Analysis of Queue Decomposition Time Due to Railway Crossing Gate Closure to Avoid Dissaster

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ABSTRACT

This research was conducted on a segment of railway at HOS Cokroaminoto Road which aims to analyze: (1) Traffic volume; (2) Delay and queue occurred due to the at-grade railway crossings; (3) Level of service; (4) Queue decomposition time due to railway crossing gate closure. The population of this research are the traffic data at an at-grade crossing in Surakarta City and the sample of this research are at-grade crossing traffic data on HOS Cokroaminoto Road segment, in Surakarta. The sampling technique used is purposive sampling technique. The data in this research is analyzed by applying inferential analysis. The research results are as follows: (1) The average traffic volume is 577,538 PCU/hour from north to south direction and 222,025 PCU/hour from the opposite direction. (2) The average delay occurred is 219,058 seconds on the north to south direction and 227,025 seconds on the opposite direction. The average of the queue length occurring is 95,25 meters on the north to south direction and 97,048 meters on the opposite direction. (3) The level of service based on the daily traffic volume is on A level on both directions, while based on the traffic volume during the at-grade railway crossing closure is on F level. (4) The average of queue decomposition time due to the at-grade railway crossing closure is 91,0833 seconds from north to south direction and 98,325 seconds from the opposite direction.

Keywords: traffic volume, delay, queue, time decomposition.

INTRODUCTION

At-grade crossing is a crossing point between a railway and a highway. The establishment of an at-grade crossing is an attempt to escalate safety and comfort for the road users and trains. Article 90 of Law of the Republic of Indonesia [1] on Railways stated that "Intersections between railway lines and roads that are not at the same level shall give priority to the safety and smooth operation of railway transportation and road traffic."

In fact, HOS Cokroaminoto road is considered to be a narrow with hectic activity alongside the road and heavy traffic. The potential of issues such as traffic delay and queue are becoming a lot bigger with the closing of the railway gate. Delay is time difference resulted from the at-grade crossing compared to normal traffic with no traffic hindrance. On the other hand, queue is the accumulation of vehicles in a certain road, which in this context is caused by the railway gate closing. Due to the previously elaborated issues, implementation of traffic reorganization needs to be established on HOS Cokroaminoto Road.

The traffic characteristics on a road segment with an at-grade crossings may undergo changes caused by the traffic reorganization. It is stated in research [2] that changes occurred on Manahan Road segment after the construction of Manahan flyover. The traffic volume went from 2437,7 PCU/hour to 1070,5 PCU/hour. Moreover, the construction has caused a significant decrease in the degree of deterioration from 0,67 to 0,38. With the significant decrease on the degree of deterioration, the level of service has been improved from B level to A level [3].

Transportation management at intersections is one of the most important aspects of reducing traffic congestion in urban road networks. Intersections are critical points where two or more traffic streams meet, cross, or merge, which often causes conflicts between vehicles, pedestrians, and sometimes public transport. If intersections are not properly designed or managed, delays, queues, and traffic congestion

can occur, especially during peak hours. One of the main strategies to overcome congestion at intersections is proper traffic control [4], [5]. This can be achieved through the installation and optimization of traffic signals. Traffic lights regulate the movement of vehicles by allocating time for each direction to pass safely. Effective signal timing, such as cycle time, green time, and phase arrangement, can significantly reduce delays and vehicle queues. Adaptive traffic signal systems that adjust signal timing based on real-time traffic conditions are also increasingly used in modern cities. Another important approach is geometric design improvement [6], [7]. This includes widening the intersection, adding turning lanes, and providing separate lanes for left-turning or right-turning vehicles. By separating these movements, traffic conflicts can be minimized and vehicle flow becomes smoother. Roundabouts can also be used as an alternative intersection design, especially in areas with moderate traffic volumes, because they allow continuous vehicle movement and reduce stopping time [8]-[10].

Traffic management measures such as channelization, road markings, and clear signage also help guide drivers through intersections efficiently. Dedicated pedestrian crossings and pedestrian signals improve safety and prevent interference with vehicle flow. In addition, the integration of public transport priority systems, such as bus priority signals or dedicated bus lanes near intersections, can improve overall transport efficiency [11], [12].

