QUEUE LENGTH PREDICTION FOR MIXED TRAFFIC

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Abstract

The characteristics of traffic in large cities in Indonesia can be described that the major intersections have very high flows during the day with no pronounced directional peak and often with 50% or more traffic turning. The vehicle types are not dissimilar to those in developed world, however the vehicle mix contains a much higher proportion of motor vehicles and non motorised vehicle, and driving standards are markedly different.
The implication of that condition is that to tackle congestion needs a special technique. Among these is the prediction of queue length for mixed traffic as introduced in this paper. Research was carried out by collection data of more than 500 signal cycles in Yogyakarta to investigate queue lengths. Queues with mixed traffic composition were extensively analysed to develop queue length predictions. The results could be used for queue length predictions by considering traffic composition such as the percentage of large vehicles.

I. INTRODUCTION

One of the main traffic problems in urban areas and their surroundings is the occurrence of oversaturation at traffic signals. Traffic flow is vulnerable to disruption, therefore when a traffic signal is oversaturated, queues of traffic build up behind the signalised intersection. The effect is then potentially quite serious: if flow exceeds the capacity considerable congestion is inevitable, resulting in excessive delay.

The cause of oversaturation at traffic signals can be seen as twofold; firstly, congestion is caused by the enormous traffic demand compared to the signal capacity, secondly, it is caused by an incident occurring in the traffic signal area which causes signal capacity decreases significantly.

In Indonesia, although this congestion may not last very long, it nevertheless does occur fairly often. For current conditions, congestion does not only happen in a metropolitan city like Jakarta as other cities in the developed world, but also spread out in other large cities like Medan, Bandung, Semarang, Yogyakarta, Surabaya and Ujung Pandang.

To cope with such problems this research aims to investigate queue length formation as part of traffic congestion, and therefore the result could contribute in congestion management. This is because the current technique in queue length analysis is still based on a vertical queue (express in number of vehicle) rather than a horizontal queue (express in metres) and resulting unrealistic values out coming unrealistic result.

2. PARAMETER DEVELOPMENT

2.1. A queue

To avoid problems that occur when drivers decrease speed slowly when approaching traffic lights, thus causing a slowly moving queue to develop, only those queues with all vehicles stationary were considered as falling within the definition, for the purpose of this analysis.

2.2. Unit queue length

Preliminary observations of traffic queuing at traffic signals showed that drivers stopped at widely varying distances from the stopline. The queue length was therefore defined as the distance between the stopline and the back bumper of the last vehicle in the queue. A parameter l_v, a unit of queue length is then defined as follows :

$$l_v = \frac{\text{total queue length (in metres)}}{\text{number of vehicles in the queue}}$$

$$l_v = \frac{L}{N_v} \text{ metres per vehicle}$$

The parameter l_v, however, is dependent on the composition of the vehicles making up the queue, thus it is important to understand the effect of there being different types of vehicles in a traffic stream. It would be convenient if the pcu values (Webster 1961, 1961a, 1962 and Holroyd 1962), for vehicles moving through junctions controlled by traffic signals were applicable to vehicles in a stationary queue. In order to investigate this, a similar parameter l_p is defined :

$$l_p = \frac{\text{total queue length (in metres)}}{\text{number of vehicles in the queue (in pcu)}}$$

$$l_p = \frac{L}{N_p} \text{ metres per pcu}$$

This definition of l_p assumes that each equivalent pcu length has a gap l_g metres associated with it, i.e. a long vehicle with a pcu equivalent of 1¾ has associated with 1¾ units of gap length compared with a passenger car (pcu = 1.0) with 1 unit of gap. If the l_p value, defined in this way, exists such that it is independent of the composition of the traffic queuing, then the total queue length can be established conveniently by multiplying l_p by the number of 'traffic signal' pcu's in the queue. This is a computationally attractive method for estimating the horizontal queue. However, by inference, the pcu equivalents associated with stationary queues are different from those for traffic moving through a signalised junction. This is because the definition of l_p (above) assumes that the pcu gap length l_g increases proportionately with the pcu value, an observation, which may not necessarily be true in all cases.

