Periodica Polytechnica Transportation Engineering, 51(1), pp. 31–39, 2023

Estimation of Queue Length at Signalized Intersection Under Non-Lane Based Traffic Conditions

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Received: 05 November 2020, Accepted: 30 June 2022, Published online: 15 August 2022

Abstract

Excessive queue length is formed at approaches of signalized intersection if demand flow rate exceeds the saturation flow. The analysis of approaching flow at signalized intersections make easier to predict the queue length for avoiding traffic congestion. At congestion level, queue length reaches to maximum, and the traffic flow becomes zero. Measurement of queuing is essential for design and evaluation of traffic flow facilities. The literature review finds various methods for estimating queue length at signalized intersection under homogeneous and heterogenous traffic flow conditions. Traffic flow data was collected at different intersections in Hyderabad city using videography method. The present study determined queue length at approaches of signalized intersection by using the existing methods given in the literature. The results showed the queue length obtained from different methods are failed to match the queue length as observed in the field. Finally, the study developed a multivariable model for predicting queue length by checking the sensitivity of various factors influencing on queue length at the approach of signalized intersections. Further, the model was validated using field data collected at other approaches based on statistical analysis. Statistical evidence confirmed that the queue length estimated from the proposed model well replicates the queue length observed in the field under the given traffic and roadway conditions. The study recommends that the proposed model works well for the signalized intersection operating with a high proportional share (above 30%) of Two-wheeler in the mixed traffic but limited to operating with higher volume conditions.

Keywords

queue length, signalized intersection, field data, mixed traffic

1 Introduction

The queue is the line of people or things waiting to be served. It is a phenomenon, which usually occurs near the toll plaza, expressway ramp, and at approaches of a signalized and unsignalized junctions. The queue length is considered as one of the important design factors which are also used to describe the experience of users on a roadway section. In other words, it is used as a measure of effectiveness to define the quality of service of a given roadway facility.

As per the definition, queue length is a line of vehicles waiting at the stop line to be served (Ravinder et al., 2014). The number of vehicles approaching very slow or joining at the end is also considered as part of the queue. The longitudinal space occupied by the number of vehicles before the stop line at an approach of a signalized intersection is also reported as queue length. At an approach of signalized intersection, formation of queue occurs when the entering traffic demand flow rate exceeds the service flow rate, and this phenomenon tends to become more chaotic under mixed traffic conditions. The analysis and prediction of queuing are needed for making better predictions of traffic congestion and level of service.

The present study is performed with the objectives to analyze and predict the queue length at approaches of signalized intersection by using field data. The study attempts to develop a multivariable regression model for estimation of heterogeneous queue length at approaches of signalized intersections under varying traffic and roadway conditions.

2 Literature review

The queue length estimated at signalized intersection approaches varies with various factors in past studies. A brief review of previous studies performed on queue length by using various methodologies is discussed as follows.

Cite this article as: Jithender, J., Mehar, A. (2023) "Estimation of Queue Length at Signalized Intersection Under Non-Lane Based Traffic Conditions", Periodica Polytechnica Transportation Engineering, 51(1), pp. 31–39. https://doi.org/10.3311/PPtr.17454

Wu (1998) studied the estimation of queue length at a signalized intersection to determine capacity and traffic control quality in Germany. The percentile of queue length was calculated under stationary and non-stationary traffic conditions using field data. A Markov chain model was used to derive the formula for non-stationary traffic conditions. This study observed that the estimated queue length as measured at the approaches may be considered for designing the number of lanes, radius of turning lane and lane width, etc. Later, a three-layered neural network model was proposed by Tong et al. (2002) to estimate queue length at an approach of signalized intersections in Hong Kong. The queue length model developed and validated by using field data was compared with other existing queue length models. van Zuylen and Viti (2003) studied the dynamics and uncertainty of queuing at approach of signalized intersections in the Netherlands by using Akçelik (1980) queue length model, which considers the initial queue equals to zero. Markow model was also used in this study to estimate queue length.

