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Analysis of Gate Queuein Cikupa Toll PT Marga Mandala SaktiUsing Deterministic Queue Model

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Abstract: *The Cikupa toll gate is the main gate on the Tangerang-Merak toll road. The condition of the Cikupa toll gate for current direction from Jakarta to Merak is currently inadequate in accommodating the traffic volume that occurs so that during peak hours the toll gate queue is very long, this is because the traffic arrival rate is not balanced with the service level. This study will examine the Queue theory of the toll gate transaction system with a deterministic queuing model approach using simple and queuing simulations that can provide an overview of the value of lost time experienced by toll road users. Based on the analysis in 2015-2017, using a simple deterministic queuing model found that the numbers produced were imaginary. But not when using a deterministic simulation queue model. The deterministic queuing model of the simulation developed by Lin and Su can be used to decipher the queue at the gate. The value of lost time experienced by toll road users, especially those passing through the Cikupa toll gate in the year of Rp. 2,062,842,000, per week, Rp.8,251,367,999, per month and Rp. 99,016,415,983, per year. based on calculations using simulation deterministic queuing theory, the number of optimal substations in 2018 was 9 substations which were previously 7 substations. so that the increase in transaction capacity is very necessary to do with the addition of operating substations*.

Keywords: *Queue, determinstik queue model, queuesimulation, optimal transaction*

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I. Introduction

The main toll gate Cikupa has 5 booths where 2 booths use Automatic Toll Gate. The number of substations that are operated every day is always a maximum of 5. With an average growth of 9-10% per year (based on 2009-2016 data). The current number of substations is deemed inadequate because based on 2015 traffic survey data the long queue of vehicles during rush hour can be 3-5 km, so the arrival rate of vehicles heading to the main Cikupa toll gate is not balanced with the level of service (capacity) of transactions at the gate the toll. This is consistent with the results of research Sodikin (2012) which shows that the queue time is directly proportional (linear) with the length of the queue in accordance with the variety of service times.

From a background review of the problem, identification of problems that occur related to the problem of queuing at the Cikupa toll gate, including the transaction capacity of each service substation at the Cikupa Main Toll Gate, now exceeds the actual capacity> 2100 vehicles per hour, the queue length at the Cikupa Toll Gate is more The number of SPM (Minimum Service Standards) for toll roads is a maximum of 10 vehicle queues while at peak hours of up to 14 queues, traffic growth in the last 3 years at the Cikupa Toll Gate is greater than the previous year's planning of 8% but in the field up to 10%.

Based on the description of the problem identification, it is necessary to study the optimal service to reduce the queue at the Cikupa toll gate. It is necessary to calculate how much time is lost due to the queue due to imbalanced traffic volume, what is the estimated value of lost time caused by the length of the queue at the toll gate, what is the optimal number of additional substations to reduce the queue, and the cost of the queue incurred

II. Literature Review

This Queues can occur because people or services that arrive at the service function (sever) are faster than the time needed to provide services to them. Operating characteristics of the queue (operating characteristic). The characteristics of a system that contains a queue function can be represented by the following values:

- Average time of arrival of customers
- Average customer waiting time
- Average service time

The average value of customer waiting time and average service time can be said as the length of time lost due to the queue and the size of the number can be used to describe the performance of a queuing system (Harinaldi, 2015).

Queuing system is a system that includes lines and service gates. Whereas the population formed from time to time from a source is called the calling population. The population comes to the system and joins to form a queue. At a certain time, one or several members of the queue are selected to receive services. This selection is based on certain rules called queue discipline (Heizer and Render, 20015). The population that has been served then leaves the service gate (Heizer and Render, 2015).

The queuing system consists of several types including the single-channel single-phase queuing system, the single-channel multy-phase queuing system, the multy-channel single-phase queuing system, and multiple line queuing system with multiple stages (multy channel-multy phase).