RESEARCH METHODS

This research employed quantitative approach using inferential analysis technique. Quantitative research method is based on deductive reasoning, which aims to elaborate problems clearly and comprehensible. The research population in this research was the traffic at an at-grade crossing in Surakarta City. Furthermore, the research sample was taken from the traffic data of HOS Cokroaminoto Road segment during peak hour. The sampling technique implemented was purposive sampling.

Purposive sampling technique mainly based the data sampling on the researchers, sorting the data characteristics to fulfill the designated research objectives. The data were collected through direct observation and literature review. The collected data were analyzed based on the Indonesian Highway Capacity [13]-[15].

RESULT AND DISCUSSION
Road Geometric Data

HOS Cokroaminoto Road Geometric Data were measured manually during field observations. The data taken were road width and shoulder width. The lane width was obtained by dividing the road width into two. Thus, the road geometric data are shown in Table 1 below.

Table 1. Road Geometric Data

No.	Factor	Geometric Condition
1.	Road Network System	Secondary Road
2.	Road Classification	Urban Road
3.	Road Class	Class II
4.	Road Type	2-lane 2-way
5.	Road Status	Urban Road
6.	Lane Width	3.75 meters
7.	Total Road Width	7.5 meters
8.	Shoulder Width	0.5 meter

Traffic

a. Traffic Volume

In calculating traffic volume, it is necessary to equalize the type of vehicle into 1 unit, namely PCU/hour. To find the equivalent, the traffic volume data obtained is multiplied by the Passenger Car Equivalent factor (PCE). The PCE used is for two-lane urban roads with undivided road types, two-way traffic flows between 0 - 1800 vehicles/hour, and lane widths of more than 6 m in accordance with Table 2.2 which is based on the Indonesian Highway Capacity Guidelines 2023. Based on the types and tables above, the PCU values used are 0.40 for motorcycles, 1.0 for light vehicles, and 1.3 for heavy vehicles. With total units of PCU/hour and 20-minute intervals the following calculations traffic volume:

1) Vehicle direction = north to south
2) Day/Time = Tuesday / 06.40 - 07.00 WIB
3) Total vehicles stopped
   Motorcycle (MC) = 625
   Light Vehicle (LV) = 26
   Heavy Vehicle (HV) = 1
4) Total vehicles in PCU/20 minutes
   $= (MC \times 0.4) + (LV \times 1) + (HV \times 1.3)$
   $= (625 \times 0.4) + (26 \times 1) + (1 \times 1.3)$
   $= 277.3$ PCU/hour
5) Traffic volume in PCU/hour
   $=$ total vehicles in PCU/20 minutes x 3
   $= 277.3 \times 3 = 831.9$ PCU/hour

Traffic volume data in PCU can be seen in figure 1 below.
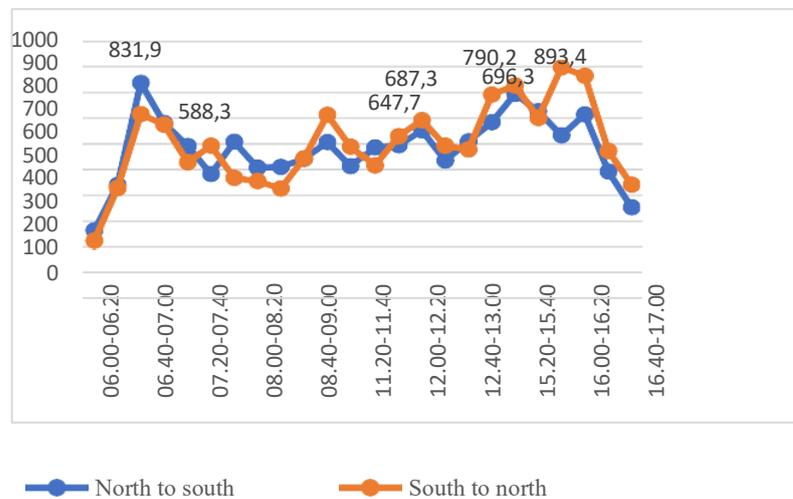