The queue length has also been influenced by arrival rate of vehicles per cycle length in many studies. Li et al. (2017) suggested queue length at signalized intersections in the Netherlands using stochastic model. The model was found to be more flexible and efficient under congested traffic conditions. Liu et al. (2009) measured real-time queue length at signalized intersection in higher traffic volume condition in the United States using detectors data. The queue length was estimated using two methods, namely input-output method and shock wave theory. The model's performance was measured by comparing the estimated queue length with the observed queue length obtained from the field measurements. The authors stated that the basic input-output model is better than the other method in terms of accuracy.

Anokye et al. (2013) estimated queue length at the signalized intersection of the Kumasi-Ashanti region, Ghana during busy hours of the day. Queuing theory model was used in the study to determine the queue length. The field delay obtained from estimated queue length was expected to be high during morning period in comparison to afternoon and evening periods. Cai et al. (2013) estimated maximum queue length by using HCM 2000 model based on floating car and loop detector data from a signalized intersection in Shanghai. The study concludes that the queue length model is more accurate to define the level of service appropriately at signalized intersection. Chang et al. (2013) developed a new methodology for estimating queue length at signalized intersection in New York City. The field data such as cycle lengths, flow, detector setback, and occupancy were measured to estimate queue length at approaches of signalized intersection. Yang and Yang (2014) observed traffic conditions at Shenzhen signalized intersection in China and estimated queue length and delay. The results were validated with the data obtained from field. The study determines the number of lanes to be added at approaches of intersection for better operational performance. Anusha et al. (2016) developed a model to estimate the queue length and delay based on data obtained from the signalized intersections in the city of Lincoln and Nebraska. The automated sensors data was used to develop a mathematical model. The developed model was further used for analyzing queuing behavior to solve various problems related to traffic operations. Motie and Savla (2017) computed the queue size at signalized intersection in California, Los Angeles. Queue length models were developed to predict the queue length at approaches of a signalized intersection. They used the M/D/1/N model to estimate queue length during each cycle under uniformed traffic conditions. Yang and Shi (2018) studied queue length at a signalized intersection approaches based on batch arrival time in a city of China. They derived a mathematical model to estimate the queue length based on arrival time and service time measurements. They validated the model using field as well as through simulation. The authors concluded that the estimated maximum queue length is directly affected by the number of vehicles in a batch. The arrival pattern was also found to be dependent on the signal control schemes at upstream section of the signalized intersections.

In countries like India, the traffic flow is heterogeneous in nature and most of the studies found in the literature are based on field data or performed through simulation. The field studies on queue length under mixed traffic conditions are less and found to be limited to the specific locations and traffic conditions. Therefore, present study attempts to identify various other factors affecting queue length significantly those have not been considered in the past studies available in the literature under non-lane based type traffic conditions.

3 Field data

Field data was collected at five signalized intersections identified in Hyderabad city. The selected intersections are four-legged and three-legged types comprising major and minor approaches. The selected signalized intersections are namely

Suchitra junction, Crown cafe junction, KBR Park junction, Karbala maidan junction, and Ranigunj junction. The snapshots of these selected intersections are shown in Fig. 1.

Videography method was used for collection of field data through recording of traffic operations during different hours of the day. Video recording was performed for 6-hours at the intersections during morning from 6:00 AM to 9:00 AM and evening from 3:00 PM to 6:00 PM. Recorded data was extracted by playing the video files on a widescreen LED display. The field queue length was observed at the sites during each cycle by counting the number of vehicles joining the queue at approaches. As observed approaching traffic volume is mixed in nature, therefore classified volume count was made that comprises six vehicle types such as Two-wheeler, Three-wheeler, Car, Bus, LCV, and Truck. The signal timings, approaching rate, and service rate were observed from the field data. The intersection details and approaching traffic

(a) (d) (b) (e) (c) (f)

Fig. 1 Snapshot of Signalized intersections approaches; (a) Bowenpally road and Suchitra road approaches; (b) Kompally road and old alwal road approaches; (c) LV Prasad Marg approach; (d) Rashtrapathi Road approach; (e) Narayanguda Road; (f) James Street approach volume obtained from the field are given in Table 1. The percentage of vehicle types, as observed at field locations are also given in Fig. 2.