Detailed deterministic queue analysis can be divided into two levels. Queue analysis can be carried out at the macroscopic level if the arrival and services are continuous. Whereas if the arrivals and services are discrete, the analysis is carried out at the microscopic level. if the arrival time and service time of each vehicle are known, both distribution of arrival and service distribution is deterministic (Reeves, 2010).There are 4 (four) main parameters that are always used in analyzing the queue namely,,, and. The definition of each parameter is:

n = number of vehicles or people in the system (vehicles or people per unit time)
q = number of vehicles or people in the queue (vehicles or people per unit time)
d = time of vehicle or person in the system (unit of time)
w = vehicle time or people in the queue (unit of time)

The following equation is an equation that can be used to calculate n, q, d, and w for FIFO queue discipline.

$$\bar{n} = \lambda / (\mu - \lambda) = \rho / (1 - \rho) \quad \text{(.1)}$$
$$\bar{q} = \lambda 2 / \mu(\mu - \lambda) = \rho 2 / (1 - \rho) \quad \text{(.2)}$$
$$\bar{d} = 1 / (\mu - \lambda) \quad \text{(.3)}$$
$$\bar{w} = \lambda / \mu(\mu - \lambda) = d\,2 - 1/\mu \quad \text{(.4)}$$

Based on previous studies (Lin & Su, 1994), for an average queue length value, the average time in the system can be estimated as follows

$$T = \frac{1605 + 3250\,\mathrm{L}}{C}\ \mathrm{L} \leq 15 \ldots \quad (5)$$
$$T = \frac{8748 + 2776\,\mathrm{L}}{C}\ \mathrm{L} > 15 \ldots \quad (6)$$
$$C = \frac{60}{ST} \ldots \quad (7)$$

Where,
T = average time in the system, seconds.
L = average length of queues, vehicles.
C = gate capacity, vehicles per hour

The relationship between the average queue length and gate capacity and the volume capacity ratio can be expressed as follows:

L ≈ 0 jika v/c 0,5 .... (8)
L = 7 – 3.5 jika 0,5 ≤ ≤ 0.93 .... (9)
L = 3[1+6.29(– 1)(– 1)][1+(14 -13)2 t] .. ..(10)

Where,
V / C = volume-capacity ratio.
T = current duration, hour.
(Lin & Su, 1994)

The cost / cost model of this queue is used to obtain the level of service with optimal results, which are reviewed both in terms of service value and the number of services available in a system. This can be achieved by balancing service costs with waiting costs for each customer per unit time.

III. Methods

The problem solving methodology used in this research is a method of solving quantitative models with analysis approaches based on queue theory, queue cost calculations, and the analysis of optimal service amount Starting from the field survey stage to find the primary data and collect secondary data for the need of calculation simulation.

To be more helpful in understanding the problem solving method, it can be illustrated in the flowchart as follows:

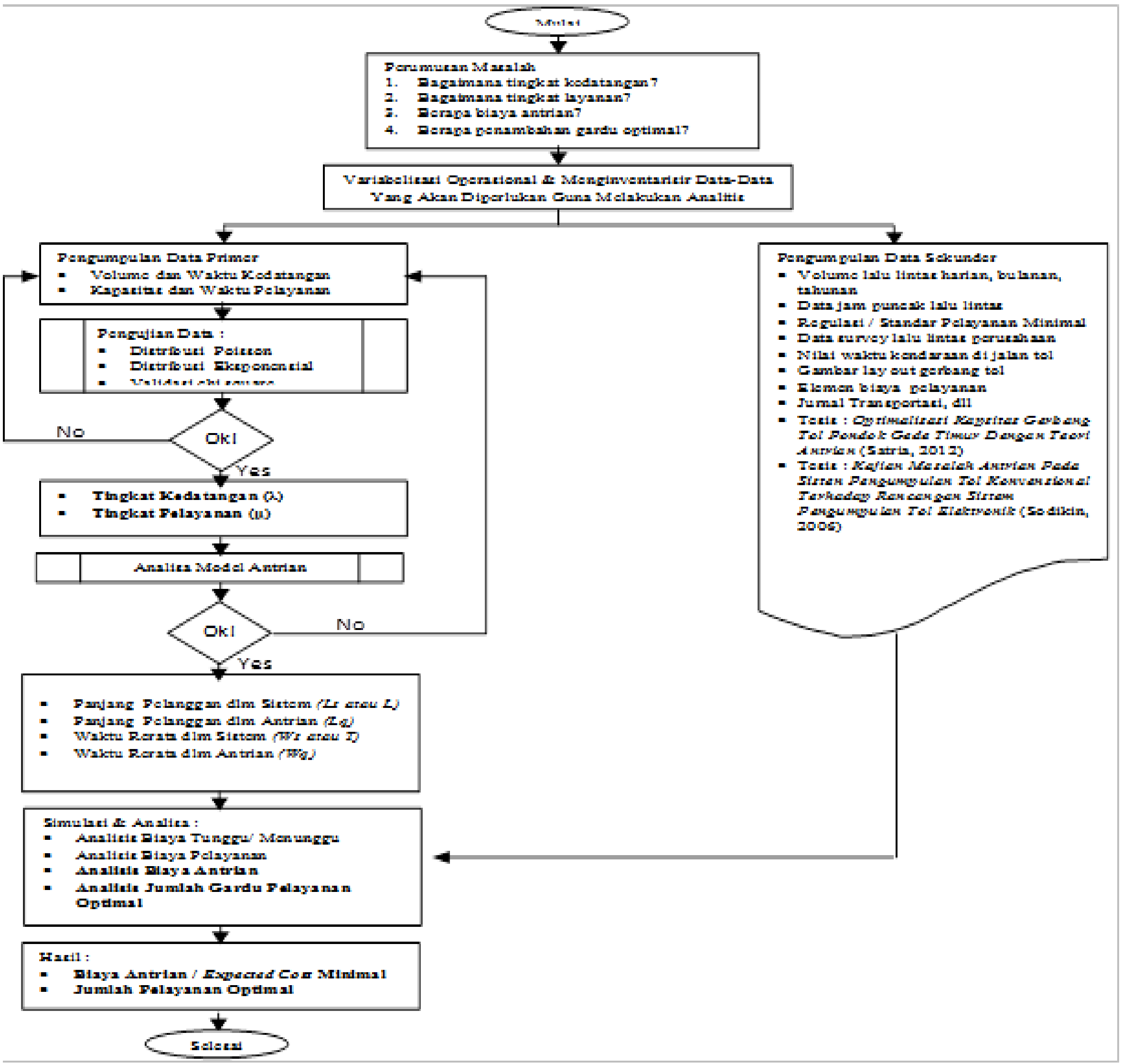

Figure 1. Research Flow Chart

In this study, the population to be studied is vehicles / traffic coming to toll booths at Cikupa Gate. To represent this population, a sample is taken. The sampling method used in this study is simple random sampling, which is a sampling method, where each element in the population has the same probability of being selected as a sample member (Mathyn, 2007). The sample used in this study was a transaction activity at the Cikupa toll booth at 1 week (May 21-27, 2018).

IV.Results

4.1. Analysis of Deterministic Queue Models with Queue Simulation

If λ / μ> 1.0, then it is solved by a macroscopic deterministic approach to simulation, but it does not rule out the possibility of completing calculations where λ / μ <1.0.The Queue Simulation Method at the toll gate has been developed by F.B. Lin and C.W. Su, and was published in the Journal of Transportation Engineering, ASCE, Vol. 120, No.2 Th 1994 under the title Level of Service Analysis of Toll Plazas on Freeway Main Lines and has shown consistency in solving queuing problems at toll gates with same model forDetermining the Number of Toll Gates Operated Based on Hybrid Service Level Model with Fuzzy Logic (Sutanto,2014)

Based on the calculations that have been done it turns out it can be used to complete the queue calculation at the Cikupa toll gate as shown in the following table.

Table 1. Example of the process of calculating a deterministic queuing model with simulations