**Figure 1**. Traffic Volume Chart

b. Traffic Volume during the Crossing Gate Closure

The traffic volume during the closing of the crossing gate is calculated starting from the time the gate was closed until the gate is opened. The period of time used in this research are 06.00 - 08.00 WIB and 15.00 - 17.00 WIB. The following is an example of the calculation of traffic volume during the crossing gate closure.
a. Closing time = 16.14 WIB
    Duration of crossing gate closure = 130.6 seconds
b. Total vehicles stopped = 154 MC + 10 LV + 1 HV
c. Total vehicles in PCU = (MC x 0.4) + (LV x 1) + (HV x 1.3) = (154 x 0,4) + (10 x 1) + (1 x 1,3)
    = 72,9 PCU
d. Traffic volume during the crossing gate closure = total vehicles in PCU

$$\frac{3600}{duration\ of\ crossing\ gate\ closure} = 72,9 \times \frac{3600}{130,6} = 2009,495 \text{ PCU/hour}$$

The traffic volume data during the closure of the railway crossing gate can be seen in table 2 below.
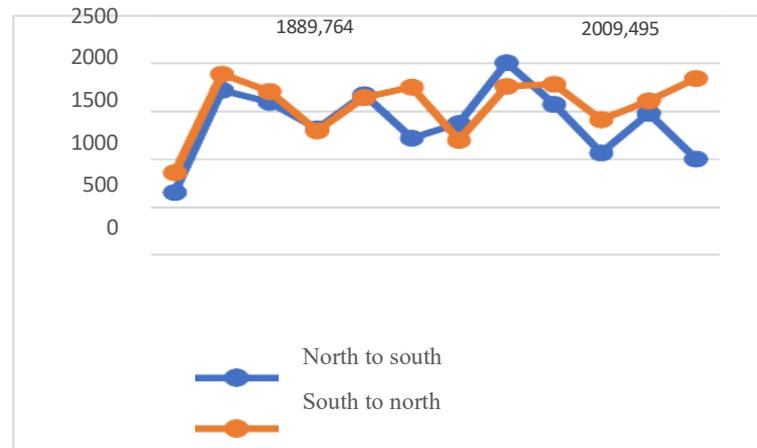
Figure 2. Traffic Volume Graph during At-Grade Crossing Gate Closure

Traffic Composition

Traffic composition analysis used data from observations of traffic volume which has been converted into PCU/hour units. The data is divided into daily traffic composition and traffic composition when closing the crossing gate.

a. Daily traffic composition

An example of the calculation of traffic composition, data from the survey of vehicle volume at 06.40-07.00 WIB is taken. The volume of vehicles in PCU is 250 PCU for motorcycles, 26 PCU for light vehicles, and 1.3 PCU for heavy vehicles. If converted into a presentation, the vehicle composition is 90.155% for motorcycles, 9.376% for light vehicles, and 1.3 PCU for heavy vehicles. light vehicles, and 0.469% for heavy vehicles. Meanwhile, the average vehicle composition obtained is 83.093% for motorcycles, 16.32% for light vehicles, and 0.587% for heavy vehicles.

b. The Average Volume of Traffic Composition

The average value of traffic composition at the time of closing the crossing gate from north to south is 77.817% for motorcycles, 20.27% for light vehicles, and 1.916% for heavy vehicles. Meanwhile, from south to north, the vehicle composition is 80.134% for motorcycles, 17.067% for light vehicles, and 2.8% for heavy vehicles. Based on data from the Central Bureau of Statistics, Surakarta City is a city with a population of 523,008 in 2022. Based on normal values, the traffic composition of the 2023 Indonesian Road Capacity Guidelines is 63% for light vehicles or passenger cars, 2.5% for heavy vehicles, and 34.5% for motorcycles.

