Determination of toll gate optimal number: A case study of Kertosono – Kediri toll road in Indonesia

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Abstract. The Kertosono-Kediri toll gate is currently under construction and operated in 2021. This toll gate is the entrance of vehicles that move from the industrial area of Mojokerto, Kertosono. For exit access this toll gate serves vehicles through the Maron Kediri toll gate, and the Sonoagung Pambon toll gate. If the toll booths operated are not in accordance with the amount of vehicle flow, it can cause poor vehicle traffic performance. The purpose of this study was to determine the optimal number of the gate in serving toll user transactions. The method in this study uses the number of optimal gate rules carried out by organizing data based on variable values and parameters traffic intensity per lane in the toll-gate section. These variables include the average number of vehicles received per hour and the average number of vehicles received per hour. Based on the analysis shows the number of toll booths for the Maron Kediri toll gate with 95 units/hour as many as 4 gates, 189 units/hour requires 8 gates, and 284 units/hour requires 10 gates. The Sonoagung Prambon toll gate with 118 units/hour as many as 4 gates, 236 units/hour requires 8 gates, and 353 units/hour requires 10 gates.

1. Introduction
The Kertosono-Kediri toll gate is currently under construction and is expected to operate in 2021. This toll gate is the entrance of vehicles that move from the downtown area of Mojokerto, Kertosono, and surrounding areas. For exit access, this toll gate serves vehicles that enter through the Maron Kediri toll gate and the Sonoagung Pambon toll gate. “Expressways in China make use of the toll-by-weight scheme, in which expressway tolls are collected based on the weight and traveling distance of the vehicle” [1].

The existence of the Kertosono - Kediri toll gate which is close to the Mojokerto industrial area, Kertosono, Kediri is predicted to make this toll gate experiencing a dense traffic volume during peak hours every day. This situation will certainly cause traffic congestion, given that the function of the toll road must provide services in the form of a smooth flow of vehicles without any significant obstacles. “Single-server queuing systems in order to determine queue length, user waiting time, and other statistics. Even though a more accurate representation of multiple queuing at toll plazas may be obtained by applying a multi-queue” [2]. Another factor that often causes congestion is the queuing process that occurs at the toll gate when processing at the toll gate toll road users are required to take an entrance ticket at the entrance gate and pay the appropriate toll tariff at the exit gate. “We study the traffic states
and jams occurring in traffic flow on a two-lane toll highway with electronic and manual (traditional) tollgates. The electronic and manual collection vehicles sort themselves into their respective lanes at low density, while they mix at each tollgate at high density” [3]. Thus, the length of processing at the toll gate greatly influences the smooth flow of vehicle traffic. If the toll booths operated are not balanced with the amount of vehicle flow, then the smooth flow of vehicle traffic can be disrupted. In other words, if too few substations are operated, it can cause a long queue of vehicles, but if too many substations are operated, it can cause high operating costs for the substation. This study aims to determine the number of Kertosono-Kediri toll booths as well as Gradually the Kertosono - Kediri toll gate section seeks to provide socialization and education to consumers to conduct transactions using electronic cards because it can reduce service processing time, a better data collection system, as well as efficiency and effectiveness of resources, compared to regular substations. “A system especially adapted for facilitating the collection of tolls on highways, includes the provision of exteriorly visible bar codes or other machine-readable customer account identifications, on vehicles using toll roads” [4]. However, at this time there are still many consumers who still choose to use regular toll service substations compared to automatic toll booths which make service processing times longer and cause vehicle queues to occur.

Vehicle queues that occur make the Kertosono - Kediri toll gate sections must use all available substations and resources to reduce the number of vehicle queues even though the use of all these substations cannot eliminate the vehicle queue completely. Besides the vehicle queue will also cause losses for consumers “describes the main outcomes of a study aimed at identifying, assessing and forecasting the effects of fuel prices and tax changes on traffic flows along with a 365 km toll motorway corridor project” [5].

The purpose of the Traffic Calculation Survey is to find out the amount and current traffic in the study area by counting the number of vehicles of various types that pass a certain road. “Improving the knowledge of demand evolution over time is a key aspect in the evaluation of transport policies and in forecasting future investment needs”[6]. Survey Locations Adjusting the traffic modeling needs, traffic count survey locations are generally placed in locations that affect the amount of traffic estimated to pass through the Kediri-Kertosono toll road. Besides that, the location of the traffic count survey (TC) is also placed on the screen line, according to the traffic zone system used. The main purpose of the traffic survey is to collect basic data relating to the volume and characteristics of traffic on the road that will have an impact on the work of the Kediri-Kertosono toll road.