NO	Periode	Tingkat Kedatangan (λ)	Tingkat Pelayanan (μ)				Panjang Rata-rata Antrian Kendaraan	Waktu Rata-Rata Dalam Sistem, detik (T)		
		λ (Kend/jam)	WP (det/kend)	Jmlh. Gardu (K)	(Kend/jam)	(ρ) λ/μ	L = 0, jika λ/μ < 0.5 L = 7*λ/μ - 3.5* jika 0.5 < λ/μ < 0.93 L = 3[1+6.29(λ/μ-0.93)(μ 3600/360-1)][1+t(14λ/μ-13)^2], jika λ/μ>0.93Jika	T =(1.605+3.250L)/μ jika L<15 =(8.748+2.776L)/μ jika L>15		T
						Now	Hasil Simulasi (kend)	Jam	Menit	detik
1		4	9	10	11	12	15	17	18	19
1	00.00-01.00	2061	10.81	5	1665.3	1.237	21.19	0.04	2.43	146.05
2	01.00-02.00	1458	10.81	4	1332.3	1.094	7.89	0.02	1.23	73.67
3	02.00-03.00	975	10.81	3	999.2	0.976	6.04	0.02	1.27	76.49
4	03.00-04.00	926	10.81	3	999.2	0.927	2.99	0.01	0.68	40.77
5	04.00-05.00	935	10.81	3	999.2	0.936	6.00	0.02	1.27	76.05
6	05.00-06.00	1547	10.81	4	1332.3	1.161	11.19	0.03	1.71	102.64
7	06.00-07.00	2436	10.81	7	2331.5	1.045	7.15	0.01	0.64	38.38
8	07.00-08.00	2723	10.81	7	2331.5	1.168	15.90	0.02	1.36	81.67
9	**08.00-09.00**	3417	10.81	7	2331.5	1.466	117.59	0.14	8.63	517.56
10	**09.00-10.00**	4330	10.81	7	2331.5	1.857	583.13	0.70	41.88	2513.04
11	**10.00-11.00**	4463	10.81	7	2331.5	1.914	695.86	0.83	49.94	2996.25
12	**11.00-12.00**	4042	10.81	7	2331.5	1.734	381.79	0.46	27.50	1650.01
13	12.00-13.00	3068	10.81	7	2331.5	1.316	47.89	0.06	3.65	218.77
14	13.00-14.00	2812	10.81	7	2331.5	1.206	21.41	0.03	1.75	105.28
15	14.00-15.00	2871	10.81	7	2331.5	1.231	26.03	0.03	2.08	125.10
16	15.00-16.00	2750	10.81	7	2331.5	1.179	17.41	0.02	1.47	88.13
17	16.00-17.00	2801	10.81	7	2331.5	1.202	20.69	0.03	1.70	102.18
18	17.00-18.00	2835	10.81	7	2331.5	1.216	23.12	0.03	1.88	112.62
19	18.00-19.00	2486	10.81	7	2331.5	1.066	7.91	0.01	0.70	42.16
20	19.00-20.00	2309	10.81	7	2331.5	0.991	6.19	0.01	0.56	33.53
21	20.00-21.00	2451	10.81	7	2331.5	1.051	7.36	0.01	0.66	39.41
22	21.00-22.00	2625	10.81	6	1998.4	1.314	41.24	0.06	3.70	222.00
23	22.00-23.00	2438	10.81	6	1998.4	1.220	21.32	0.03	2.04	122.37
24	23.00-24.00	2211	10.81	6	1998.4	1.107	9.51	0.02	0.98	58.59
	Total	**60970**						**2.13**	**159.71**	**9582.70**

Source: Calculation

4.2. Analysis of Lost Time and Missing Time Value

The variables that influence the calculation of lost time include the level of vehicle arrival and the level of service.The method of calculating the amount of time a vehicle in a queue is obtained from the calculation process using the Lin & Su queue simulation model. Based on the calculation of the amount of time lost from Monday to Sunday in secondary data 21 to 27 May 2018 which will be projected until 2023 with a projected amount of traffic growth of 9.3% per year (Traffic Growth of Tangerang-Toll Road Peacock) is as follows**:**

Table 2. Time lost in average vehicles on the Cikupa GT

No	Uraian	Senin	Selasa	Rabu	Kamis	Jumat	Sabtu	Minggu
1	Lalin Puncak (Kend/ Jam)	4,463	4,341	4,061	4,107	3,595	3,551	2,533
2	Kapasitas Max (Kend/ Jam)	2,331	2,331	2,331	2,331	2,331	2,331	2,331
3	Rasio (ρ) λ/μ	1.914	1.862	1.742	1.762	1.542	1.523	1.087
4	Panjang Antrian (Kend)	695.86	591.41	393.52	422.65	172.17	157.37	8.88
5	Waktu Rata-Rata Dalam Sistem (Jam)	0.832	0.708	0.472	0.507	0.209	0.191	0.013
6	Total Waktu yang Hilang (Kend-jam)	579.160	418.676	185.856	214.277	35.942	30.078	0.116
Total Waktu Hilang Per Minggu		**1,463.988**						**Kend-Jam**
Total Waktu Hilang Per Bulan		**5,855.953**						**Kend-Jam**
Total Waktu Hilang Per Tahun		**70,271.436**						**Kend-Jam**

Source: Calculation

4.3.Missing Time Value Due to Queue Effec

The value of lost time is the value of costs (in rupiah / hour / vehicle) that should not be experienced by vehicles or toll road users. The value of lost time is referred to as the amount depending on the time value in the year of analysis multiplied by the amount of time the vehicle is in the queuing system.The number of daily lost time values experienced by vehicles heading to the Cikupa toll gate due to the influence of the queue can be seen in the following table.

From the above data cumulative calculations of the value of time lost for one week, one month and one year as an economic impact can result from travel pending due to traffic barriers at the toll gate. The following is the accumulation of time lost due to the gate queue if no repairs are made until 2023.

