Predicting Queues and Delays at Toll Plazas by Computer Simulation
(Case Study: Cililitan Toll Plaza, Jakarta)

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Abstract—**Toll plazas are bottlenecks on toll roads. The predictions of queues and delays at toll plazas, therefore, are very important. A computer simulation model has been developed and has been implemented to predict the queues and delays at Cililitan Toll Plaza, Jakarta. The results have been compared to actual results at the site. It is concluded that there is no significant different between the simulation and actual results.**

Index: **delay, toll plaza, queue, simulation**

I. INTRODUCTION

Queues and delays at toll plaza may be predicted by the use of empirical, mathematical and simulation approaches. Empirical models attempt to predict queues and delays on the basis of past observations, whereas in the mathematical approach, vehicular queues and delays are calculated in terms of the traffic flow parameter relationships. Both mathematical and empirical models have limitations in their use. Traffic flow is such a complex phenomenon that even the most complex mathematical model has to adopt a macroscopic approach in that all vehicles and drivers generally have the same characteristics. An empirical model would require a considerable amount of data for its calibration and its often very difficult to obtain these data with the precision, in the quantity or the required traffic volume levels. Often the traffic volumes required may not persist enough for sufficient observations to be obtained [1].

In contrast, a simulation model can be flexible enough to cover a wide range of highway and traffic conditions. Input to the model can be specified to any distribution and the form of traffic control and driver characteristics varied. Simulation time may be as long as desired and several figures of merit may be printed out during simulation process. A simulation model requires the formation of a model system which represents the real situation at the site being studied. This model has, therefore, been developed by many researchers in the recent years, such as Tian et al [2].

II. METHODOLOGY AND ANALYSIS

A. Methodology

Flow chart of the simulation is shown in Figure 1.
The simulation program contains:
1. Data inputting system
   a. Traffic data: traffic counting data
   b. Percentage of each type of vehicles.
   c. Average service time at toll plaza
2. Random generator.
   To generate random numbers to be used for simulation, i.e.: vehicle time arrival at toll plaza, vehicle type and service time at toll plaza.
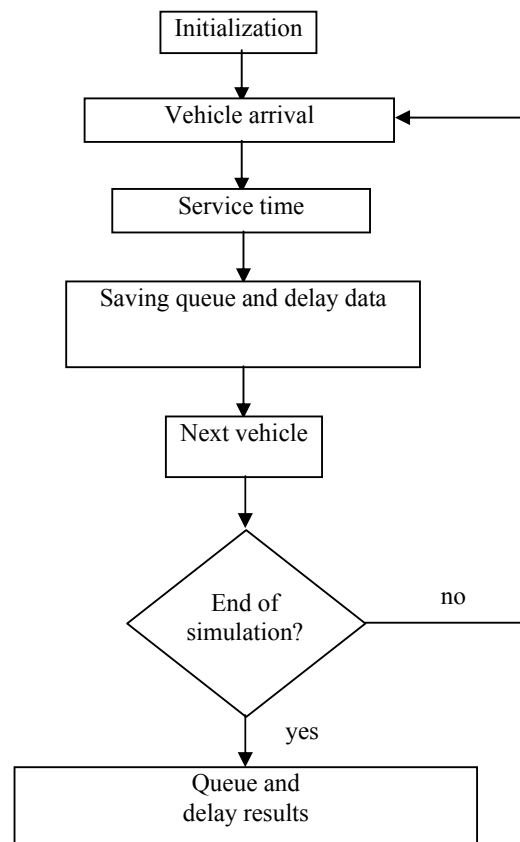

Figure 1. Simulation Flow Chart

A simulation model requires the formation of a model

system which represents the real situation at the site being studied. Two forms of simulation can be used: analog simulation and digital simulation. In analog simulation, an analogy is made between the real world situation and an analog physical system. In digital simulation, the state of simulated system is stored in digital form and the situation is updated in accordance with stored instructions or rules of the model. Digital simulation has been used for this model. In traffic simulation, the system can be updated in two ways, by regular time scanning or by event scanning. For this simulation, event scanning, i.e.: vehicle arrival time, has been employed. The program has been developed by using Borland Delphi.

