

ESTIMATION OF CYCLE BY CYCLE QUEUE LENGTH AT APPROACHES OF SIGNALIZED INTERSECTION UNDER MIXED TRAFFIC CONDITIONS

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Abstract

Signalized intersections are essential nodes in the urban network for better operational performance of traffic flow. At approaches of signalized intersection the formation of excessive queue occurs due to demand leads the service rate. The analysis of queuing helps in predicting the accumulation of excessive queue and the condition of a traffic jam at an approach of signalized intersections. The present study analyzes the queuing of vehicles at approaches of signalized intersection under mixed traffic conditions by collecting field data at approaches of two different intersections in Warangal City. A new queue length model was proposed by considering various factors identified in field related to roadway, vehicle, driver's standstill behaviour etc. The average number of vehicles observed at approach during a cycle was also used as an input to determine queue length using proposed model. The model was validated by field queue length observed at different approaches of signalized intersections. Statistical evidence confirms a successful validation of the queue length model under mixed traffic conditions. The method suggested in the present study may help in determining queue length expected at a given approach of signalized intersections with better accuracy and provide an easy estimation of length of storage lane required for right turning vehicles as well.

Keywords: Queuning, queue length, signalized intersection, mixed traffic

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Introduction

The traffic congestion arises due to the maximum length of queue formation at approaches of signalized intersection under mixed traffic conditions. Nowadays in progressive Nations like India, vehicular traffic volume is growing up day by day on urban roads. The growth of traffic volume on roadway networks has led to the formation of queues near intersections that causes a traffic flow to become zero. The queue is the line of people or things waiting to be served. It is the phenomena, which occur in daily life, mainly at the approaches of the signalized intersection on typical urban road networks. The queue length is defined by Highway Capacity Manual (HCM, 2010) as the average number of vehicles standing in the queue. The queue length considered as one of the crucial factors which can describe the experience of road user over the length or section of a roadway. In other words, it is used to define the quality of service of a given roadway facility under given traffic and roadway conditions. Queue length is a line of vehicles waiting at the stop line for the green phase to be served by a signalized intersection. The number of vehicles in traffic streams traveling slowly or joining at the rear end of a queue also considered as part of the queue. The longitudinal space occupied by several vehicles before the stop line at the approach of a signalized intersection also called queue length (INDO-HCM, 2017). The queue formation for an extended time at the signalized intersection leads to excessive delay, which increases the diver frustration level of the users and fuel consumption. The analysis of queuing helps in making better predictions of the traffic congestion and its management.

The present study performed to seek clarity on queuing behavior at signalized intersections under mixed traffic conditions. A model developed for estimating cycle by cycle queue length by considering various factors. The queue forming behavior at approaches of signalized intersection varies due to multiple factors affecting it under mixed traffic conditions.

Literature Review

The queue length estimated at signalized intersection approaches varies with various factors. A brief review of different studies performed around the world on queuing behavior and its estimation using various methodologies is discussed as follows. Wu (1998) studied the estimation of queue length at a signalized intersection for determining capacity and traffic control quality in Germany. The percentile of queue length was calculated under stationary and non-stationary traffic conditions. The estimated queue length during the red time at approaches of signalized intersections is further suggested for determining the number of lanes, and lane width, etc. Cruz *et al.* (2002) developed a simulation model to study traffic parameters in M/G/C/C state-dependent queue networks in the United States. They evaluated the blocking parameter, queue length, and service time of queuing vehicles. M/G/C/C state-dependent queue models were validated in the field using data collected at approaches of signalized intersection under congested traffic conditions. Later, a three-layered neural network model was proposed by Tong and Hung (2003) to estimate queue length at an approach of signalized intersections in Hong Kong. The developed model was validated by using field data and compared with other popular queue length models. Viti *et al.* (2004) suggested queue length estimation at approaches of signalized intersections in the Netherlands. The stochastic queuing model was used for estimating the queue length that found to be more flexible and efficient under congested traffic conditions. Henry *et al.* (2009) measured real-time queue length at signalized intersection under higher traffic volume in the United States using detectors data. The queue length was estimated using two methods namely the input-output method and shock wave theory, and the performance of models was measured by comparing the estimated queue length with the observed queue length obtained from the field. They observed that the basic input-output model is better than the other methods in terms of accuracy. Anokye

