Development of Vehicle Queue Model for Selected Signalized Intersections at CBD in Sulaymaniyah City

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Abstract. The objective of this paper is to develop an empirical model for queue length prediction at Signalized Intersections as a function of influence traffic and geometric features. Two Signalized Intersections with different characteristics are selected in Sulaymaniyah city. Geometric design elements were measured through a field survey and satellite image. Field traffic volumes, signal timings and phasing, control delay and queue length were measured during peak and off-peak periods using video recording technique. A statistical approach (SPSS) is used to develop a queue length model. The statistical analysis indicates that both geometric and traffic variables have a significant effect on queue length. The regression model, developed to estimate queue length, shows good correlation with field values. The model has been compared with the SYNCHRO software model. It is found that although SYNCHRO queue overestimates at high v/c (range, but it does not have a significant difference with the field queue a 95% confidence level.

1. Introduction
Queue length is one of the most important performance measures of an intersection. Using queue length, other arterial performance measures, such as intersection delay, travel time and level of service can be estimated quite readily. For traffic engineers, these performance measures to provide indicators for identifying problems, thereby, helping decision makers to improve the level of service from individual intersections to the entire road network [1]. Traffic signals create vehicle queues at signalized approaches that are typically dissipated during the green interval, queue lengths, play an important role, for this is measures not only of the level of service that is offered to the drivers but also of the fuel consumption, and air pollution associated with traffic operations and designing the length of left turn pocket lanes. The existing models for queues at an intersection can be distinguished in micro-simulation models, macroscopic functions and mesoscopic models, e.g. Markov models [2],[3].

Newell provided in 1971 a rigorous method for calculating the time-dependent queues in a general context using the diffusion equation. Newell was the first to characterize the queue state distribution as normally distributed and attests the importance to give an estimate also of the variance. His assumption of a normal probability distribution limits the validity of his model since the queue length distribution has a standard deviation that is often higher than the expected value. A normal distribution would mean that the probability of negative queue lengths is non-zero. On the other hand, his method doesn’t lead to a simple expression and the solution can be found only through numerical approximations) [4]. For the situation that initially the queue is zero, Kimber and Hollis developed a suitable heuristic analytic model for queue length and delay using the coordinate transformation technique [5]. Their model has been applied in e.g. the TRANSYT program [6]. Xuejin built a VISSIM agent-based simulation model and
calibrated based on field data [7]. Akcelik formulated the expression that is most frequently used at present and provided a continuous formulation of the queue evolution using the coordinate transformation technique [8].

\[ Q(T) = \frac{cT}{4} \left( x - 1 + \sqrt{(x-1)^2 + \frac{12(x-x_0)}{cT}} \right) \]  

(1)

Where:
- T is the time step (expressed in number of cycles);
- Q is the number of vehicles in queue at the starting of a green phase;
- \( c = \frac{S \cdot g}{C} \) is the capacity of the arm, equal to the saturation flow S multiplied by the green ratio g / C;
- x is the degree of saturation, ratio between the flow and the capacity;
- \( x_0 = 0.67 + \frac{S \cdot g}{600} \) is the limit value of the degree of saturation above which the stochastic effects are relevant.

This formula is the most used model in case of flows approaching capacity and initial queue \( Q_0 = 0 \). On the other side, it fails in all the other cases where the queue starts from a non-zero initial value limiting its applicability. Catling adapted equations of classical queuing theory to oversaturated traffic conditions and developed a comprehensive queue length estimation procedure that captured the time-dependent nature of queues [9]. Cronje treated traffic flow through a fixed-time signal as a Markov process and developed equations for estimating the queue length and number of vehicle stops. Both the Catling model and the Cronje model were developed for both undersaturated and oversaturated conditions [10].

2. Study Objective

The purpose of this study is to develop a statistical model for the prediction of vehicle queue length at the signalized intersection based on existing traffic and geometric conditions.

3. Data Collection and Abstraction

In order to achieve the objective of this study, traffic and geometric data have been collected. A total of nine lane groups were selected from two intersections in Sulaymaniya city. The locations are illustrated in Figure 1.

In this research, the statistical approach will be followed to develop the model for estimating queue as a function of the influencing traffic and geometric factors. Several variables are used to simulate the geometric and traffic characteristics that affect total queue (geometric and control delay), it can be categorized as traffic conditions and geometric features. Traffic conditions such as effective green time for movement or lane group (g), capacity of lane group (c), cycle length (C) and vehicular flow rate (v). Geometric features such as width of lane group at stop line (w).