The measured queue length at approaches of selected intersections varied in the range of 20–150 vehicles during each signal cycle due to variation of geometric, traffic

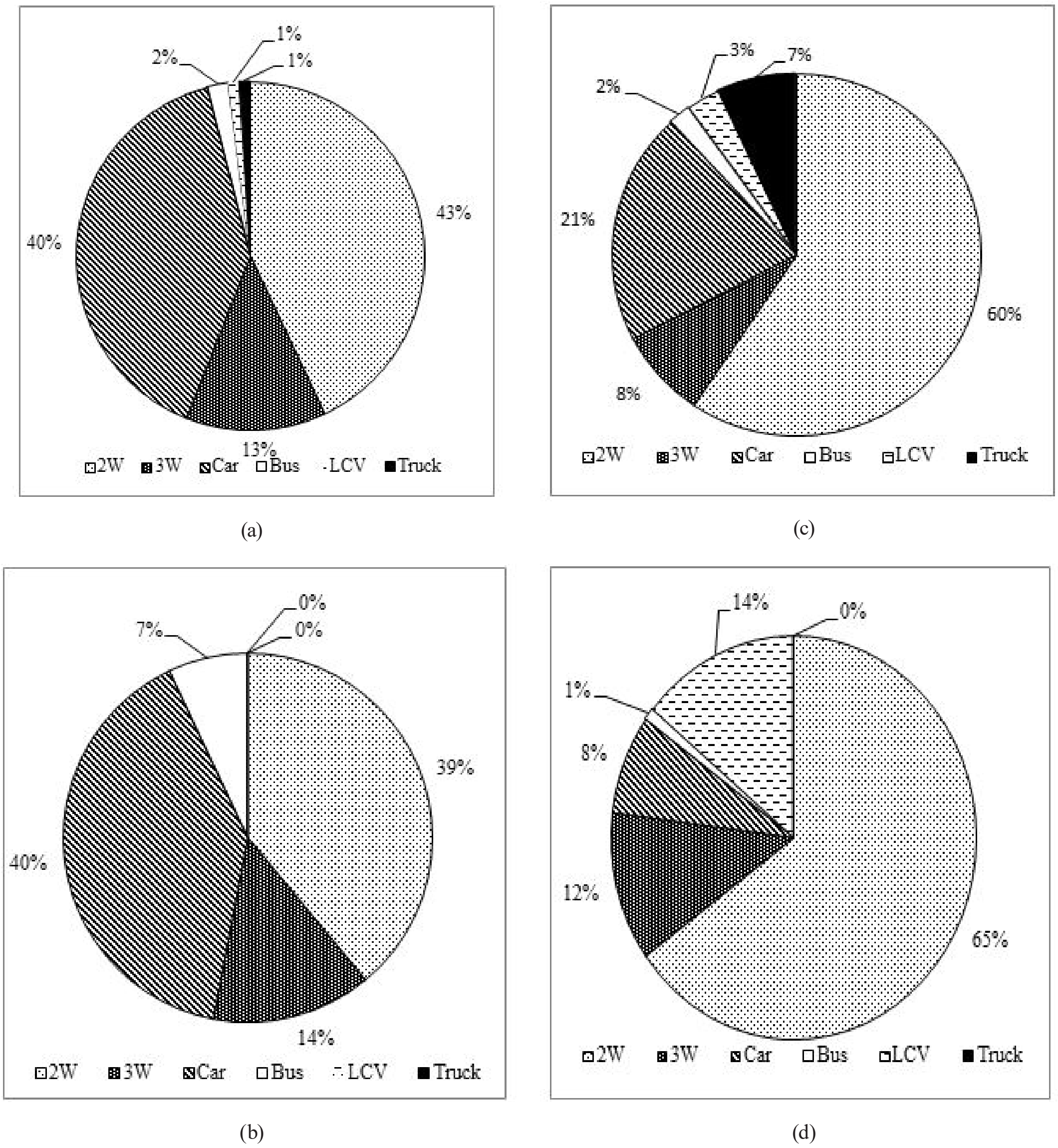


Fig. 2 Composition of vehicle types signalized intersection approaches; (a) Crown cafe junction; (b) KBR park junction; (c) Karbala maidan junction; (d) Ranigunj junction

Table 1 Roadway, traffic and signal control details of the selected signalized intersections

Intersection name	Approach name	Approach ID	Approach width (m)	Approach volume (veh/hr)	Cycle length	Red time(s)
Suchitra	Bowenpally Road	I	15	2995	180	90
	Kompally Road	II	18	2444	180	90
	Suchitra Road	III	18	1175	180	130
	Old alwal Road	IV	30	1163	180	130
Crown cafe	Narayanguda Road	V	8	924	130	80
KBR park	LV Prasad Marg	VI	7	1030	125	85
Karbala maidan	Rashtrapathi Road	VII	12	1119	110	75
Ranigunj	James Street	VIII	6.5	726	225	180

compositions, and control details under mixed traffic conditions. The average field queue length measured at different approaches of signalized intersections are given in Table 2.