Delay

Analysis of delays that occur due to at-grade crossings is obtained by determining the difference in average time at a certain distance in the presence of at-grade crossings with average travel time at the same distance without at-grade crossings or normal roads. There are 2 delays that occur due to the closure of the crossing gate, stopped delay and geometric delay. Stopped delay occurs due to the crossing gate closure and geometric delay occurs due to the queue decomposition. The average delay appeared to be 219.06 seconds for the north to south direction and 227.025 seconds for the south to north direction.

To determine the value of the average traffic delay on road segments with traffic interference, it was adjusted to the degree of saturation occurring on the road segment. For example, at 06.12 WIB for degree of saturation 0.43308, the value of the average traffic delay is as follows:

T_{LL} = 2 + 8.2078 Dj - (1-Dj)2

= 2 + 8.2089. 0.43308 - (1 - 0.43308)2 = 5.2332 seconds

The complete delay data at Table 2 below.

Table 2. Traffic Delay Data

No	Time	North to South Direction		South to North Direction	
		Delay	Average Traffic Delay	Delay	Average Traffic Delay
1	6,12	175,03	4,2631	186,03	5,2332
2	6,48	278	10,75	283,6	13,08
3	7,21	222,2	9,485	230,8	10,60
4	8,12	220,1	7,451	219,5	7,320
5	8,54	241,6	10,24	249,1	9,945
6	11,2	187,3	6,915	215,2	11,14
7	11,4	201,7	7,794	199,1	6,795
8	16,1	258,3	15,44	256,2	11,22
9	16,3	245,0	9,276	259,4	11,53
10	17,0	200,3	6,176	218,5	8,040
11	17,2	222,1	8,530	224,9	9,605
12	17,5	177	5,892	181,9	12,33

Queue

Analisis panjang antrian dilakukan Queue length analysis is carried out by measuring the queue length in units of meters, from the front-most vehicle to the rear-most vehicle. By using the marker stakes that have been installed every 25 meters outside the shoulder, researchers measured the rear-most vehicle by pulling the meter from the nearest stake. The result of the observation showed that the longest queue was 136 meters at 06.48 WIB from north to south and of 142.6 meters at 06.48 WIB from south to north. The data on the length of the queue due to the crossing gate closure are shown in Table 3 below.

Table 3. Queue Length Data

No	Time	Closing Duration (Seconds)	Queue Length from North to South (Meter)	Queue Length from South to North (Meter)
1	6,12	130,33	44,7	52,4
2	6,48	152,4	125,6	142,6
3	7,21	122,6	99,6	102
4	8,12	128	92,1	96
5	8,54	133,2	108,4	111,3
6	11,24	119,8	67,5	94
7	11,47	121,5	80,2	70
8	16,14	130,6	127,7	103
9	16,36	132,67	112,4	122
10	17,09	129,5	70,8	83
11	17,22	125,4	96,7	95
12	17,57	118,4	58,6	87,4

To provide a control value, the queue length was estimated using a formula based on the 2023 Indonesian Highway Capacity Guidelines. The calculation involves multiplying the average number of queued vehicles (Nq) by the average area occupied by a single passenger car unit (PCU), which is assumed to be 15 m². This product is then divided by the width of the entry lane (m). Based on the collected data, the following is the resulting queue length calculation:

$$P_A = 72,9 \times \frac{15}{7} = 156,21 \text{ meters}$$

The complete queue length data based on the formula is presented in Table 4 below.

Table 4. Data of Queue

No	Time	Closing Duration (Seconds)	Queue Length from North to South (Meter)	Queue Length from South to North (Meter)
1	6,12	130,33	51,00	66,86
2	6,48	152,4	156,21	171,43
3	7,21	122,6	116,57	124,71
4	8,12	128	100,50	98,79
5	8,54	133,2	132,86	130,50
6	11,24	119,8	87,21	125,14
7	11,47	121,5	99,43	86,79
8	16,14	130,6	156,21	136,93
9	16,36	132,67	124,29	141,00
10	17,09	129,5	82,50	108,86
11	17,22	125,4	110,57	120,21
12	17,57	118,4	70,71	129,86