Vehicle can be divided into four types, i.e.:
a. light vehicle (4 meter length)
b. heavy vehicle (8 meter length)
c. semi trailer (12 meter length) and
d. trailer (16 meter length).

Distributions to be used for this simulation are as follows:
a. exponential distribution for vehicle arrival
b. uniform distribution for vehicle type
c. normal distribution for service time at toll plaza.

These types of distribution have been chosen by using trial and error method by comparing distribution results and the real condition in the fields.

To generate uniform random number, multiplicative congruent method has been used. The formula to generate random number is shown below [3]:

$$Z_i = Z_{i-1} \ \text{mod} \ (m) \tag{1}$$

with
Z_i = the ith random number
Z_{i-1} = the (i-1)th random number

The initial random number has been determined according to Moshman [4].

To generate exponential random number, the formula is shown below:

$$h = - \ln (Z)/q \tag{2}$$

with
h = headway between vehicle arrival (second)
Z = generated uniform random number
q = traffic flow (vehicle/second)

The following steps are used to generate normal distributed random number [5]:

1. Generate 2 uniform random numbers which are independent each other (Z_1 and Z_2).
2. $w1 = (2 \ x \ Z_1) - 1 \tag{3}$
3. $w2 = (2 \ x \ Z_2)) - 1 \tag{4}$
4. $w = (_{w1})^2 + (w_2)^2 \tag{5}$
5. If $w \geq 1$, generate again 2 random numbers, determine again w_1, w_2 and w.
6. If $w < 1$, determine:
    $c = \{- 2 \ln (w)/w\}^{0,5} \tag{6}$

$$z = c \ x \ w \tag{6}$$

7. Normal random number = average value +
    {z x variant x (average value)}

At the end of the simulation, the last generated random number will be used as the initial random number for the next simulation. Therefore, for each simulation run, the results will be different.

Surveys have been carried out at Cililitan Toll Plaza, Jakarta (see Figure 1 and 2).

Figure 1. Vehicle Arrival at Cililitan Toll Plaza, Jakarta
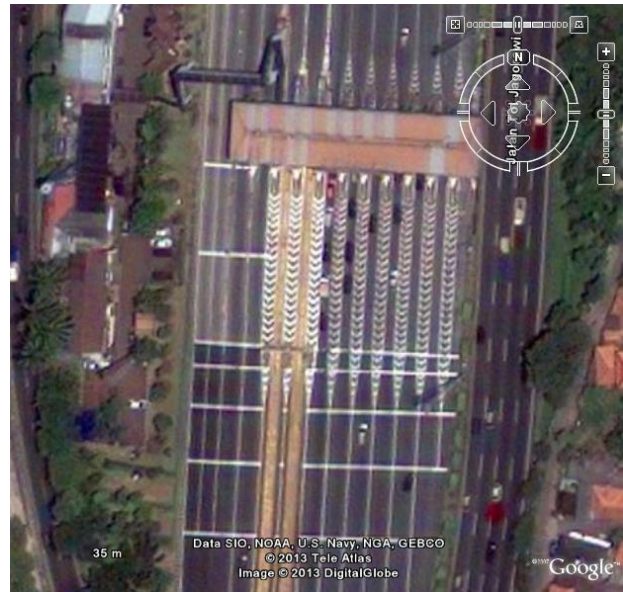

Figure 2. Layout of CililitanToll Plaza, Jakarta

Video recording technique has been employed to measure:
a. traffic flow,
b. vehicle time arrival,
c. vehicle type,
d. service time at toll plaza,
e. exit time and
f. queue length.

The results have been divided into 6 time intervals
An example of the results, for 3 time intervals, are shown in Table 1.