The observed queue length varied from minimum to maximum at the sites during each cycle by counting the number of vehicles joining the queue. The variation of queue length observed at approach of selected intersection is shown in Fig. 3.

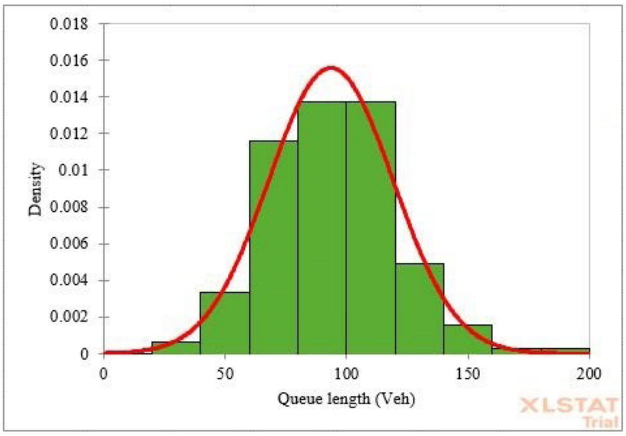
4 Analysis of field queue length

The number of vehicles standing in a queue at the approaches of different intersections have been observed during each cycle. The average queue length was measured in the field for the entire period of observation. The distribution of measured queue length was analyzed to understand the queuing behavior. The frequency of queue length was observed at different approaches of selected intersections by selecting appropriate class intervals. Chi-Square test was performed at the 5% significance level to check whether the observed data fit a normal distribution. The statistical p-value estimated for each test ranges between 0.234 to 0.982, which confirms that the distribution of queue length observed at the approaches are conforming with different distributions. The percentage of vehicle type two-wheeler varies from 32% to 69%, which may also be the reason for affecting the queuing behavior. Distribution profiles pertaining to different approaches are shown in Fig. 4.

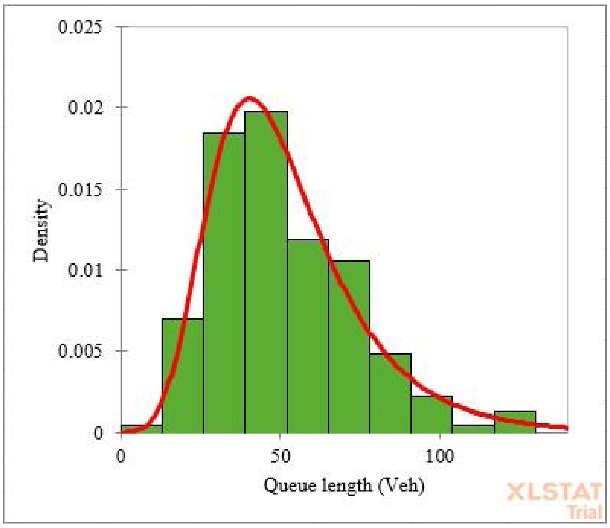
The distribution profiles of queue length data was developed for intersection approaches. The measured queue length obtained from the field at different approaches of selected intersection was followed the various type of distribution which are given in Table 3.

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

Location	Intersection name	Approach name	Average queue length (Veh)
Hyderabad	Suchitra	Bowenpally Road	99
		Kompally Road	83
		Suchitra Road	49
		Old alwal Road	41
	Crown cafe	Narayanguda Road	49
	KBR park	LV Prasad Marg	61
	Karbala maidan	Rashtrapathi Road	65
	Ranigunj	James Street	55



(a)



(b)

Fig. 3 Distribution analysis of Suchitra junction approaches; (a) Bowenpally Road (normal distribution); (b) Kompally Road (Fisher-Tippett disribution)

5 Determination of queue length

Present study applies two methods for determining queue length based on the data collected from the field based on queuing theory (Anokye et al., 2013) and HCM (2010). The queuing theory method requires arrival rate and service rate as inputs to estimate queue length at intersection approaches during each cycle. The traffic intensity was estimated in every cycle based on arrival rate and service rate values. The M/M/1 model has been considered to estimate the queue length for study assuming total approach width as single lane. The average queue length estimated at an individual approach during the entire observation period was compared with field observed values. The charts for comparing two average queue lengths during peak and non-peak periods are shown in Fig. 5.