5. Road Capacity

    The road capacity analysis was carried out using the 2023 Indonesian Highway Capacity Guidelines as a reference. This segment outlines the calculation of capacity for Jalan Raya HOS Cokroaminoto.

a. Basic Capacity (C_0)

    HOS Cokroaminoto Road is a two-lane undivided, two-way urban road. Thus, the basic capacity value (C_0) of this type of road is 2,900 PCU/hour.

b. Calculating Lane Width Adjustment Factor (FCw)

    HOS Cokroaminoto Road effective lane width is 3.5 meters. Thus, the value of the lane width adjustment (FCw) is 1.00.

c. Directional Separation Adjustment Factor (FCsp)

    Since the directional separation is 50-50 (i.e., no physical median), the adjustment factor for this parameter (FCsp) is also 1.00.

d. Side Friction Adjustment Factor (FCsf)

    The road segment passes through a market area, leading to relatively high roadside activity. Based on this condition, it falls under the category of commercial zone, with a side friction adjustment factor (FCsf) of 0.73.

e. City Size Adjustment Factor (FCcs)

    The population of Surakarta City is 904,862 people, in the second semester of 2022, then the value of the factor of urban scale adjustment (FCcs) is 0.94.

f. Final Road Capacity (C)

    By multiplying all the adjustment factors with the basic capacity, the final road capacity is calculated as follows:

    C = C0×FCw×FCsp×FCsf×FCcs
       = 2900×1×1×0.73×0.94
       = 1,989.98 PCU/hour

6. Degree of Saturation (DS)

    By comparing between the traffic volume and road capacity, the degree of saturation can be used to measure whether there are capacity issues or not. The degree of saturation calculation can be measured using the following methods:

a. 20-Minute Traffic Volume Data

    For example, the data used were taken on HOS Cokroaminoto Road, on Wednesday, April 3rd, 2024, between 06:40 and 07:00 WIB, vehicles going from north to south:

    V   = 831,9 PCU/hour

C   = 1989,98 PCU/hour
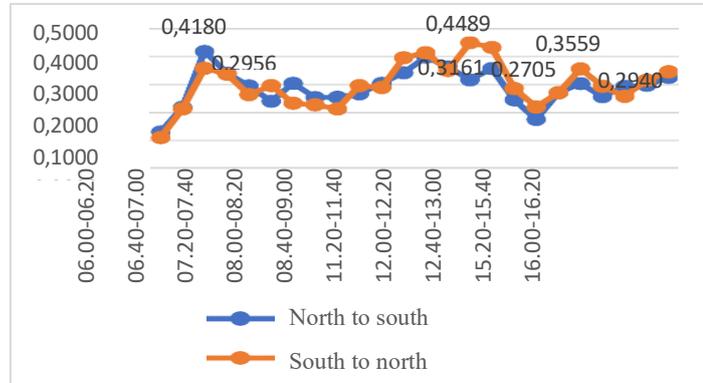DS   = V/C = 831,9/1989,98
       = 0,41804 PCU/hour

Figure 3. Degree of Saturation Chart

b. Based on the traffic volume recorded during the closure of the railway level crossing gate, the following is an example of saturation degree calculation during the closure of the railway crossing gate on HOS Cokroaminoto Road, conducted on Wednesday, April 3rd, 2024 at 16:14 WIB.

V = 2009.495 PCU/hour
C = 1989.98 PCU/hour
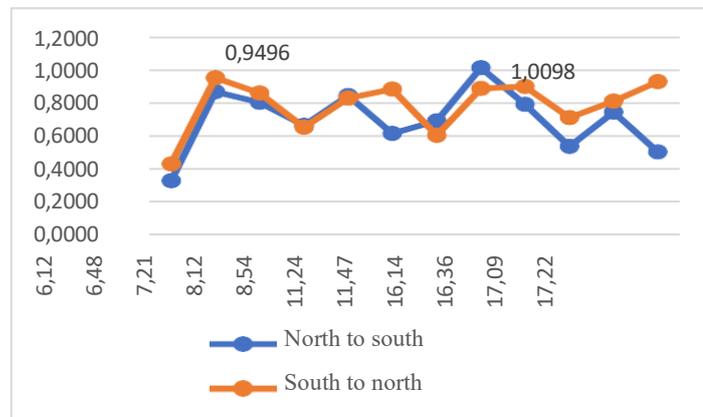DS   =V/C   = 2009.495/1989.98
       =1.0098 (PCU/hour)

