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Toll Gate Capacity Analysis (Case Study:Sentul Toll Gate 2)

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Abstract

Toll roads are organized to support optimal traffic movement and increase the efficiency of distribution services in order to support increased economic growth, especially in areas with a high level of economic development. Along with the development of the city in Bogor, West Java, the need for toll road infrastructure is also getting higher, where every year toll road users is increasing, so that the increase in toll road users will have an impact on increasing queues which cause congestion, especially during peak hours on weekdays. Long queues of vehicles at the Sentul 2 toll gate location on the alternative sentul road often result in traffic jams on arterial roads and around the toll gate locations. For this reason, this research is needed to determine the capacity and needs that can be accommodated by the toll gate at the time of arrival and also evaluate or plan the number of substations at Sentul 2 Toll Gate to match the capacity that can be served and there are no long queues. From the calculation of the capacity that can be served, the average service level and the arrival rate using the FIFO queue, the ideal number of substations at the Sentul 2 toll gate requires 4 toll booths to anticipate long queues.

Keywords
Capacity, Service Level, Queue

1. Introduction

In Indonesia, we are currently experiencing rapid population growth, causing an increase in human activities and needs. In addition, population growth has also resulted in increased human movement, the need for transportation facilities, and the growth of increased traffic flow, causing congestion and road congestion. For this reason, it is necessary to develop adequate road networks and infrastructure in order to be able to provide optimal services in accordance with the capacity handled.

Toll roads are organized to support optimal traffic movement and improve the efficiency of distribution services in order to support increased economic growth, especially in areas with a high level of economic development. Along with the development of the city of Bogor, West Java, the need for toll road infrastructure is also getting higher. Every year, the number of toll road users increases, so the increase in toll road users will have an impact on increasing queues that cause congestion, especially during peak hours on weekdays, and also on the number of vehicles that exceed the capacity at the toll gate.

An example is at the Sentul 2 toll gate. The Sentul 2 toll gate is one of the toll gates that is intended as a connecting access from the Sentul area to the Jagorawi toll road section. Congestion that often occurs at this toll gate occurs during peak hours in the morning and evening working hours. Long queues of vehicles at the Sentul 2 toll gate location, which is on the Sentul alternative road, often result in traffic jams on arterial roads and around the toll gate locations.

2. Literature Riview

2.1. Capacity of a toll gate

Toll gate capacity, according Winarsih and Kusumaningrum 2013, is the maximum number of vehicles that can pass through a toll gate in a certain period of time. Several factors, including the road itself, operational control, toll gate facilities, motorist conduct, toll road officer activities, and several environmental conditions, might influence the maximum value.

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2.2. Service Time

Service time is the time given for serving service recipients effectively and efficiently. With a fast and precise servicetime, the service recipient will feel satisfied. The additional volume of traffic using toll roads demands reliable servicefrom these toll roads as an imbalance in the amount of money/toll they provide. The targets were in the form of substation service time, toll road travel time, facility level, facility level, customer complaint level, and road grade standards. In this case, the service provider must be able to provide excellent service to toll road users by knowing what toll road users want. The smooth running of the toll road can describe the actual role of the toll road in supportingthe transportation system and the economic sector. According to the Minimum Service Standards for toll roads, the service time on an open system must be 8 seconds/vehicle.

2.3. Theory of Queuing

Queuing theory is a waiting line of customers (units) who require services from one or more waiters (service facilities). The queue at the toll entrance is a condition when the vehicle faces a delay caused by an imbalance between the arrival rate (flow rate) and the service rate. Queues of vehicles can cause problems for toll road users, namely the waiting time is getting longer if the queue is getting longer. Queuing theory is a method for analyzing and providing information to solve the above problems.

According to Sihotang, Sugito, and Mukid 2019, a queue is a waiting line of a number of customers who require service from one or more service facilities. The queuing process is a process related to the arrival of customers at a service facility, waiting in line if they can not be served, being served and finally leaving the facility after being served.