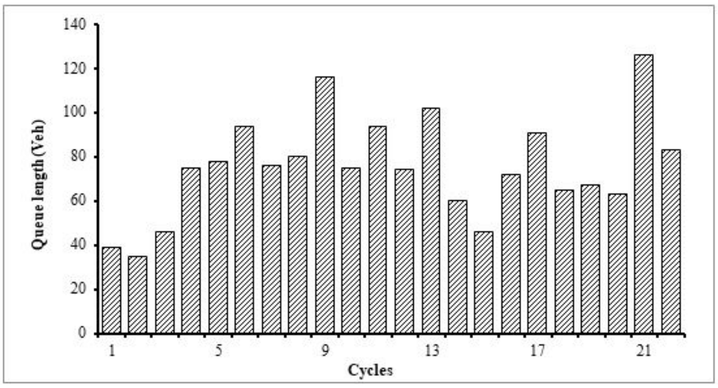
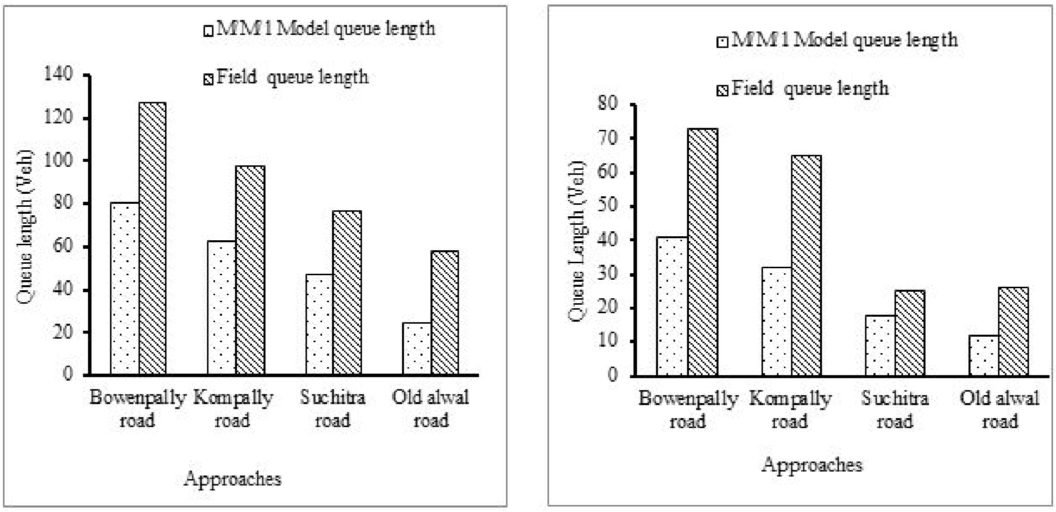


Fig. 4 Observed queue length with cycle by cycle

Table 3 Distribution analysis of the selected signalized intersections

Distribution	Approches							
	Bowenpally Road	Kompally Road	Suchitra Road	Old alwal Road	Narayanguda Road	LV Prasad Marg	Rashtrapathi Road	James Street
Beta4	–	–	–	–	–	–	Beta4	–
Fisher-Tipp	–	Fisher-Tipp	–	–	–	–	–	–
Normal	Normal	–	–	–	–	Normal	–	–
GEV	–	–	–	–	GEV	–	–	–
Gamma	–	–	Logistic	–	–	–	–	Gamma
Wei bull	–	–	–	Wei bull	–	–	–	–
p-value	0.855	0.607	0.970	0.521	0.234	0.505	0.982	0.539