Table 3. Accumulation of Missing Time Values

No	Tahun	Nilai Waktu Kendaraan / jam (Rupiah)	Lalu Lintas (Kend)	Nilai Waktu Hilang Rata-Rata (Rupiah) (Per Mingggu)	(Per bulan)	(Per Tahun)	Nilai Waktu Hilang Kumulatif (Rupiah)
	1	2	3	4	5	6	7
1	2018	77,401	26,651	2,062,842,000	8,251,367,999	99,016,415,983	99,016,415,983
2	2019	83,593	29,130	2,435,061,210	9,740,244,840	116,882,938,083	215,899,354,065
3	2020	90,281	31,839	2,874,443,655	11,497,774,619	137,973,295,430	353,872,649,496
4	2021	97,503	34,800	3,393,108,268	13,572,433,071	162,869,196,858	516,741,846,354
5	2022	105,303	38,036	4,005,360,724	16,021,442,895	192,257,314,739	708,999,161,092
6	2023	113,728	41,574	4,728,088,013	18,912,352,051	226,948,224,610	935,947,385,703

Source: Calculation

4.4. Analysis of Addition of Optimal Time Substance Lost

Increasing service capacity is not only to reduce queues, but also automatically reduce the loss of time value experienced by toll road users. Various reviews on various alternatives in increasing service capacity need to be carried out. The most traditional alternative is to increase the number of toll booths. The following is an analysis of the addition of the number of substations at the Cikupa toll gate from the original number of 7-door substations.

Table 4. Missing Time for Increasing the Number of Toll Stations

Tahun	Waktu Rata-rata yang Hilang Akibat Antrian di Gerbang Tol (Kend-jam) 7	8	9	10	11	12	13
1	2	3	4	5	6	7	8
2018	1574.5	605.7	225.7	84.9	35.9	24.0	10.9
2019	3010.5	1267.7	523.1	209.1	84.4	37.4	24.5
2020	5504.9	2493.8	1124.9	495.8	211.9	90.8	41.6
2021	9709.0	4663.4	2260.1	1086.0	509.9	232.4	105.0
2022	16627.6	8372.8	4296.2	2212.1	1127.7	562.7	273.0
2023	27795.8	14547.2	7813.5	4248.7	2312.2	1246.3	659.2

Source: Calculation

From the table above it can be seen that the more number of available substations, the less time lost due to the queue. While the greater the volume of vehicles entering the toll gate, the time lost due to the queue is greater.

4.5. Analysis of Service Costs in Adding Toll Gate Numbers

The following is the estimated cost of procuring 1 transaction substation service:

Table 5. Service Costs for Adding 1 Toll Gate Unit

Uraian	Biaya per Tahun	Sumber
Konstruksi Gardu		
- Gardu	1,500,000,000.00	Kontrak Pelebaran Gerbang Cikupa 2017
- *Canopy*	150,000,000.00	
- *Pavement*	3,000,000,000.00	
Toll Equipments	800,000,000.00	Kontrak Peralatan Toll
Gate Maintenance	450,000,000.00	Kontrak *Gate Maintenance*
Personil Operasional @ 3 orang	295,000,000.00	Data SDM 2017
Total	**6,195,000,000.00**	Asumsi Per Tahun
Biaya Pelayanan / Gardu	**17,401,685**	Asumsi Per Hari

Source: PT MargaMandalasakti Work Unit Data, processed

Service fees will certainly be greater along with the increasing number of transaction capacities and each item of cost will naturally experience price escalation in the years to come. The following in table 16 is the amount of service costs based on variables adding the number of service substations and years

Table 6. Service Costs for Adding Transaction Capacity

Tahun	Biaya Pelayanan (Rp) / hari						
	7	8	9	10	11	12	13
1	2	3	4	5	6	7	8
2018	121,811,798	139,213,483	156,615,169	174,016,854	191,418,539	208,820,225	226,221,910
2019	133,992,978	153,134,831	172,276,685	191,418,539	210,560,393	229,702,247	248,844,101
2020	147,392,275	168,448,315	189,504,354	210,560,393	231,616,433	252,672,472	273,728,511
2021	162,131,503	185,293,146	208,454,789	231,616,433	254,778,076	277,939,719	301,101,362
2022	178,344,653	203,822,461	229,300,268	254,778,076	280,255,883	305,733,691	331,211,499
2023	196,179,118	224,204,707	252,230,295	280,255,883	308,281,472	336,307,060	364,332,648
Total	**939,852,325**	**1,074,116,943**	**1,208,381,561**	**1,342,646,178**	**1,476,910,796**	**1,611,175,414**	**1,745,440,032**

