THE PREDICTION OF QUEUE LENGTHS AND DELAYS AT A U-TURN

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Abstract: An empirical study was carried out to investigate queue lengths and delays at a U turn of a busy street in Surabaya. The intention of the study was to predict appropriately of queue lengths and delays at U-turns that are mostly found on busy streets in Indonesia. This is because the western formulae for queue lengths and delays do not always suitable for traffic conditions in Indonesia, due to traffic composition and driver behavior are markedly different from those in western countries.

The results of the study vindicate that the queue length and delay prediction can be approached by Tanner formula (1962) with slightly modification, and hence an appropriate formula can be derived for queue lengths and delays of the Indonesian traffic conditions.

Keywords : queue lengths, delays, U-turn

1. INTRODUCTION

Locating U-Turn facility as a strategy to maintain intersection performance is an urgent need in its relation to traffic management to be applied. Problems emerge when the volume of main flow and turning flow increases resulting in delay and queue of vehicle which will make at a U-turn. Therefore, the objective of this study is to find out how far the method for calculating delay at non-signaled intersection developed by Tanner (1962) can be applied, and to find out the model of delay and queue of turning vehicle at a U-turn facility.

Highway transport infrastructure consists of road section and intersection, and the efficiency of road network is very much influenced by its intersection performance. An intersection may be either at-grade or non-at-grade. Better organization of intersection can be achieved through good traffic management, one of which is the application of forbidding vehicles to make right turning. The consequence of this regulation is the need for providing a U-turn location on road sections. Meanwhile, intersection's performance can be observed from whether or not there is high volume of vehicle's delay and queue at a particular time-interval. This delay and queue may result from the existing traffic volume, U-turn geometry, and the existing priority system. This research aims to find out how far the method of delay calculation at non-signaled intersection developed by Tanner (1962) is applicable at a U-turn, and to formulate an empirical model on delay and queue of vehicle turning the opposite direction at a U-turn.

The following presents the equation model as a further review of Tanner's model (1962).

$$w_2 = \frac{1/2\,E(y^2)/Y + q_2 Y \exp(-\beta_2 q_1)(\exp(\beta_2 q_1) - \beta_2 q_1 - 1)/q_1}{1 - q_2 Y (1 - \exp(-\beta_2 q_1))} \quad (1)$$

$$Y = E(y) + 1/q_1$$

In which :

$$E(y) = \frac{\exp(q_1(\alpha - \beta_1))}{q_1(1 - \beta_1 q_1)} - \frac{1}{q_1}$$

v = gap rate at main flow received by drivers at miner flow when entering main flow.
q_1 = main flow (opposite direction)
q_2 = turning flow
β_1 = minimum headway time of main flow
β_2 = minimum headway time of turning flow.

Tanner's equation model (1962) was at first used to analyze delay at a non-signaled intersection. From this formula, it can be seen that the volume of delay will be influenced by the amount of direction and gap from traffic flow that arises. This empirical study aims to try out whether or not the equation model is suitable for analysis at a U-turn facility.

2. RESEARCH METHOD & DATA COLLECTION

This research focuses on the analysis on field observation findings on the smoothness of turning traffic flow. It puts these findings into a model following Tanner's model, and makes an evaluation based on a statistic test in order to draw a conclusion whether or not this model is suitable.

The research makes the validation of Tanner's result by rate value comparison and independence test (Hay's, 1981). Then, it compares the result with the observation while conducting fine-tuning using statistic test.

The empirical model to be developed consists of linear regression and linear transformational regression; the dependent variables are delay and queue, and the independent variable is turning flow. It uses t-test, F-test and correlation among variables to evaluate the model.

The primary data include those seven variables, which are divided into variables for the analyzed model, and for observation variables (delay and queue). The field observation uses video camera, and for data transcription process to obtain acceptances gap variable, it uses several aiding program developed by Priyanto (1995). For the other variables, it uses manual process. It derives the data from a U-turn facility on Jalan Sungkono, Surabaya, which has three lanes with a volume rate of 600 vehicles/hour/lane as depicted in Figure 1.