et al. (2013) estimated queue length at the signalized intersection of Kumasi-Ashanti Region, Ghana, during busy hours. Queuing theory model was used to determine the queue lengths. The estimated queue length is to be more during the morning session compared to the afternoon and evening sessions. Cai *et al.*, (2014) estimated maximum queue length by using HCM (2000) methodology using floating car and loop detector data collected at approaches of signalized intersection in Shanghai. The study concluded the queue length model was more accurate, which may be used to define the level of service at signalized intersection. Yang and Yang (2014) observed traffic conditions at Shenzhen signalized intersection in China for estimating the queue length. The estimated queue length values were validated with observed queue length values as obtained from the field. The study determines the number of lanes required at the approach of a signalized intersection with consideration of queues. Anusha *et al.* (2016) developed a new model for estimating the queue length based on data obtained from the signalized intersections in the city of Lincoln and Nebraska. The automated sensors based data was used for developing a mathematical model to predict queuing behavior for solving problems that emerged with traffic operations.

In countries like India, traffic conditions are heterogeneous and vehicles have a lack of lane discipline. Most of the studies are conducted under uniform traffic conditions where vehicle follows strict lane discipline and

suggested various sophisticated queuing models using field data. The models developed earlier can not be directly used under highly mixed traffic conditions as prevails in India. The factors commonly influence the development and behavior of the queue at signalized intersection need to be considered thoroughly for proposing a more suitable model for mixed traffic conditions. The present study proposed a new methodology for estimating the cycle by cycle queue length at signalized intersection approaches by considering various factors affecting under mixed traffic conditions.

Study Area and Data Collection

Field data was collected at two signalized intersections in Warangal City, India. The selected intersections are four-legged, comprising major and minor stream approaches. The layout and geometry of selected intersections are quite unsymmetric. The selected signalized intersections are namely Ku crossroad and Hanmakonda junction. Snapshot and layout of selected intersections are shown in Figures 1 and 2.

Data Extraction

Videography method was used for the collection of field data by recording the operation of traffic flow that covers peak and non-peak hours. Video recording was performed for 6 h at the intersections during the morning from 6:00 AM to 9:00 AM and



Figure 1. Snapshot of (a) Ku crossroad intersection, and (b) Hanmakonda intersection

evening from 3:00 PM to 6:00 PM. Recorded data was extracted by playing the video files on a widescreen LED display in the laboratory. The number of vehicles joining in the queue by their types was observed at the site during each cycle at approaches of selected signalized intersections. The distance occupied by queued vehicles were measured with tape in the field at all approaches during each signal

cycle. The classified volume count was made to determine approaching traffic volume that comprises several vehicle types such as two-wheeler, Three-wheeler, Car, Bus, HCV. Approaching traffic volume was observed at both intersections. At Ku crossroad junction traffic volume was in the range between 1,100 veh/h to 2,500 veh/h and in case of Hanmakonda junction, the range is between

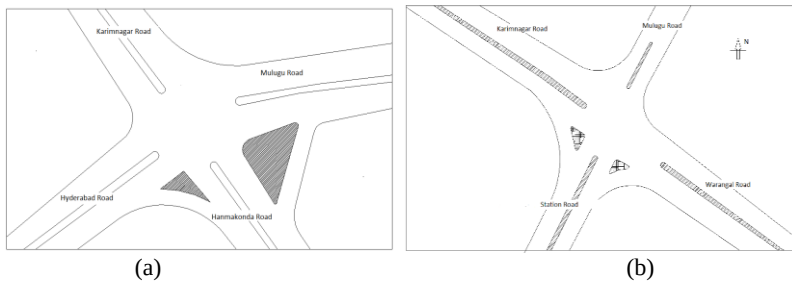


Figure 2. Lay out of (a) Ku crossroad intersection, and (b) Hanmakonda intersection