Likewise, l_v will vary according to the composition of the traffic stream, l_v and l_p are both affected by driver behaviour which is responsible for variations in :

1. The distance l_d metres between the stopline and the front bumper of the first vehicle in the queue; and
2. The critical gap length l_g metres between the back bumper of the nth vehicle in the queue and the front bumper of the (n + 1) the vehicle in the queue.

2.3. Large and small vehicles

In order to assess the validity of the 'traffic signal' pcu in a queuing situation, the seven classes of vehicle that exist in Yogyakarta may be divided into two groups, 'small' and 'large'. The following two definitions result :

(I) the proportion of large vehicles

$$x = \frac{\text{goods vehicles} + \text{long vehicles} + \text{buses}}{\text{sum of all vehicles}}$$

and (II) the proportion of small vehicles

$$s = 1 - x$$

x and s are often expressed as a percentage

3. DATA COLLECTION

3.1. The Survey

The surveys were performed at 6 intersections in Yogyakarta. The name of the intersections can be mentioned as follows :

1. Jl. Kaliurang - Ringroad Utara (North bound)
2. Persimpangan IAIN (East bound)
3. Persimpangan Gramedia (South bound)
4. Persimpangan Senopati (South bound)
5. Persimpangan Jlagran (West bound)
6. Persimpangan Jetis (West bound)

The survey involved four different observers working in pairs. One observer stood discreetly near the stopline of the junction and counted the number of vehicles that stopped at any one period in a queue. These vehicles were categorised according to the groups defined previously and the number of vehicles in each category was noted for all vehicles as they passed the observer. The total numbers of the traffic signals over the whole observation period of between 30 and 70 minutes.

A second observer noted the position of the back bumper of the last vehicles of each queue using either a scale of marks chalked at interval of 3 m along the kerb edge or the spacing of railings which were conveniently constructed of 3 m units. The data, which included almost 500 signal cycles, were extensively analysed to establish various characteristics of vehicles queuing at the six signalised junctions.

3.2. Distribution of vehicle length

Traffic in Yogyakarta has been categorised for this study as follows :

a) motor cycles
b) passenger cars
c) vans and mini-buses
d) city buses
e) coaches
f) trucks
g) trailers

Motor cycles refer to cycles with mechanically powered. Passenger cars include all family cars ranging in length from about 3 metres to a little over 6 metres. Vans are those vehicles that carry more than six passengers but are not a conventional coach or bus and the smaller goods vehicles that do not display heavy goods vehicle reflector plates at the rear of the vehicle. City buses are conventional buses for city public transport that carry 20 - 40 passengers. Coaches are conventional buses with larger size than city buses that transporting inter city passengers. Trucks are those goods vehicles for more than 3 tons gross unloaded weight but not long vehicles. Trailers are those goods vehicles constitutes a long vehicle category.
Table 1 provides a summary of the average vehicle lengths assumed for each category.

Table 1. Data relating to lengths for typical vehicles

Category of vehicle	Mean length (metres)	Standard deviation (metres)	Number of observation
Motorcycles	1.9	0.1	103
Passenger cars	4.0	0.4	104
Vān and minibus	4.4	0.3	75
City bus	6.6	0.1	73
Coaches	10.3	0.6	89
Truck	6.7	0.1	95
Trailer	13.6	0.2	97

4. RESULTS and DISCUSSION

4.1. Queues involving only passenger cars

By selecting those queues involving only passenger cars, the variations in the unit queue length due to different values of vehicle length is reduced to a minimum. The variation due to vehicle length will be similar to that suggested by the distribution of passenger car lengths appearing in Figure 1. The passenger car unit (pcu) is based on the standard-sized passenger car; therefore, for queues made up of passenger cars only, l_v is equivalent l_p.
The summary of l_v and l_p calculation from data can be seen in the table below :