Table 1. Example of Survey Results at Toll Gate No. 2

Description		Time interval		
		I	II	III
Traffic Flow (Vehicle)		86	75	68
Service time (second)		3.425	3.340	4.113
Total delay (second)		3444	1796	1437
Average delay (second)		40	23	21
Average queue (m)		29	18	13
Max queue (m)		44	44	28
LV	Number	70	63	61
	%	81	84	90
	Av. moving time (seconds)	3.5	3.7	3.6
HV1	Number	11	8	5
	%	13	11	7
	Av. moving time (seconds)	4.8	5.2	4.8
HV2	Number	5	3	2
	%	6	4	3
	Av. moving time (seconds)	6.1	7.5	6.3
HV3	Number	0	1	0
	%	0	1	0
	Av. moving time (seconds)	0	9.7	0

Note:
LV   = light vehicle
HV1 = heavy vehicle
HV2 = semi trailer
HV3 = trailer

The data to be inputted into the simulation computer program are as follows:
    a.   The number of vehicles at time interval.
    b.   Service time.
    c.   Simulation time.
    d.   Interval queue length.
    e.   Vehicle data.
When the data is ready, press "Calculate" button to run the simulation process and it will be shown on the output data as in Figure 3.
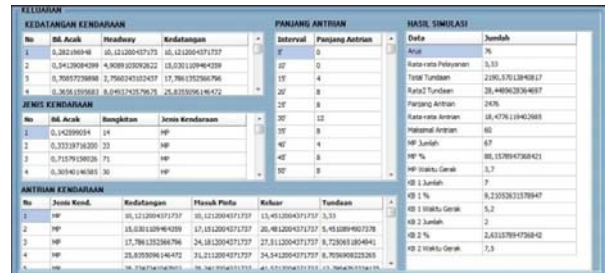

Figure 3. Computer Simulation Display

The simulation results are divided into five sections as follows:
    a.   Vehicle arrival time,
    b.   Vehicle type,
    c.   Vehicles in queue:
        1) Vehicle type.
        2) Arrival time.
        3) Time to enter the gate.
        4) Exit time from toll gate
        5_ Delay time
    d. Queue length and delay for each interval

B. Analysis

The simulation has been run for many times. A comparison of three simulation results (Sim1, Sim2 and Sim3) and survey data at Gate 2 are shown in Table 2 and 3. Table 2 shows the comparison of delay, and Table 3 shows the comparison of queue length. Chi squared method has been employed for statistical comparison analysis.

Table 2. Comparison of Delay at Gate 2

Average delay (seconds)							
Interval	Survey	Sim1	Sim2	Sim3	X^2_1	X^2_2	X^2_3
I	40	33	29	47	1.09	2.89	1.12
II	24	27	30	26	0.52	1.78	0.25
III	21	25	23	25	0.68	0.15	0.77
IV	31	38	35	40	1.68	0.44	2.38
V	12	19	18	17	4.64	2.52	2.29
VI	14	20	18	16	2.00	1.17	0.22
X^2 calculated					10.59	8.95	7.03
X^2 from statistical table					11.07	11.07	11.07

Table 3, Comparison of Queue Length at Gate 2

Average Queue Length (meters)							
Interval	Survey	Sim1	Sim2	Sim3	X^2_1	X^2_2	X^2_3
I	29	25	23	36	0.61	1.58	1.49
II	18	20	21	20	0.20	0.64	0.26
III	13	16	14	16	0.56	0.04	0.58
IV	21	26	23	26	1.24	0.25	1.10
V	9	14	11	12	2.78	0.74	1.01
VI	11	13	13	11	0.49	0.47	0.04
X^2 calculated					5.88	3.73	4.48
X^2 from statistical table					11.07	11.07	11.07

It is shown that there is no significant different between the simulated results and the survey data.

III. CONCLUSION

It is concluded that this simulation computer program can be used to simulate the traffic flow at toll plaza. There is no significant different between the simulation results and the actual results. However, it would be better to run the simulation many times (at least three times) and use the average as the final result.

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