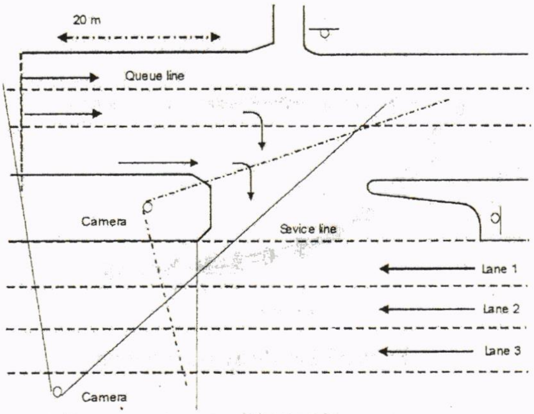

Figure 1. Research Location

3. DISCUSSIONS

3.1. Headway Distribution Test

The data show that headway on the main flow, which consists of 3 lanes, has different distributions. Result of the test using Chi-square with Poisson theoretical distribution indicates that headway of lane 1 and 3 has a Poisson's distribution, which can be negative exponent when t=0

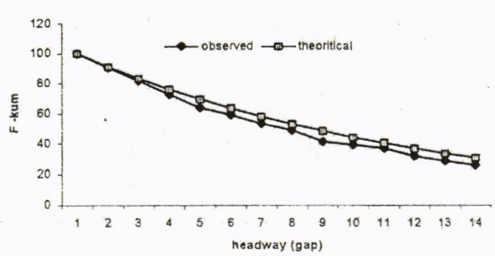

Figure 2 Headway Distribution.

Lane 2 (center) of the main flow has a headway distribution following Erlang's Distribution, which can be negative exponent when k=1. This headway test result suggests preference of the vehicle passing on the main flow to move onto lane 2 (center) to avoid the possibility of conflicting with traffic flows from accesses along the main road.

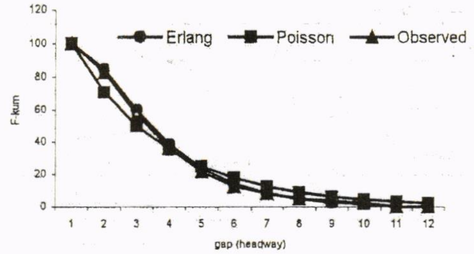

Figure 3 Headway Distribution

This figure shows that the existing (observation) headway distribution is close up the line of Erlang's distribution, while it is less so with the Poisson's.

3.2. Validation and Calibration of Tanner's Model (1962)

Validation is done by repeating (3 times) each Tanner's model calculation result with the same input variables. The F-test result shows that each repetition result gives no different rate, and similarly the result from the independence test using orthogonal method. Some descriptive statistic values from each repetition also reveal that the rate of all Tanner's result repetition is not significantly different.

Table 1 Tanner's Result Validation

Lane	repetition	1	2	3
1	Mean	1.919	2.148	1.958
	Deviation standard	0	0.4147	0.548
	n	12	12	12
2	Mean	2.089	2.238	2
	Deviation standard	0.648	0.6303.	0.4714
	n	12	12	12
3	Mean	2	2.955	2.874
	Deviation standard	1.348	1.725	1.313
	n	12	12	12

This table presents that the average value of the 1st, 2nd, and 3rd running is not different from the deviation standard, i.e. between 0.4147 – 0.548.

From the analysis result, it shows that Tanner's model result is, in general, lower than the regression result. This is translated into the amount of regression constant obtained from that relation. This relation analysis will give a value that tells how far Tanner's result will differ from observation result.

Table 2 Relation of Model Delay and Observation

Turning vehicle	Main lane flow	Relation model	R^2	$T_{calculation}$
Light vehicle	1	Y = 0.37418x	0.71	16.19
	2	Y = 0.2718x	0.79	20.3
	3	Y = 0.5594x	0.63	13.58
Heavy vehicle	1	Y = 0.09x	0.77	19.4
	2	Y = 0.253x	0.86	25.71
	3	Y = 0.179x	0.69	15.6

T table value is calculated with a 95% reliability level, i.e 3.93. The independent variable is delay from observation result, and the dependent variable is delay from Tanner's result. Thus, the table tells that within the existing relation, Tanner's result is lower than observation result as indicated by the regression constant, which is less than one. The above result also shows that Tanner's result is lower than the delay and queue of observation result; the range of difference varies from one relation to the other. Basically, however, it is lower than the observation result.

Table 3 Relation of Model Delay and Observation

Turning vehicle	Main lane flow	Relation model	R^2	$T_{calculation}$
Light vehicle	1	Y = 0.065x + 0.95	0.146	3.05
	2	Y = 0.379x + 0.1205	0.105	3.5
	3	Y = 0.1912 + 0.1259x	0.1	3.23
Heavy vehicle	1	Y = 0.0119 + 0.0027x	0.1	2.12
	2	Y = 0.034 + 0.0069x	0.108	2.32
	3	Y = 0.024 + 0.0051x	0.103	2.07

From this table, it shows that although the R^2 value from the resulting relation is relatively low, the F-test value of all relation is relatively high. Using the queue from observation result as independent variable, the study finds out that Tanner's result is lower than the observation result.

The following stage is calibration, which is made to obtain a factor by fine tuning, i.e. using t test. The following table presents the result.

Table 4 Calibration t-test result.