Table 2. l_v or l_p calculations

Site names	Queue Length (m)			l_v or l_p	
	N	Mean	SD	Mean	SD
Jl. Kaliurang	15	55.27	14.25	5.50	0.37
IAIN	9	45.56	7.37	5.55	0.16
Gramedia	11	58.73	34.80	5.78	0.68
Senopati	1	---	---	---	---
Jlagran	3	49.67	11.59	5.68	0.55
Jetis	5	29.00	11.45	6.39	0.10

The l_v or l_p values defined by ignoring Jl. Senopati were shown not to be significantly different from one another. The resulting weighted mean by ignoring Senopati was found to be 5.70 ± 0.39 metres.

4.2. Queues with mixed traffic composition

The queue length for passenger cars was shown, in a typical queuing situation, to vary linearly with the number of vehicles in the queue : that is the unit queue length for passenger cars is constant. Variation in the unit queue length is made up of the variation in the gap lengths, as well as the variation in the lengths of the passenger cars themselves. If a queue were made up solely of vehicles of another class, then a similar linear dependence between queue length and number of vehicles would be expected. However, although the variation in the gap lengths would be expected to be similar the variation in vehicle lengths would change: increasing as the mean vehicle length of the class increased. There were very few queues observed which consisted of only vehicles from the goods vehicle, long vehicle and bus category so the analysis is limited to investigating the variation in queue lengths as a function of the proportion on heavy vehicles in the traffic stream. First, the data were analysed to show how the unit queue length l_v varied with composition and, secondly, the possibility of using the traffic-signal passenger car unit to describe queue lengths was investigated.

4.2.1. Unit queue length l_v for queues of mixed composition

An analytical result shows that the standard deviation of the averaged unit queue lengths, $\sigma\ l_v$ increases linearly with the percentage of large vehicles x, according to the regression equation.

$$\sigma\ l_v = 0{,}0136\ x + 0{,}4924, \text{ with } r^2 = 0{,}794 \qquad [1]$$

The dependence of $\sigma\ l_v$ on x is probably associated with the larger variation in vehicle lengths of large vehicles compared with small. (Only those standard deviation based on 10 or more observations have been plotted in and used to define the regression equation).

For all queues observed at each of the five survey sites, the unit queue length l_v was plotted as a function of the proportion of heavy vehicles. The distribution adjacent to the ordinate illustrates the variation in the unit queue lengths observed for small vehicle queues i.e. x = 0%. Because σ l_v is dependent on x a linear equation of the type.

$$l_v = \beta\, x + \alpha \qquad [2]$$

was fitted to the data using the weighted regression method. The weight was assumed to take the from σ l_v where σ l_v is defined by equation (1) above.

Empirical weighted regression equation from five location by ignore Jl. Kaliurang obtained

$$l_v = 0.043\, x + 5{,}413, \text{ with } r^2 = 0{,}971 \qquad [3]$$

This equation used to predict l_v where percentage of large vehicle is known.

4.2.3. Random Error Component

The normal distribution fitted to this data was found to be :

$$f(l_p) = 0.545 \exp.\,(-0.933\,(l_p - 6.14)^2) \qquad [4]$$

With a x^2 of 9.91 and 11 degrees of freedom. This result implies that the l_p values are distributed randomly about a mean value of 6.24 metres/pcu such that the standard error of the mean is 0,06.

The fact that l_p is constant for all queues implies that the traffic signal pcu applied to stationary vehicles is valid, provided that each pcu has associated with it one gap as discussed. The random variation in l_p is due to variation in the stopline distance and to the vehicle length as well as gap length. A measure of the error in l_p becomes important when trying to accurately predict the total queue length particularly in a critical situation e.g. queue-back.

4.3. Estimate of the average stopline distance

The average stopline distance at motorcycle category from Table 3 seems not significant with another category, where value of average for motorcycle is 0.02m, and the other category vary from 0.62 to 0.83m. Average stopline distance value for all category without motorcycle is 0.72m and standard error is 0.05.