2.4. Queue Service System

According to Pardede 2018, the queue system is the entire process of customers or goods arriving and entering the queue line, which then requires service as it should apply. There are factors related to queue lines, namely queue length, number of queues and queue discipline:

1. Queue length is grouped into two:
   a. Potentially unlimited queue length
   b. The length of the queue capacity is limited because of the regulations
2. Number of queues The number of queues can be grouped into two:
   a. A single queue that has one service facility to serve the queue
   b. Multiple queues, several service facilities in front of the queue.
3. Queuing discipline is a decision rule that explains how to serve the queue, There are 5 forms of queuing disciplinethat can be used, namely:
   a. First Come First Served or First In First Out (FIFO) means that the queue who comes first will be served.
   b. Last Come First Served (LCFS) or Last In First Out (LIFO) is a queue that arrives last, first out.
   c. Service In Random Order (SIRO) is a queue based on random chance.
   d. Priority Services (PS) are priority services given to customers who have a higher priority than other customers.
4. Queue structure There are 4 queue structures:
   a. Single Channel-Single phase means that there is only one service line or there is only one service.
   b. Single Channel-Multi Phase The Multi Phase shows that there are or more service terms that are carried outsequentially.
   c. Multi Channel - Single Phase occurs anytime where two or more service facilities are fed by a single queue.
   d. Multi Channel – Multi Phase Multi There are two or more service facilities that are fed by more than one customerand can be served at the same time. For example, re-registration of new students at a university.

2.5. Queue System Characteristics

According to Kane, Mishra, and Dutta 2016, the characteristics of queues are that there are arrivals, services, and queues. To be able to explain the queuing process properly, an explanation of the four (four) main components of queuing theory must be properly known and understood, that is :

1. The arrival of the population, which includes the average arrival rate and the probability distribution of services.
2. Service level, which includes the average service level and the probability distribution of service time.
3. Number and arrangement of service gates
4. Queuing discipline, which determines the queue where the traffic unit will be served. Each component in thequeuing system has its own characteristics.

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2.6. Arrival Pattern

The arrival pattern of customers is usually calculated by the interarrival time, which is the time between the arrival of two consecutive customers at a service facility. If the pattern of customer arrivals arrives one by one, then the arrival of customers follows a process with a certain probability distribution. The probability distribution that is often used is the Poisson distribution, where the arrival is independent, not affected by the arrival before or after it. The Poisson distribution assumption shows that customer arrivals are random.

2.7. Output Process

The queuing system requires a service pattern known as service time. This service pattern requires a service process that is carried out randomly, using a certain distribution of opportunities. service must be carried out after the customer enters the queue. However, whether the customer can be served immediately depends on the number of customers in the queue, which is expressed as infinity or limited. After getting good service, the customer will immediately leave the service facility. All of these are then expressed as the output process.

2.7 Output Process

Traffic volume is the number of vehicles crossing one observation point in a certain time unit (days, hours, minutes). High traffic volume requires a larger road width in order to create traffic comfort and safety. While the traffic volume is low, but having a wide road creates a risk of accidents because drivers tend to drive their vehicles at high speeds.

Traffic volume units commonly used in connection with determining the number and width of lanes include:

1. Average daily traffic
2. Volume of planning hours

3. Results and Analysis

3.1. The Growth Rate of Toll Road Use

Table 1. Traffic Volume 2016 - 2020

Year	Vehicle Volume (in million vehicles)
2016	206,8
2017	180,5
2018	147,6
2019	151,1
2020	123,1

Sumber : Traffic Volume PT. Jasa Marga

2016 – 2017 : $\frac{180{,}5-206{,}8}{206.8}$ x 100 = -0.127 %

2017 – 2018 : $\frac{147{,}5-180{,}5}{180{,}5}$ x 100 = -18,28%

2018 – 2019 : $\frac{151{,}1-147{,}6}{147{,}6}$ x 100 = 2,37%

2019 – 2020 : $\frac{123{,}1-151{,}1}{151{,}1}$ x 100 = -18,53%

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3.2. Average Daily Traffic Volume (LHR) At Peak Hours During Observation Day