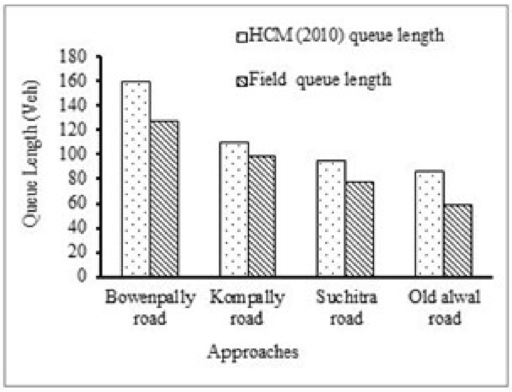
(a) (b)

Fig. 5 Comparisons of peak hour and non-peak hour of estimated queue lengths with observed queue lengths; (a) Avg. queue lengths at peak period; (b) Avg. queue lengths at non-peak period

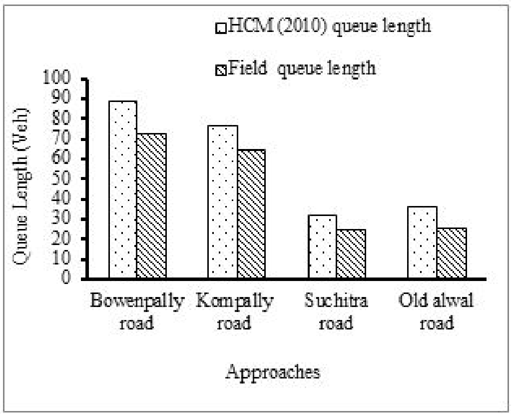
The root means square error (RMSE) calculated and Chi-square test performed between queue length estimated from queueing theory and field observation was found in the range of 7% to 46% and 0.00089 (P-value) during peak and non-peak hours showed a huge difference with field observed values. It may be seen that average queue length estimated from queueing theory method is underestimating the queue lengths as measured in the field. Further, queue length model suggested in HCM (2010) was applied for determining queue length from the field data. The HCM (2010), chapter 18 and 31 suggested in Eq. (1) to estimate the queue length.

$$Q = Q_1 + Q_2 + Q_3, \quad (1)$$

where Q is the average number of the vehicles in queue (average queue length), Q_1 is the first term back of queue size (Veh), Q_2 is the second term back of queue size (Veh), and Q_3 is the third term back of queue size (Veh). The first back of queue size (Veh) is caused by the number of vehicles in the queue by signal cycling with its sequence of phases. The second term back of queue size gives the number of vehicles in the queue by the random effect and fluctuation of cycle-by-cycle when demand exceeds its capacity. The third back of the queue is the initial number of vehicles counted in the queue. Three terms related to the queue size were calculated based on the relations provided by HCM (2010) for estimating the average queue length. The average queue length estimated at an individual approach using HCM (2010) method is also compared with the queue length measured in the field. Fig. 6 provides the charts for comparing the queue lengths under different traffic conditions.



(a)



(b)

Fig. 6 Comparision of field queue lengths with estimated queue length using HCM (2010) method; (a) Avg. queue length during Peak period; (b) Avg. queue length during non-peak period

The comparison performed between the queue lengths from two different methods was based on RMSE and Chi-square test. The RMSE was found in the range of 7% to 32% and the P-value calculated based on the Chi-square test was obtained as 0.00126 and 0.00986 for peak and non-peak hours, respectively. It has been observed that the average queue length estimated from HCM (2010) method is marginally higher than field observed values. Therefore, the method suggested by HCM (2010) also cannot be used directly under mixed traffic conditions. Hence, present study attempted to develop a model for estimating queue length which suits highly mixed traffic conditions as observed in the field.

6 Estimation of field queue length

The various factors influencing queue length are analyzed based on field data collected from the selected intersection approaches I, II, III, IV, and V. The several factors related to traffic, geometric and signal timings were analyzed to check their correlation with field observed queue length. The result of correlation analysis performed between variables are found to be influencing the queue length is shown in Table 4.