Model result	Lane 1	Lane 2	Lane 3
Delay of light vehicle lane	- 1.64	- 1.38	- 1.51
Delay of heavy vehicle lane	- 1.27	- 1.44	- 1.1
Queue of light vehicle lane	- 1.78	1.72	- 1.51
Queue of ligh vehicle lane	- 1.83	- 0.08	1.14

This table shows that when constant factor unit is used, Tanner's result will be not significantly different from the observation result, in a 95% reliability level.
Table 5 and 6 present The constant units produced from fine tuning process.

Table 5 Constant Unit for Delay Result

Turning vehicle	Main flow lane	The Constant
Light Vehicle	Lane 1	Ln (31.99567 x Ljr_1)
	Lane 2	Ln (41.955 x Ljr_2)
	Lane 3	Ln (24.9 x Ljr_3)
Heavy vehicle	Lane 1	Ln (4800 x Ljr_1)
	Lane 2	Ln (1336.9765 x Ljr_2)
	Lane 3	Ln (2450 x Ljr_3)

Note: Ljr-1 – so on = Data from Tanner's results.

The constant tells that Tanner's result is lower than observation result, and this is in accordance with the phenomenon from the equation of relation of Tanner's result and observation model previously discussed.

Table 6 Constant for Queue Result

Turning vehicle	Main flow lane	The Constant
Light Vehicle	Lane 1	Log (56.25 x Ljr_1)
	Lane 2	Ln (37.5 x Ljr_2)
	Lane 3	Log (100.2 x Ljr_1)
Heavy vehicle	Lane 1	Log (525 x Ljr_1)
	Lane 2	16.75 x Ljr_2
	Lane 3	20 x Ljr_3

3.3. Empirical Model

Regression model is used to find out relation between independent and dependent variables. This research uses two regression methods: linear and exponential. Turning vehicle flow variable is regressed against turning vehicle delay and queue (dependent variable) with a 95% reliability level. The selected model is linear regression.

Table 7 Selected Model

Variable relation	Model	Equation	R^2
Light vehicle queue (y) – q2 of light vehicle (x)	Linear	Y = 0.05754 x	0.756
Light vehicle delay (y) – q2 of light vehicle (x)	Linear	Y = 0.06315 x	0.880
Heavy vehicle queue (y) – q2 of light vehicle (x)	Linear	Y = 0.07759 x	0.869
Heavy vehicle delay (y) – q2 of light vehicle (x)	Linear	Y = 0.144	0.468

On the first model, the queue of turning light vehicle increases as the volume increases, whereas on the second model, an increase of delay happens when the volume increases. The third model is an interesting phenomenon where heavy vehicle delay is influenced by the volume of turning light vehicle. This can be explained regarding the geometry of the existing U-turn: it has only one server while there are two approaching lanes of turning. It makes heavy vehicle delay influenced by light vehicle which enters the server simultaneously with heavy vehicle.

3.4. Variant Analysis and Significance Test.

The selected model is the model with the highest suitability and ability to describe relation among variables significantly. The significance of regression coefficient (bi) can be known from the t-test and F-test. When t calculation value is higher than that of t table, or when regression coefficient is less than 0.05 (with a 95% reliability level), the null hypothesis is rejected, meaning that bi =/ 0. Table 8 presents the significance test result of the selected model.

Table 8 Significance Test Result of the Selected Model

No.	T_{test}			F_{test}	R^2	Ajs. R
	T_{count}	T_{table}	$F_{significant}$			
1	18.2	1.66	0.0000	0.05	0.756	0.753
2	28.119	1.66	0.0000	0.05	0.88	0.879
3	26.715	1.66	0.0000	0.05	0.869	0.868
4	9.705	1.66	0.0000	0.05	0.468	0.463

4. CONCLUSIONS

The following presents some conclusions drawn from field research performed at a U-turn facility on Jalan Sungkono, Surabaya.

1) Validation process of Tanner's Model gives a fact that there is no significance among the first to the third running models of each lane; the average values are: lane 1=2, lane 2=2.2, and lane 3=2, all at a deviation standard of 0.5 second. This suggests that Tanner's Model (1962) which was developed for vehicle delay and queue analysis at non-signaled intersection can be applied at a U-turn facility.
2) The Rate of light vehicle delay on approaching lane is 6.27 second/vehicle, while that of heavy vehicle is 9.55 second/vehicle. Queue happens when the most front vehicles, that are about to turn the opposite direction, are driven by too careful drivers that they reject gap many times. This phenomenon appears every 5 minutes during the observation period, happening on two light vehicles. On approaching lane for heavy vehicle, the situation is different, owing to the geometry of the facility where it lacks space to accommodate the whole length dimensions of vehicle which is waiting for making a U-turn. Consequently, the delay increases although the queue remains low.

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