Source: Calculation

4.6. Optimal Substation Analysis Based on Queue Costs in a 5 Year Period

Based on the results of the analysis and discussion of the value of lost time and service costs on adding toll booths, the results of the analysis of queue costs are summarized in the table below so that it can then be used as material to analyze and determine the optimal number of additional substations from 2013 to / in 2018

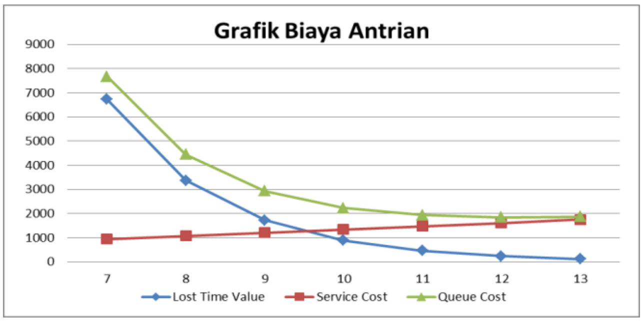

Figure 2. Queue Costs

4.7.Optimal Substation Analysis Based on Service Level Criteria

Here is the optimal substation analysis based on the service criteria table

Table 7. 5-year Planning Service Criteria

Tingkat Pelayanan	Panjang rata-rata antrian, L (kendaraan	Waktu rata-rata didalam sistem, T (detik/kendaraan)
A	≤ 1	≤ 15
B	$1 < L \leq 2$	$15 < T \leq 30$
C	$2 < L \leq 3$	$30 < T \leq 45$
D	$3 < L \leq 6$	$45 < T \leq 60$
E	$6 < L \leq 10$	$60 < T \leq 80$
F	> 10	> 80

Periode	Panjang Rata-rata Antrian	Waktu Rata-rata Dalam Sistem			Gardu ops
	L (Kend)	Tingkat Pelayanan	T (detik/kend)	Tingkat Pelayanan	
2013-2017	42	F	461	F	7
Setelah Peningkatan Kapasitas					
2018	6	D	62	E	9
2019	5	D	53	D	10
2020	4	D	49	D	11
2021	5	D	50	D	12
2022	5	D	53	D	13
2023	6	E	61	E	14

V. Coclusionn

Based on the analysis using a deterministic queuing model with queuing simulation it is found that an imbalance between the arrival volume and transaction capacity causes long and time-consuming queues, so the greater the ratio between the arrival volume per transaction capacity (ρ), the longer the queue and the more time wasted in the queue. For the time lost alone 1,463,988 vehicles-hours per week, 5,855,953 vehicles-hours per month and 70,271,436 vehicles-hours per year in.

The value of lost time experienced by toll road users, especially those passing the Cikupa toll gate in the year of Rp. 2,062,842,000, per week, Rp.8,251,367,999, per month and Rp. 99,016,415,983, per year. The losses experienced by road users will continue to increase every year in proportion to the growth in the volume of traffic flow to the Cikupa toll gate if there is no improvement in the service capacity at the toll gate..

Based on the analysis of the addition of optimal service (substation), the number of transaction service substations is very influential in reducing the length of the queue and the time value lost. However, the addition of as many transactions as possible is not the right solution in solving queuing problems because there are large service costs to be incurred. based on calculations using the theory of deterministic queuing simulations obtained the optimal number of substations in 2018 9 previously 7 substations.

VI. Sugestion

For PT MargaMandalasakti as the manager of the Tangerang-Merak road, it is better to re-evaluate the addition of toll booths both before and after the addition of the substation is operated by collecting data more thoroughly and comprehensively to prove the level of accuracy of the analysis in this study.

It is better for PT. MargaMandalasakti also conducts a feasibility study related to investment in the addition of the transaction substation to get a comparison of the real costs and benefits received by the company related to the investment.

For Toll Road Managers (PT MargaMandalasakti) and the government, related to the losses experienced by road users due to weak service systems at toll gates should be immediately addressed by increasing service capacity at toll gates by implementing technologies such as ETC and Multy system Lane Free Flow. The addition of toll gates in parallel, the separation of vehicle classes in order to minimize traffic slowdown due to disorderly large vehicles, as well as the diversion of toll gates which are less effective in solving problems of queuing at the gate in a comprehensive and prospectus manner

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