Table 2. Arrival Rate Monday 10th May 2021

Vehicle Class Time	1	2	3	4	5	Number of Vehicles
06:00 – 07:00	903	215	36	22	5	1181
07:00 – 08:00	1008	187	54	18	8	1275
16:00 – 17:00	1109	132	59	26	6	1332
17:00 – 18:00	1158	144	42	37	4	1385
Total	**4178**	**678**	**191**	**103**	**29**	**5173**

$$\lambda = \frac{number\ of\ vehicles}{research\ time}$$

$$\lambda = \frac{51733}{4} = 1293{,}3 = 1294 \text{ vehicle/hour}$$

Table 3. Arrival Rate Monday 15th May 2021

Vehicle Class Time	1	2	3	4	5	Number of Vehicles
06:00 – 07:00	847	160	28	15	4	1208
07:00 – 08:00	951	174	34	13	7	1179
16:00 – 17:00	1126	167	54	25	8	1380
17:00 – 18:00	1271	186	48	13	5	1521
Total	4195	687	164	66	24	5136

$$\lambda = \frac{number\ of\ vechies}{research\ time}$$

$$\lambda = \frac{5136}{4} = 128 \text{ vehicle/hour}$$

Table 4. Arrival Rate Monday 19th May 2021

Vehicle Class Time	1	2	3	4	5	Number of Vehicles
06:00 – 07:00	1032	137	20	18	6	1213
07:00 – 08:00	927	158	52	13	5	1155
16:00 – 17:00	1077	187	49	17	13	1343
17:00 – 18:00	1104	124	36	9	4	1277
Total	**4140**	**606**	**157**	**57**	**28**	**4988**

$$\lambda = \frac{number\ of\ vehicles}{research\ time}$$

$$\lambda = \frac{4988}{4} = 1247 \text{ vehicle/hour}$$

The traffic volume in this calculation uses the traffic volume during the observation day, namely Monday, Saturday, and Wednesday. Then the calculation of the average daily traffic volume (at peak hours) is as follows :

$$LHR = \frac{5173+5136+4988}{3}$$

$$LHR = \frac{15297}{3}$$

LHR = 5099 vechicle/day

After knowing the volume of traffic per day, the next step is to calculate the volume of vehicles per hour as follows: $\frac{LHR}{reseacrh\ time} = \frac{5099}{4}$ = 1274,8 = 1275 vechicle/hour

3.3. Calculating Sentul Toll Gate Capacity 2

Capacity calculation using the traffic intensity table obtained from Pt. Jasa Marga. Then the following results are obtained:

$K = \frac{3600}{wp}$ x p x s

$= \frac{3600}{8}$ x 0,929 x 4

= 1673 vehicle/hour

3.4. Average Service Level and Substation Requirements

The average service level is the number of vehicles that can be served by toll booths in a certain time. When viewed from the ideal service time for the Sentul 2 toll gate, it can be seen as follows using the service time based on the Minimum Service Standards (SPM) for automatic toll gates (GTO):

Table 5. The maximum number of cars that can be accommodated

WP (Second)	N (Number of toll booths)	μ (Vehicle/Hour)	P (Traffic Intensity)
4	3	900	< 1
5	3	720	< 1
6	3	600	< 1
7	3	515	< 1
8	3	450	< 1
9	3	400	> 1
	4		< 1

From the results of the analysis in the table above, it can be said that the faster the service time at the toll booth, the more the number of vehicles that can be served, while the longer the service time, the fewer the number of vehicles that can be served and will have an impact on increasing the queue length.

3.5. FIFO Queue Length Analysis (first in first out)

The FIFO queuing method is a queuing method where the person who comes first will be served first. The purpose of the FIFO analysis is to find out the queue length and the number of queues at the toll gates. The following is the outcome of applying the FIFO approach to analyze queues:

Table 6. Length and Number of queues

WP	N (Number of Toll Booths)	n (Vehicles)	Queue Length (n)	q (vehicle)	queue (n)	d (second)	w (second)
4	3	1	4.2 m	1	4.2 m	7.57	3.57
5	3	2	9.9 m	1	4.2 m	12.21	7.20
6	3	2	9.9 m	2	9.9 m	20.57	14.37
7	3	4	21.3 m	4	21.3 m	40	33.1
8	3	17	92.2 m	16	86.6 m	144	136
	4	3	15.3 m	2	9.9 m	27.43	19.43
9	3	17	92.2 m	18	87.8 m	144	153
	4	4	21.3 m	3	15.3 m	44.31	35.30

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3.6. Potential Growth of Sentul 2 Toll Gate Users in the future