Figure 4. Graphic of saturation degree during the closure of the railway crossing gate on HOS Cokroaminoto Road

7. Road Service Level

The Road Service Level is determined based on the degree of saturation and the volume of traffic with an interval of 20 minutes and during the closure of the at-grade crossing gate. The data elaboration is shown in appendix 2. From the results of the calculations that have been carried out, the data showed that the level of service of the HOS Cokroaminoto road segment is at Level A which is categorized as a road with free flow and average travel speed of 40km/hour.

Table 5. Road Service Level

No.	Time	Degree of Saturation	Level of Service – North to South Direction (meters)	Level of Service – South to North Direction (meters)
1	6,12	130,33	A	A

No.	Time	Degree of Saturation	Level of Service – North to South Direction (meters)	Level of Service – South to North Direction (meters)
2	6,48	152,4	D	E
3	7,21	122,6	C	D
4	8,12	128	B	B
5	8,54	133,2	D	D
6	11,24	119,8	B	D
7	11,47	121,5	B	A
8	16,14	130,6	F	D
9	16,36	132,67	C	D
10	17,09	129,5	A	B
11	17,22	125,4	C	C
12	17,57	118,4	A	E

Queue Decomposition Time

Decomposition time is determined by calculating the length of time from the beginning of the opening of the railway crossing gate until no more queues on the road segment. From the research results, the longest decomposition time from north to south direction occurred at 16:14 WIB which took 127.7 seconds. As for the south to north direction, the longest decomposition occurred at 6:48 WIB with a decomposition time of 131.2 seconds. The complete decomposition time data can be seen in Table 6 below.

Table 6. Quenue decompotition time

No.	Time of Gate Closure	Closure Duration Data (second)	Decomposition Tim (North Direction)	Decomposition Tim (South Direction)
1	6,12	130,33	44,7	55,7
2	6,48	152,4	125,6	131,2
3	7,21	122,6	99,6	108,2
4	8,12	128	92,1	91,5
5	8,54	133,2	108,4	115,9
6	11,24	119,8	67,5	95,4
7	11,47	121,5	80,2	77,6
8	16,14	130,6	120,5	125,6
9	16,36	132,67	112,4	126,8
10	17,09	129,5	70,8	89
11	17,22	125,4	96,7	99,5
12	17,57	118,4	58,6	63,5

DISCUSSION

a. Traffic Volume

After going through the data, the highest traffic volume from the northbound direction (heading south) happened between 06:40 and 07:00 WIB, when 410 vehicles passed through. If we convert that into PCU units, it comes out to about 555 PCU/hour. At the same time, traffic moving from the south to the north reached 565 vehicles, or 757 PCU/hour. This shows that during that specific interval, more vehicles were heading north, and that's when overall traffic was at its peak.

Now, if we look specifically at traffic conditions when the railway gate was closed, we get a different picture. The highest flow while the gate was down came at 16:14 WIB from the north, with 175 vehicles or about 2,009.5 PCU/hour. On the opposite side, the busiest moment happened around

06:48 WIB, when 173 vehicles were recorded heading north — about 1,889.8 PCU/hour. So overall, the most congested time on Jalan HOS Cokroaminoto during gate closures was at 16:14 WIB, heading south.

b. Delay and Queue

The worst delay caused by the railway gate happened at 06:48 WIB, lasting 283.6 seconds. When compared to average delays during normal conditions (when the gate stays open), the difference is obvious — the smallest difference was around 36 seconds, and the biggest was more than 120 seconds. If we compare those numbers to the delays calculated using the 2023 PKJI standard, the gap becomes even larger. According to the guideline's formula, the smallest difference was 169.57 seconds, and the largest was 270.52 seconds.