Table 3. Statistical stopline distance analysis for each category at all street

	Motor cycle	Passenger car	City bus	Van/ minibus	Truck	Coach & trailer
Number of data	349	82	34	148	6	4
Mean (m)	0.02	0.74	0.62	0.73	0.83	0.81
Standard deviation	1.39	0.66	0.71	0.7	0.92	0.63
SE Mean	0.09	0.09	0.15	0.07	0.50	0.39

Table 4. Statistical stopline distance analysis for four wheel vehicles and all motorised vehicles at all street

	Four wheel vehicles	All motorized vehicles
Number of data	274	623
Mean (m)	0.72	0.33
Standard deviation	0.69	1.19
SE Mean	0.05	0.06

4.4. Absolute spatial gap lengths between queuing vehicles

The definition of l_p above, which assumes the gap length l_g varies proportionately with pcu-value, has been shown to be satisfactory in the context of this research program. However, it is interesting to investigate the length of the absolute spatial gap between vehicles and to establish whether or not it does vary with vehicle-type, gradient of road, etc.

The average gap length based on observations of 200 queues was found to be 1.24 metres with a standard deviation of 0.73m.

4.5. The traffic composition of vehicles both in queues and not in queues

The numbers of each vehicle-type that were queuing and not queuing during each survey period were noted. Applying a x^2-test to these data, it was shown that with 99% confidence the composition of the traffic queuing is not significantly different from the composition of traffic not queuing. This implies that larger vehicles are not more often associated with queues than small vehicles. A situation seems to exist where larger vehicles keep up with the smaller vehicles or, conversely, the larger vehicles suppress the factor movements of smaller vehicles when travelling through a signalised network.

4.6. The use of queue length relationship for prediction purpose

Consider a typical queue made up of 10 stationary vehicles as follows : 8 passenger cars, 1 long vehicle and a bus. Using the empirical equation [3] (Empirical equation for predict l_v), where, the percentage of large vehicle is 20% for data combined, value of l_v obtained 6.277 ± 0.08m. The estimate of queue length is 62.8 ± 0.8 metres. Using the fact that $l_p = 6.23 \pm 0.06$ metres/pcu and that there are 10.4 pcu in this 10 vehicle queue, the queue length is estimated at 64.8 ± 0.62 metres.

5. CONCLUSIONS

If the proportion of large vehicles in a traffic stream is known, the length of a queue at traffic signals can be predicted using the following weighted regression equation :

$$lv = 0{,}043\ x + 5.413 \text{ metres/vehicles}$$

l_v is the queue length in metres occupied by one vehicle and x is the proportion of large vehicles expressed as a percentage of the total vehicle flow. The standard error on the predicted l_v varies with x in the following way :

$$SE(l_v) = 0.9\sqrt{0.003 + 0.00002(x - 4.5)^2}$$

Provided that the number of traffic signal pcu equivalent vehicles in a queue is known the length of a queue can be predicted using the unit queue length $l_p = 6.23 \pm 0.06$ metres per traffic-signal pcu.

Five out of six links studied similar queuing characteristics, which could be assumed to exist at other similar sites. However, the stopline at one site was located in such a position that it was often ignored by drivers of the first vehicle in the queue. This tendency to overshoot the stopline made the analysis of the data for this site more complicated. In typical queuing situation the first vehicle was shown to stop behind the line at a distance not statistically significantly different from the actual spatial gap lengths between vehicles further back in the queue. The average gap length for all vehicles was shown to be 2.24 ± 0.73m with no statistical evidence that large vehicle queue closer together than smaller ones.

It is important, however, to point out that this definition of l_v assumes that associated with every pcu length there is a pcu gap which together give the unit of queue length l_p. This implies that a heavy goods vehicle with a pcu of 1.75 has 1.75 units of gap. In real terms the average gap the gap increasing proportionately with pcu infers that the actual pcu equivalents associated with stationary queue are different from those for traffic moving through a signalised junction.

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