The projection of the growth in the number of toll gate users is needed in carrying out this analysis as a consideration. Growth projections can be carried out using various factors. In this study, we used the West Java GRDP growth factor and used the volume of vehicles per day that has been calculated previously. The following is the prediction of Sentul 2 toll gate users 5-20 years later:

F = P. (1 + i)
description :
P = current passenger
i = GRDP of West Java (5.85%) N = number of years later

Table 7. Potential Growth

Year	Vehicle Volume/day
2025	6772
2030	9004
2035	11968
2040	15898

3.7. Traffic Volume Estimations

This calculation uses data on the analysis of potential users of the Sentul 2 toll gate which is planned for 2025 to 2040 which aims for gradual development. The calculation required consists of the volume of vehicles per hour so that the VJR formula (planned hour volume) will be calculated as follows:

description :
k = 11 % for the freeway
VJR = VLHR x $\frac{k}{100}$

Table 8. Volume Estimations

Year	Vehicle Volume/hour
2025	745
2030	990
2035	1316
2040	1748

3.8. Analysis of queue length in the future

Calculation of demand and queue of sentul 2 toll gate using data in the form of arrival rate (λ) , also service level (μ) and volume of planned hours that have been calculated previously. The following is a calculation of the needs and capacity of Sentul 2 toll gate using FIFO queue discipline :

Table 9. estimation queue length 2025 - 2040

Tahun	N (Number of Toll Booths)	p	n	q	d	w
2025	4	< 1	1 vehicle	1 vehicle	11.48 second	4.28 second
2030	4	< 1	1 vehicle	1 vehicle	14.26 second	7.06 second
2035	4	< 1	2 vehicle	1 vehicle	21.05 second	13.85 second
2040	4	< 1	7 vehicle	7 vehicle	57.15 second	49.95 second

4. Conclusion

By looking at the results of the analysis of the survey data, the following conclusions are obtained:

1. The capacity that can be accommodated at the Sentul 2 toll gate is 1225 vehicles/hour for 3 substations and 500 vehicles/hour per substation and the ideal capacity that can be accommodated is 1673 vehicles/hour with a vehicle volume of 1275 vehicles/hour\
2. Based on the results of the FIFO queue, the queue length that occurs is as follows: WP 4 seconds = 4.2 m with the number of vehicles in the system 1 vehicle and in the queue 1 vehicle, WP 5 seconds = 9.9 m with the number of vehicles in the system 2 vehicles and in the queue 1 vehicle, WP 6 seconds = 9.9 m with the number of vehicles in the system of 2 vehicles and in the queue of 1 vehicle, WP 7 seconds = 21.3 m withthe number of vehicles in the system 4 vehicles and in the queue 4 vehicles, WP 8 seconds = 92.2 m with the number of vehicles in the system 17 vehicles and in the queue16 vehicles, WP 9 seconds = 92.2 m with the number of vehicles in the system 17 vehicles and in the queue 18 vehicles.
3. From the calculation of the capacity that can be served, the average service level and the arrival rate using the FIFO queue, the ideal number of substations at the Sentul 2 toll gate requires 4 toll booths to anticipate long queues until 2040

References

Kane, S. N, A. Mishra, and A. K. Dutta. 2016. “International Conference on Recent Trends in Physics 2016 (ICRTP2016).” *Journal of Physics: Conference Series* 755: 011001. https://iopscience.iop.org/article/10.1088/1742-6596/755/1/011001.

Pardede, A. M. H. 2018. “Simulasi Antrian Kedatangan Berkelompok Dengan Pelayanan Weibull Oleh Banyak Server.”

Sihotang, Erna Fransisca Angela, Sugito Sugito, and Moch. Abdul Mukid. 2019. “Analisis Antrean Dan Kinerja Sistem Pelayanan Gardu Tol Otomatis Gerbang Tol Muktiharjo (Studi Kasus: Gardu Tol Otomatis Gerbang Tol Muktiharjo).” *Jurnal Gaussian* 8(1): 106–16. https://ejournal3.undip.ac.id/index.php/gaussian/article/view/26625.

Winarsih, N., and J. Kusumaningrum. 2013. “Analisis Kapasitas Gerbang Tol Karawang Barat.” *Psikologi, Ekon. Sastra, Arsit. Tek. Sipil*.

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