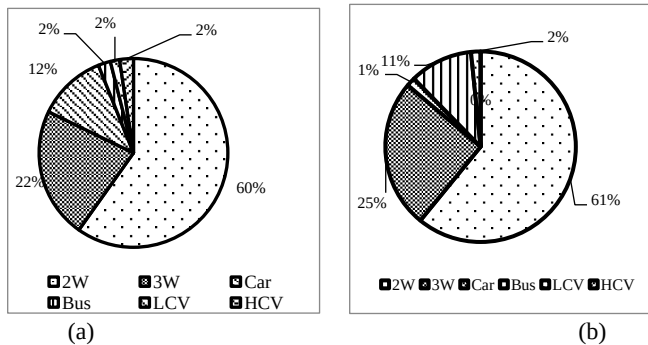


Figure 3. Percentage of vehicle types (a) Ku crossroad intersection, and (b) Hanmakonda intersection

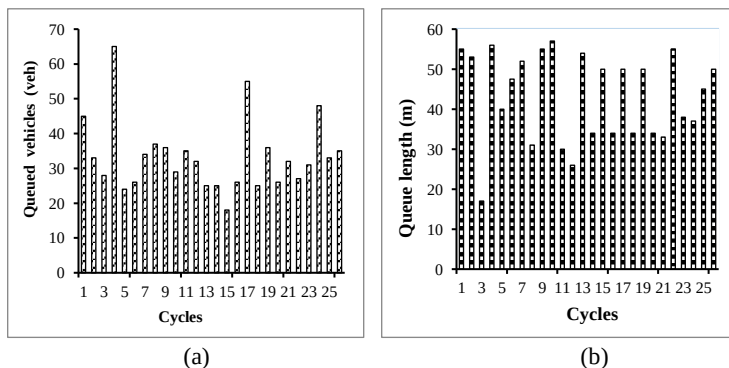


Figure 4. Variation of cycle by cycles (a) queued vehicles and (b) queue length at approach of Ku crossroad intersection

1,000 veh/h to 3,300 veh/h. The percentage of vehicle types as observed in the field are given in Figure 3. The approaching width and important timings of pre-timed signal operation were noted during the data collection. The geometric, traffic flow, and signal control timing data related to selected signalized intersections are given in Table 1. The field observed queued vehicles and queue length during each cycle at approaches of the selected signalized intersections is given in Table 2. The numbers of vehicles joined in the queue

and measured length of the queue along the roadway during each cycle at approaches of selected intersections are shown in Figure 4.

Statistical Distribution of Queue Length

The number of vehicles standing in a queue, and length of queued vehicles behind the stop-line were measured at the approaches of signalized intersections during each cycle. The graphical

Table 1. Geometric, traffic and control details of the selected signalized intersections

Intersection Name	Approach name	Approach width (m)	Red time (Sec)	Cycle length (Sec)	Approach volume (Veh/h)
Hanmakonda	Station Road	9	114	130	1,260
	Warangal Road	8.5	95	130	2,856
	Mulugu Road	6.5	114	130	1,087
	Karimnagar Road	8	95	130	2,642
Ku crossroad	Karimnagar Road	12	90	150	2,257
	Mulugu Road	7.5	120	150	1,160
	Hanamkonda Road	10	90	150	2,404
	Hyderabad Road	8.5	120	150	1,427

Table 2. Field observed queue and queue length at approaches of the selected signalized intersections

Intersection Name	Approach name	Average queued Vehicles (Veh)	Average queue length (m)
Hanamkonda	Sation Road	49	56
	Warangal Road	93	69
	Mulugu Road	36	28
	Karimnagar Road	104	66
Ku crossroad	Karimnagar Road	42	43
	Mulugu Road	40	33
	Hanamkonda Road	56	61
	Hyderabad Road	47	26

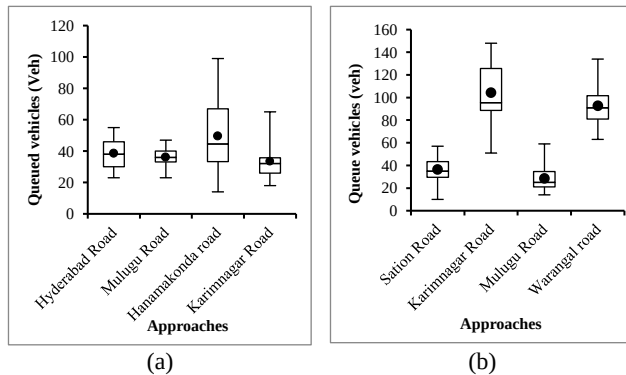


Figure 5. Graphical representation of number of queued vehicles at approaches of (a) Ku crossroad intersection (b) Hanmakonda intersection

