THE USE OF A QUEUE LENGTH UNIT TO PREDICT HORIZONTAL QUEUE WITH MIXED TRAFFIC COMPOSITION

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ABSTRACT

The prime objective of this paper is to introduce queue length unit to predict horizontal queue lengths at traffic signals. Research was carried out by collecting data of more than 500 signal cycles in Yogakarta 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.

1. 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 stopline at 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 divided into two types: 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 occur 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, Yogakarta, Surabaya and Ujung Pandung.

Actually, the characteristics of traffic in large cities in Indonesia can be described as follows the major intersections normally have very high flows sustained during the day with no pronounced directional peak and also with 50 percent or more turning traffic. Although vehicle types are not much different to those in the developed world,
the vehicle mix contains a much higher proportion of motorcycles and driving standards are markedly different.

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

2. METHODOLOGY

As mentioned previously, the aim of this study is to investigate queue lengths at traffic signals. To achieve it, two main objectives have already been formulated:

- to develop queue length unit,
- to analyse the sensitivity of queue length due to traffic composition.

The methodology involves conducting field survey to six traffic signals in Yogyakarta, and to model queue length prediction by statistical analysis.

3. PARAMETER DEVELOPMENT

3.1. A queue

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

3.2. Unit queue length

Preliminary observations on 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 $l_q$, a unit of queue length is then defined as follows:

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

$$l_q = \frac{L}{N_q} \text{ metres per vehicle}$$

The parameter $l_q$, however, is dependent on the composition of the vehicles making up the queue thus it is important to understand the effect of there being

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

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

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 1.5 has associated with 1.5 units of gap length compared to a saloon car (pcu = 1.0) with 1 unit of gap. If $l_g$ is not 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 length. 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 in proportion with the pcu value, an assumption which may not necessarily be true in all cases.

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

1. The distance $l_g$ 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 $n$th vehicle in the queue and the front bumper of the $(n + 1)$th vehicle in the queue.

3.3. Large and small vehicles

In order to assess the validity of the ‘traffic signal’ pcu in a queuing situation, the six classes of vehicle may be divided into two groups, “small” and “large”. The following two definitions result:

1. the proportion of large vehicles

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

and

2. the proportion of small vehicles

$$s = 1 - x$$

(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:

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

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

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4. DATA COLLECTION

4.1. 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 Urars (North bound)
2. Persimpangan IAIN (East bound)
3. Persimpangan Gramedia (South bound)
4. Persimpangan Senopati (South bound)
5. Persimpangan Jalan (West bound)
6. Persimpangan Jalan Jalan (West bound)

The survey involved four different observers working in pairs at each intersection. 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.

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

4.2. Distribution of vehicle length

Traffic on roads has been categorised for this study as follows:
- motorcycles
- passenger cars
- vans and mini-buses
- city buses
- coaches
- trucks
- trailers

Motorcycles refer to cycles 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. 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 intercity 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>
<thead>
<tr>
<th>Category of vehicle</th>
<th>Mean length (metres)</th>
<th>Standard deviation (metres)</th>
<th>Number of observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorcycles</td>
<td>1.9</td>
<td>0.1</td>
<td>103</td>
</tr>
<tr>
<td>Passenger cars</td>
<td>4.0</td>
<td>0.4</td>
<td>104</td>
</tr>
<tr>
<td>Van and minibus</td>
<td>4.4</td>
<td>0.3</td>
<td>75</td>
</tr>
<tr>
<td>City bus</td>
<td>6.6</td>
<td>0.1</td>
<td>73</td>
</tr>
<tr>
<td>Coaches</td>
<td>10.3</td>
<td>0.6</td>
<td>89</td>
</tr>
<tr>
<td>Truck</td>
<td>6.7</td>
<td>0.1</td>
<td>95</td>
</tr>
<tr>
<td>Trailer</td>
<td>13.6</td>
<td>0.2</td>
<td>97</td>
</tr>
</tbody>
</table>

5. RESULTS AND DISCUSSION

5.1. Queues involving only saloon cars

By selecting those queues involving only saloon cars, the variations in the unit length due to different values of vehicle length is reduced to a minimum. The passenger car unit (pcu) is based on the standard-sized saloon car; therefore, for queues made up of saloon cars only, Lq is equivalent to Lp.