The factors those were found as sensitive to observed queue length are further used for developing a multivariable regression model. With the trial and error, best-fit model is proposed that provides an accurate prediction of average queue length formed at a given approach of signalized intersection. The relationship developed using significant variables is given by Eq. (2).

$$\begin{aligned} Q_i &= 19.411 + 0.029 \times (n + V) - 0.166 \times W_a \\ &+ 0.060 \times R + 0.593 \times \ln P_{2W} + 7.738 \times \ln P_{Car}, \\ R^2 &= 0.91, \end{aligned} \quad (2)$$

where:

- V = approaching volume (veh/hr),
- n = minimum number of queued vehicles (veh/cycle),
- W_a = approach width (m),
- R = Red time (sec),
- Q_i = queue length at i[th] approach (veh),
- P_{2W} and P_{Car} are the proportion of two wheelersand proportion of cars respectively.

7 Validation of model

The relationship developed for estimating queue length in the present study was tested and validated with the field data as collected on three other signalized intersections

Table 4 Result of correlation analysis

	Queue length	Volume	Red time	Width	%2w	%Car	%HCV
Queue length	1	–	–	–	–	–	–
Volume	0.96	1	–	–	–	–	–
Red time	0.74	0.029	1	–	–	–	–
Width	−0.73	0.38	0.31	1	–	–	–
P_{2w}	0.68	−0.077	0.046	−0.17	1	–	–
P_{Car}	0.55	0.098	−0.19	−0.27	−0.26	1	–
P_{HCV}	0.22	0.058	−0.23	−0.020	−0.18	0.38	1

approaches VI, VII, and VIII. The traffic and geometric characteristics of these approaches are given in field data section. Average queue length was estimated using Eq. (2) by using the inputs from field. The queue length estimated for the given data (approaching volume, approach width, observed red time and proportions of vehicle types Cars and Two-wheelers) was compared with the actual queue length observed at approaches. The queue lengths were compared based on 45-degree line chart and non-parametric test such as Chi-square test was applied. The chart constructed with the 45-degree line is shown in Fig. 7. The statistical Chi-square test conducted at 5% significant level showed a successful validation of the model developed in the present study as p-value is estimated to be 0.994. The model validated in the present study is appropriate for the approaching volume higher than 350 veh/hr.

8 Conclusions

The analysis of statistical distribution of queue length was carried out in the present study to understand queueing behavior at approaches of signalized intersection. The results confirm that different types of distributions (Normal, Logistic, gama, beta, Fisher-Tipp,Wei bull and GEV) are followed by queueing vehicles at approaches of signalized intersection. The queue length calculated from two different methods (Queueing theory and HCM, 2010) showed marginal difference from field observed values as Root means square error (RMSE) was estimated as high as 46%. The queuing theory method is found to be highly underestimating the field values whereas queue lengths obtained from HCM (2010) are over predicting the values observed in field.

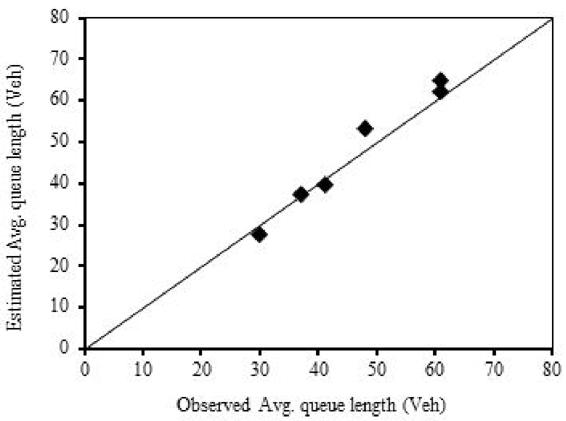


Fig. 7 Validation of queue length model

A multivariable regression model was developed for estimating the queue length by identifying various factors significantly affecting queue length at the approaches of signalized intersection based on correlation analysis. The factors significantly affecting the queue length were identified as approaching volume, width of approach, red time and proportion of vehicle types Car and Two-wheelers. The validation of the proposed queueing model was successfully performed based on field data which was also confirmed by a statistical non-parametric test such as Chi-square. The study concludes that the proposed model for queue prediction is appropriate as it requires the basic input data. The study recommends that the proposed model works well for the signalized intersection operating with a high proportional share (above 30%) of vehicle type Two-wheeler in the mixed type traffic stream. The present study suggested a simple method for estimating the number of vehicles accommodating in queue formed at an approach of signalized intersection and it is limited to the intersections operating under higher volume conditions.

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