representation of queued vehicles and length of queued vehicle at approaches of selected intersections in the form of box-chart are shown in Figures 5 and 6 respectively. The distribution analysis of measured length of queue and number of vehicles standing in the queue have been performed to understand the queuing behaviour pattern. The frequency of data was

analysed to observe distribution in both the cases by selecting appropriate class intervals. The distribution profiles of length of queue and number of queued vehicles as developed for intersections approaches are shown in Figures 7 and 8 respectively. Chi-Square test was performed at the 5% significance level to check whether the observed data fits normal

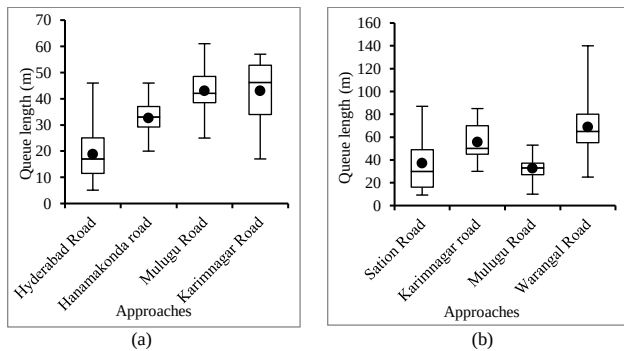


Figure 6. Box plot of queue length measured at approaches of (a) Ku crossroad intersection (b) Hanmakonda intersection

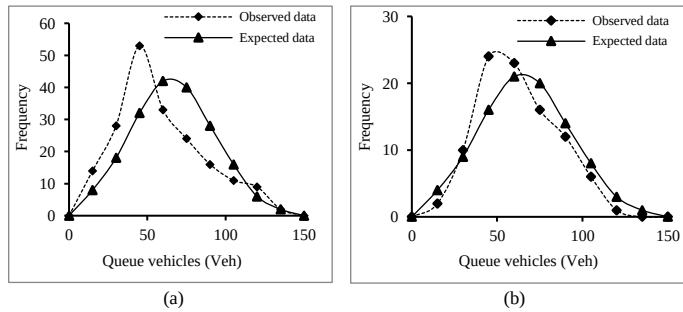


Figure 7. Frequency analysis of queued vehicles (a) Ku crossroad intersection (b) Hanmakonda intersection

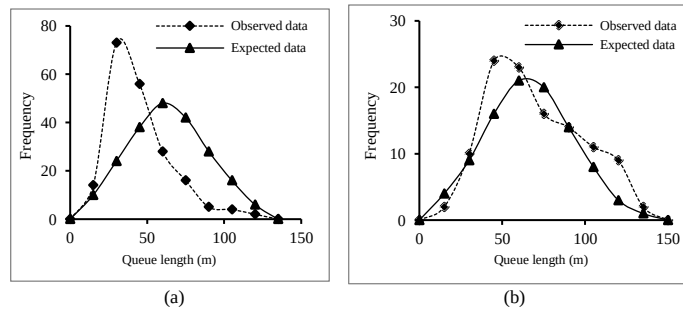


Figure 8. Frequency analysis of queue length (a) Ku crossroad intersection (b) Hanmakonda intersection

distribution. The statistical p-values estimated for each non-parametric test showed the distribution of measured length of queue and number of queued vehicles are not conforming with normal distribution. The percentage of vehicle types two-wheeler and three-wheeler varies in small interval may be a reason for affecting the queuing behaviour.