The summary of Lq and Lp calculation from data can be seen in Table 2:

<table>
<thead>
<tr>
<th>Site names</th>
<th>Queue Length (m)</th>
<th>Lq or Lp</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jl. Kaliurang</td>
<td>55.27</td>
<td>14.25</td>
<td>5.50</td>
<td>0.37</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IAIN</td>
<td>45.56</td>
<td>7.37</td>
<td>5.55</td>
<td>0.16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gramedia</td>
<td>58.73</td>
<td>34.80</td>
<td>5.78</td>
<td>0.68</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Senopati</td>
<td>49.67</td>
<td>11.59</td>
<td>5.68</td>
<td>0.55</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jalan</td>
<td>29.00</td>
<td>11.45</td>
<td>6.39</td>
<td>0.10</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Lq or Lp calculations
5.2. Queues with mixed traffic composition

The queue length for saloon cars was shown, in a typical queueing situation, to vary linearly with the number of vehicles in the queue: that is the unit queue length for saloon cars is constant. Variations in the unit queue length would be expected in the gap lengths, as well as the variation in the lengths of the saloon cars themselves. If a queue were made up solely of vehicles of other than saloon cars 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 of heavy vehicles in the traffic stream. First, the data were analyzed to show how the unit queue length $L_u$ varied with composition and, secondly, the possibility of using the traffic signal passenger car unit to describe queue lengths was investigated.

5.2.1. Unit queue length $L_u$ for queues of mixed composition

Figure 1 shows that the standard deviation of the averaged unit queue lengths, $\sigma L_u$, increases linearly with the percentage of large vehicles $x$, according to the regression equation:

$$\sigma L_u = 0.0136x + 0.4924$$

(1)

The dependence of $\sigma L_u$ on $x$ is probably associated with the larger variation in vehicle lengths of large vehicles compared with small vehicles. (Only those standard deviations 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 three survey sites, the unit queue length $L_u$ 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 $\sigma L_u$ is dependent on $x$ a linear equation of the type:

$$L_u = \beta x + \alpha$$

(2)

was fitted to the data using the weighted regression method. The weight was assumed to take the from $\sigma L_u$, where $\sigma L_u$ is defined by equation (1) above.

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Empirical weighted regression equation from five location by ignore Kallurang obtained

$$L_u = 0.043x + 5.413$$

(3)

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

5.2.2. Random Error Component

A plot of the distribution of $L_u$ at all intersections is given in Figure 2. The normal distribution fitted to this data was found to be:

$$f(L_u) = 0.545 \text{ exp.}( - 0.953(L_u - 6.14)^2 )$$

(4)

with a $\chi^2$ of 9.91 and 11 degrees of freedom. This result implies that the $L_u$ values are distributed randomly about a mean value of 6.24 metres/see such that the standard error of the mean is 0.06.

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

5.3. Estimate of the average stopline distance

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

<table>
<thead>
<tr>
<th>Category</th>
<th>Motor cycle</th>
<th>Saloon Car</th>
<th>City bus</th>
<th>Van/ Mini bus</th>
<th>Truck</th>
<th>Coach &amp; trailer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of data</td>
<td>149</td>
<td>82</td>
<td>34</td>
<td>148</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Mean (m)</td>
<td>0.02</td>
<td>0.74</td>
<td>0.62</td>
<td>0.73</td>
<td>0.83</td>
<td>0.93</td>
</tr>
<tr>
<td>S Dev.</td>
<td>1.39</td>
<td>0.66</td>
<td>0.71</td>
<td>0.7</td>
<td>0.92</td>
<td>0.63</td>
</tr>
<tr>
<td>SE Mean</td>
<td>0.09</td>
<td>0.09</td>
<td>0.15</td>
<td>0.07</td>
<td>0.50</td>
<td>0.39</td>
</tr>
</tbody>
</table>
5.4. Absolute spatial gap lengths between queuing vehicles

The definition of $L_q$ above, which assumes the gap length $L_q$ varies proportionately with pce-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 is 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.

5.5. 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 to this data, it was shown that at 95% 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.

5.6. The use of queue length relationship for prediction purposes

Consider a typical queue made up of 10 stationary vehicles as follows: 8 saloon cars, 1 long vehicle and a bus. Using the empirical equation (3) (Empirical equation for predict $L_q$), where, the percentage of large vehicle is 20% for data combined, value of $L_q$ obtained is 6.277 ± 0.08 m. The estimate of queue length is 62.8 ± 0.8 metres. Using

$$ L_q = 0.043X + 5.413 (\text{metres/vehicle}) $$

$L_q$ 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 $L_q$ varies with $X$ in the following way:

$$ SE(L_q) = 0.934003 + 0.00002(x - 4.5)^2 $$

Provided that the number of traffic signal pce equivalent vehicles in a queue is known the length of a queue can be predicted using the unit queue length $L_q = 6.23 ± 0.06$ metres per traffic signal pce.

Five out of six signals studied showed similar queuing characteristics, which could be assumed to exist at other signal 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 over-queue 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 $2.24 ± 0.73 m$ with no statistical evidence that large vehicle queue closer together than smaller ones.

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

7. ACKNOWLEDGEMENT

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8. REFERENCES


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