These delays can seriously affect the flow of traffic and make it harder for road users to move comfortably and predictably. As for queue length, the longest lines of vehicles were seen during the gate closure at 06:48 WIB — 136 meters from north to south, and 142.6 meters from south to north, when we compare that to the calculated queue lengths (again using the 2023 PKJI method), we get 156.21 meters and 171.43 meters, respectively. That's a difference of around 20 to 30 meters.

The likely cause? Many drivers rushed forward and crowded near the gate, even ignoring road markings, which caused queues to extend more than predicted by the model.

c. Saturation and Road Service Level

Once we know the traffic volume in PCU/hour, we can calculate the degree of saturation (DS) by dividing it by the road's capacity. This tells us how close the road is to reaching its limit.

The higher the DS, the worse the road's performance tends to be — more congestion, more delays. If the DS is low, traffic can move freely, and road conditions are generally better.

On Jalan HOS Cokroaminoto, the results show clear differences between normal conditions and periods when the railway gate was closed. Those differences are reflected in both the level of service and in how smooth or difficult it is for traffic to pass through during peak times.

1) Based on Daily Traffic

From the analysis, the level of service (LOS) on HOS Cokroaminoto Street is at Level A in both directions (from south to north and from north to south). The highest saturation level from south to north is 0.3805, and from north to south is 0.2789. This means the road is still in good condition, with smooth traffic and no overload.

2) Based on Traffic During Railway Gate Closures

During railway crossing closures, the level of service on HOS Cokroaminoto Road changes, ranging from Level A to Level F, depending on the time and direction. The highest saturation level from south to north is 0.94964 (Level E), and from north to south is 1.0098 (Level F). A Level F shows that traffic gets backed up during gate closures, causing congestion and slower movement.

d. Queue Decomposition Time

From the data, the longest time needed to clear the queue was 127.7 seconds from north to south at 16:14, and 131.2 seconds from south to north at 06:48. Queue clearing time is affected by traffic volume, service level, queue length, and delay. In general, the longer the queue, the more time it takes to clear. But sometimes, longer queues don't always take longer to clear. For example, during gate closures at 16:14 and 16:36 from north to south, even though the queue at 16:36 was longer, the time to clear it was nearly the same. This happened because the traffic volume and service level were almost the same. At 16:14, the queue was 103 meters with a traffic volume of 1761.409 PCU/hour, while at 16:36, the queue was 122 meters with 1785.483 PCU/hour.

CONCLUSION

The average of the observed traffic volume was 577.538 PCU/hour (north to south) and 598.375 PCU/hour (south to north). The highest volume was 831.9 PCU/hour at 06:40–07:00 (north to

south), and 893.4 PCU/hour at 16:40–17:00 (south to north). The average delay due to the railway gate closure was 219.058 seconds (north to south) and 227.025 seconds (south to north). The average queue length was 98.5 meters (north to south) and 98.7 meters (south to north). The longer the gate stays closed, the longer the delays and queues. Based on daily traffic, the level of service on HOS Cokroaminoto Street is at Level A in both directions. But during gate closures, the service level ranges from A to F, showing that traffic conditions change significantly. The average time to clear the queue after the gate opens was 91.08 seconds (north to south) and 98.33 seconds (south to north). The longest times were 125.6 seconds and 131.2 seconds. This shows that the higher the traffic volume, delay, and queue length and the lower the service level the longer it takes to clear the traffic jam. Under normal conditions, this road segment runs smoothly with little delay and low risk of congestion. But during railway gate closures, traffic volume and delays increase, queues build up, and the road's service level drops. This causes inconvenience for road users.

SUGGESTIONS

Based on the analysis done on HOS Cokroaminoto Road, the researchers has given several suggestions as follows:

1. Pay attention to road segments with high traffic volumes to avoid congestion and maintain a good service level.
2. Evaluate traffic arrangements on roads where long queues and delays often happen.
3. Consider building flyovers or underpasses so the railway gate doesn't need to close, which would help reduce delays.

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