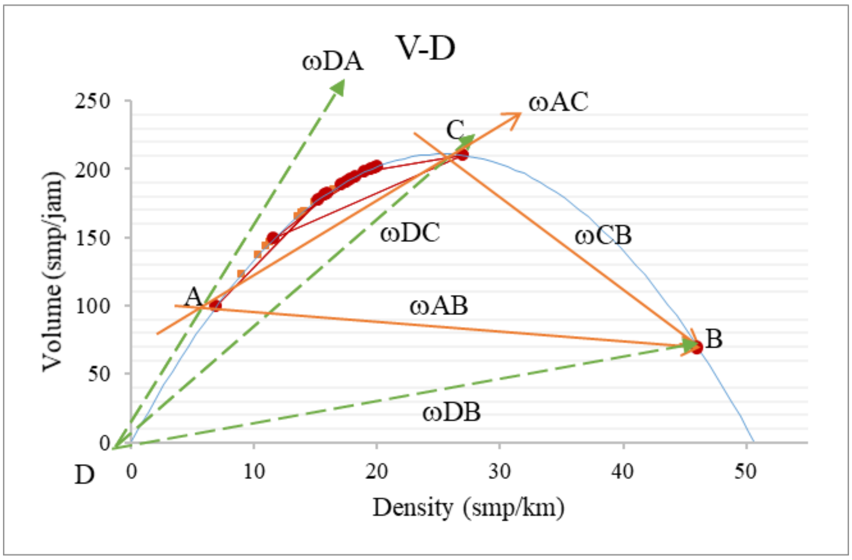

Figure 9. Greenshield Graph of Volume and Density Relationship [10]

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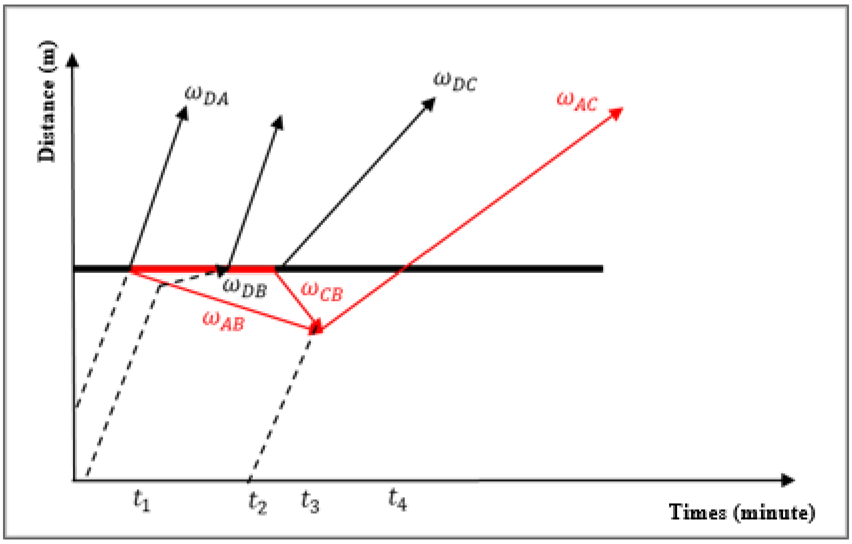

Figure 10. Constriction Shock Wave Graph

CONCLUSION

Based on the results of the analysis and discussion conducted on the Citayam Highway, Depok City, it was obtained: the minimum traffic volume occurred on Monday at 14 smp/hour and the maximum occurred on Sunday at 68 smp/hour, the average traffic density was obtained in two days at 27.01 smp/km, the average traffic speed was obtained in two days at 19.01 km/hour, the duration of the railroad crossing closure was obtained a delay time of 2 minutes 96 seconds, the relationship between speed and density on average for two days with the largest value using the greenshield method was 19.05 km/hour and the smallest was 12.84 km/hour, the relationship between volume and speed on average for two days with the largest value using the greenshield method was 210.211 smp/hour and the smallest was 99.792 smp/hour. After conducting shock wave analysis at the railroad level crossing, the results obtained were the forward shock wave formed (ωda) of 14.387 km/hour, the speed of the backward shock wave formed (ωab) -1.118 km/hour, the speed of the forward recovery shock wave (ωdc) of 7.783 km/hour, the speed of the backward recovery shock wave (ωcb) of -7.763 km/hour, the speed of the recovery shock wave (ωac) of 5.500 km/hour.

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