Estimation of Queue Length

The queue length of vehicles observed at signalized intersection has been analysed by examining different factors influencing it. The queue length at approaches of signalized intersection may be estimated through a model by incorporating various factors that show their sensitivity significantly. Present study attempts to develop a simple model by identifying the factors influencing queue length based on field data. The length of the queue measured during red time interval in each cycle are considered as dependent variable and factors such as vehicle types dimensions, vehicle accumulated and the ratio

of average longitudinal standstill distance to average lateral standstill distance of selected vehicle types are considered as independent variables for development of model. The sample photographs taken while collecting the data from the field during red time is shown in Figure 9. The longitudinal standstill distance and lateral standstill distance data as obtained from the field are given in Table 3. Based on the field data, present study developed a model for estimating length of queue formed at any approach of signalized intersection is by Equation (1)

$$Q = \left(\frac{n \times (\sum_{i=1}^n PA_i \times q_i)}{W \times \frac{1}{2} \times (N_i)} \right) \times \left(\frac{D_l}{D_t} \right) \quad (1)$$

where, Q = queue length (m), PA_i = projected area of i^{th} vehicle (m^2), q_i = number of i^{th} vehicle standing in the queue (veh), W = approach width (m), N_i = minimum number of queued vehicles (veh), D_l = Average longitudinal standstill distance (m), D_t = Average lateral standstill distance (m), n = number of vehicle types in the traffic stream.



Figure 9. Measured (a) Queue length, and (b) Standstill distance of selected approaches of intersections

Table 3. Longitudinal and lateral standstill distances of vehicle types with their Projected areas

Vehicle types	Average longitudinal standstill distance (m)	Average lateral standstill distance (m)	Projected area (m^2)
2W	0.40	0.55	1.20
3W	0.54	0.60	4.48
Car	0.70	0.65	5.36
LCV	1.4	0.67	12.81
HCV	1.65	0.75	29.52
Bus	1.5	0.69	24.54

The relationship as developed in the present study was tested and validated with field data on different approaches of other signalized intersections. Field data obtained from other intersection approaches were used as input in the Equation (1) for estimating queue length. The queue length as estimated for each cycle based on new inputs was compared with the field observed queue length. A 45-degree line chart is used to compare two queue lengths for performing validation of the model. The validation of model is presented with 45-degree line as shown in Figure 10. The statistical Chi-square test was conducted at 5% significant level to compare two average queue lengths provides an estimate of a p-value as 0.284, which is found to be higher than 0.05 that shows a successful validation of the queue length model.

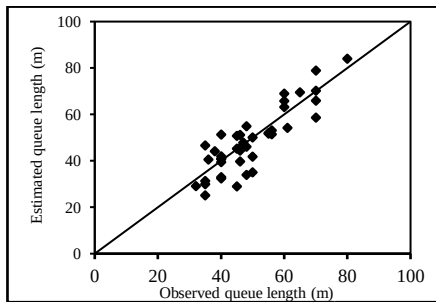


Figure. 10 Validation of developed queue length model

Discussion

Present study developed a queue length model based on various influencing factors under mixed traffic conditions. Queueing analysis carried out to understand queueing behavior based on five number summary of queued vehicles data and its distribution analysis. Box plots analysed for both numbers of queued vehicle and length of queue have shown clear differences among same approaches due to greater variation in composition of vehicles. The normal distribution applied to fit queueing field data also showed significant differences

between observed and expected frequencies. Hence, randomness in queueing behaviour is not observed.

A new model for estimating length of queueing at an approach of signalized intersection was developed and tested in field after analysing different influencing factors. The estimated queue lengths were compared with field observed queue length for validation of model. It confirms that there is no significant difference between the two sets of data at 95% confidence interval. Hence, it may be applied to any signalized intersection under mixed traffic conditions. Moreover, study presents the average standstill distances between vehicles waiting before stop line at approaches of signalized intersection.

Conclusions

In many previous studies the queue length was measured in terms of number of queued vehicles including HCM (2000) methodology. The queue length in terms of distance is required as input for design of auxiliary lanes or storage lanes at intersection approach. The present study estimates the queue lengths at the approaches of signalized intersection by using a new model developed using field data. The model was developed by incorporating factors related to vehicle, roadway and driver's standstill behavior. The model also uses number of vehicles standing at any cycle for estimating queue length. The validation of the proposed queueing model was successfully performed based on field data as collected on other approaches of intersections. The model developed in the present study may help in determining the queue length expected at an approach of signalized intersections with better accuracy. The queue length determined by using proposed methodology may be used for designing queue storage lane for right turning vehicles.

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