2. Methods

Queueing analysis method so that the calculation results of variables such as the probability of busyness, “The method also comprises determining a multiplier value based on the capture rate of the toll location” [7]. Probability of vehicles in the system will be known absence, the average number of vehicles in the system, average time spent each vehicle in the queue or being serviced in the system, the average number of vehicles waiting in the queue, the average time spent by each vehicle waiting in the queue. Relationship intensity of traffic per lane on toll gates. “This distribution depends on the three fundamental variables, speed, flow and density, and on which section is considered (near or far a toll-gate)” [8].

\[ \mu = \frac{b}{a s s} \]  

\( \mu = \text{traffic intensity per lane (}\mu > 1\text{, then the queue of vehicles at the toll gate)} \)

\( b = \text{average service time (seconds)} \)

\( a = \text{average arrival interval (seconds)} \)

\( s = \text{number of lanes or toll booths} \)

In this context, information about the needs and characteristics of existing traffic will be obtained through the collection of survey data in the field, namely a traffic count survey; counting the volume of traffic in the observation sections for 2x24 hours in 4 survey locations. Intersection Count Survey; traffic
volume calculation in the observation sections for 2 days in 4 survey locations, especially at peak hours. Travel Time Survey; observing vehicle speed in 3 travel routes for 2 days. “In addition to those detectors used for location detection at the Maut boundaries, a number of other detectors are used therefor detecting the respective vehicle Speed, significant deviations from a reference Speed value leading to an increase in the toll” [9]” The location of the intersection counting survey is shown in Table 1.

| No  | Survey Location          |
|-----|--------------------------|
| TC-01 | Adipura Roundabout        |
| TC-02 | Mengkreng Intersection    |
| TC-03 | Papar Intersection        |
| TC-04 | Kediri Intersection      |

A traffic count survey is conducted at each determined survey post. Each vehicle that crosses the survey post is recorded according to the type of vehicle and the hourly traffic volume of each type of vehicle is calculated. The survey method applied is to calculate the volume of vehicle traffic (cross-sectional vehicle traffic count) according to the type of vehicle that is carried out using a manual counting tool for vehicles that pass the observation point. The survey was conducted for 2 days; each for 6 hours per day. “The prediction is structured into three levels: trend prediction for all calendar days in the year, long-term prediction for the current day and short-term prediction for the next hour. The error of long-term prediction was less than 15% per hour over the whole day” [10].

Survey Locations Adjusting the traffic modeling needs, traffic count survey locations are generally placed in locations that affect the amount of traffic estimated to pass through the Kediri-Kertosono toll road. Besides that, the traffic count survey location is also placed on the screen line, according to the traffic zone system used. The traffic counting survey team for each shift will consist of 1 supervisor and around 4-8 surveyors depending on the amount of traffic observed. The task of each person is the supervisor who is the field coordinator at each survey post location, supervises all surveyors at his post, is expected to be able to prepare the survey continuity requirements at the location, collect and recapitulate the survey results, regulate the smoothness and readiness for conducting the survey. “We collected survey data before and after tolls were implemented or removed and supplemented them with data from traffic counts and other sources. We find a mean short-run elasticity at 0.45 and a mean long-run elasticity at 0.82. Further, elasticities seem to vary with the characteristics of projects, e.g. road type, project location, etc” [11].

Surveyors who are executors of activities at each survey post location are generally recruited at the local survey post location, tasked with collecting data / carrying out traffic calculations in accordance with the provisions that have been given and providing survey results to the supervisor. Travel Time Survey (Travel Time Survey) is to obtain information on the average travel speed of vehicles that pass a certain road so that it can describe the current traffic conditions as input for making a model of “speed-flow relationship”. “Research efforts have been focused on the indirect estimation of road travel times, using the fundamental traffic variables, primarily each vehicle’s speed observed at discrete points in the freeway” [12]. Within the scope of the Travel Time Survey, the activity carried out is recording the time required by the average vehicle to travel on certain routes using GPS. “Toll data (including both ETC data and MTC data) could provide the vehicle ID, entering/ exit toll station and corresponding passing time of this vehicle, as well as the vehicle type” [13].

The survey location was chosen that can represent the existing traffic conditions with observation time of 2 days, namely at peak hours in the morning, afternoon and evening. Travel speed survey on each route is conducted on 2 working days, and holiday for each survey route.
3. Results and discussion
Graphs of fluctuations in the movement of traffic volume in passenger car units per hour (unit/hour) on weekdays and holidays that can represent traffic volume during peak hours (Peak Hour) on the Kertosono-Kediri road can be seen in the following figure 1 and figure 2.

**Figure 1.** Fluctuations traffic flow in Kediri-Nganjuk road (direction of Kediri-Nganjuk working day).

**Figure 2.** Fluctuations traffic flow Kediri-Nganjuk road) (Direction of Kediri-Nganjuk working day).

Based on the figure 1 can be analyzed as follows, the direction of Kediri to Nganjuk holidays. The total volume at peak hours occurs in the afternoon which is around 17:00 - 18:00 amounted to 427 units/hour. The Nganjuk direction to Kediri is a holiday. The total volume at peak hours occurs in the morning, which is around 08.00 - 09.00 at 925 units/hour. Direction Kediri to Nganjuk weekdays. The total volume at peak hours occurs in the afternoon which is around 15:00 to 16:00 at 445 units/hour. Direction Nganjuk to Kediri weekdays. The total volume at peak hours occurs during the day, which is around 13.00 - 14.00 at 460 units/hour. Growth of LV, HV, and MC vehicles, Kediri regency can be seen on Table 2.
Table 2. Growth of LV, HV, and MC vehicles, Kediri regency.

| No. | Vehicle Type | Years | 2013 | 2014 | 2015 | 2016 |
|-----|--------------|-------|------|------|------|------|
| 1   | Truck        |       | 8.555| 8.254| 8.928| 9.671|
| 2   | Bus          |       | 349  | 382  | 455  | 560  |
|     | % Heavy Vehicle Growth | -3,009 | 8,650 | 9,038 | 8,84 |
| 3   | Jeep         |       | 1.159| 1.124| 1.189| 1.283|
| 4   | Sedan        |       | 2.271| 2.022| 2.081| 2.148|
| 5   | Colt-STWG    |       | 13.339| 14.526| 16.195| 18.590|
|     | % Light Vehicle Growth | 5,385 | 10,146| 13,131 | 11,64 |
| 6   | Motor Cycle  |       | 33.983| 332.739| 332.613| 354.478|
|     | % Motor Cycle Growth | 5,047 | 3,059 | 6,574 | 11,53 |

Source: Kediri Regency in Figures

3.1. Traffic intensity per lane of maron Kediri gate
Data on the number of vehicle arrivals at the Maron Kediri toll gate queue can be analyzed by determining the optimal number of toll booths with variable models and queuing parameters determined by two factors, namely \( \mu = \) traffic intensity per lane \((\mu > 1, \text{ so the queue of vehicles at the toll gate})\), \( b = \) average service time (seconds), \( a = \) average arrival interval (seconds) \( s = \) number of lanes or toll booths.

“the vehicle enters into the entrance of a toll road and data obtained from the onboard unit mounted on the vehicle as the entrance passing data and the data showing that the vehicle exits from the exit of the toll road” [14].

The queues that occur at the Maron Kediri toll gate produce traffic intensity in the lane with the assumption that modeling of 25% vol inbound traffic entering the toll road requires 4 toll gates (2 directions), 50% vol in traffic entering the toll road requires 7 toll gate (2 directions), 75% of traffic volume entering the toll road is required 10 toll gates (2 directions). More can be seen in the following table 3.

Table 3. Traffic intensity per Maron Kediri toll gate lane.

| a   | b    | s    | \( \mu \) |
|-----|------|------|------|
| 0.635 | 2 second | 4      | toll gate | 0.788 |
| 0.317 | 2 second | 7      | toll gate | 0.9   |
| 0.212 | 2 second | 10     | toll gate | 0.945 |

Traffic volume of Maron Kediri toll gate = 378 pcu / hour in 2021 = 95 units / hour, 50% = 189 units / hour, 75% = 284 units / hour.

3.2. Traffic intensity per lane toll gate Sonoagung Prambon
The queues that occur at the toll gate produce traffic intensity in the lane with the assumption that modeling of 25% vol inbound traffic entering the toll road requires 4 toll gates (2 directions), 50% vol in traffic entering the toll road requires 7 toll gate (2 directions), 75% of traffic volume entering the toll road is required 10 toll gates (2 directions). More can be seen in the following table 4.

Traffic volume Sonoagung Prambon toll gate = 471 pcu / hour in 2021 = 95 units / hour, 50% = 189 units / hour, 75% = 284 units / hour.

Table 4. Traffic intensity per Sonoagung Prambon toll gate lane.

| a   | b    | s    | \( \mu \) |
|-----|------|------|------|
| 0.51 | 2 second | 4      | toll gate | 0.981 |
| 0.255 | 2 second | 8      | toll gate | 0.981 |
| 0.17 | 2 second | 12     | toll gate | 0.981 |
4. Conclusion

Based on observations of traffic surveys predicted in 2021 when the Kertosono - Kediri toll gate operates, the results of the analysis with the variable model and queuing parameters show that the number of Maron Kediri toll gates with 95 units/hour is 4 gates, 189 units/hour as many as 8 gates, and 284 units/hour requires 10 gates. While the Sonoagung Pambon toll gate prediction with 118 units/hour is 4 gates, 236 units/hour is 8 gates, and 353 units/hour requires 10 gates.

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