3.1 Traffic Volume Data Collection

Traffic volumes for the intersections must be specified for each movement on each approach. Data are gathered during times when there were no holidays or occasions and clear weather for the intersections. The selected intersections were recorded four days in a week (Monday, Tuesday, Wednesday, and Thursday) during peak and off-peak periods at four hours durations (two hours at A.M from 7:00 to 9:00, two hours at P.M from 2:00 to 4:00) for each intersection in a day. The period of the volume counting was divided into 15-minute intervals distributed over the best time of data counting. Video recording technique was adopted to collect traffic volume from a vantage point nearby intersection. The recorded video films were played back many times to abstract the recorded data together with EVENT program. This program turns the computer into data capturing device, and provide a digital representation of the selected data.
3.2 Geometric Data
The details of lane geometric include number of lanes, Lane widths are shown in table 1 for the selected intersections.

Table 1. Geometric Features for the Selected Intersections

| Intersection Name | Approach Name | Lane Group | Movement | Lane Width (m) | No. of Lanes | One Way or Two Way |
|-------------------|---------------|------------|----------|----------------|--------------|-------------------|
| Palace            | Salim         | 1          | LT+UT    | 3.2            | 1            | Two way           |
|                   | Salim         | 2          | TH       | 3.2            | 1            | Two way           |
|                   | Salim         | 3          | RT       | 4.5            | 1            | Two way           |
|                   | Baban         | 4          | LT       | 2.4            | 1            | Two way           |
|                   | Baban         | 5          | TH       | 2.4            | 1            | Two way           |
|                   | Baban         | 6          | RT       | 2.4            | 1            | Two way           |
| Mamostayan        | 7             | RT         | 3.7      | 2              |              | Two way           |
| Mawlawi           | 1             | LT         | 4.1      | 2              |              | One way           |
| Kawa              | 2             | TH         | 3.2      | 2              |              | One way           |
| Kawa              | 3             | LT         | 4.5      | 1              |              | One way           |
| Sara              | Sabunkaran    | 4          | TH       | 4.8            | 1            | One way           |
| Sabunkaran        | 5             | RT         | 5.0      | 1              |              | One way           |
| Piramerd          | 6             | LT+UT      | 2.35     | 2              |              | Two way           |
| Piramerd          | 7             | RT         | 4.2      | 2              |              | Two way           |

3.3 Field Queue Length Measurement
The observation was made from replaying video films on each lane for all approaches to collect the queue length during peak hour periods. The observed data for the average queue length during the red phase, Existing Traffic Conditions of Selected intersection are as shown in table 2.
Table 2. Existing traffic condition of selected intersection

| g/C | v/c | Cycle Length (sec) | Field Queue Length (veh) | SYNCHRO Queue Length (veh) |
|-----|-----|--------------------|--------------------------|--------------------------|
| 0.61 | 1.06 | 300               | 31.333                   | 67.95                    |
| 0.58 | 0.79 | 270               | 15.166                   | 37.225                   |
| 0.56 | 1.022 | 266              | 20.66                    | 62.4                     |
| 0.37 | 1.172 | 300              | 24.333                   | 63.55                    |
| 0.39 | 1.154 | 270              | 23.75                    | 49.7375                  |
| 0.42 | 0.95 | 266              | 23.666                   | 35.4                     |
| 0.48 | 0.73 | 97               | 11.666                   | 5.6875                   |
| 0.48 | 0.56 | 196              | 9.665                    | 9.2125                   |
| 0.54 | 0.526 | 225              | 13.666                   | 9.7375                   |
| 0.47 | 0.577 | 97              | 2.625                    | 1.8                      |
| 0.48 | 0.5 | 196              | 6.166                    | 6.2625                   |
| 0.44 | 0.691 | 225             | 16.666                   | 11.275                   |
| 0.47 | 0.547 | 97              | 6.5                      | 1.5375                   |
| 0.48 | 0.535 | 196             | 12.666                   | 5.8875                   |
| 0.44 | 0.5 | 225              | 11.25                    | 6.7625                   |

4. Model Development

4.1 Left Turn Queue Model
The summary of the stepwise regression model for queue length of left turn movements can be seen in table 3.

Table 3. Stepwise regression models summary for queue length of left turn movements. (by SPSS v.20)

| Model | Unstandardized Coefficients | Standardized Coefficients | t | Sig. | R² | Adj.R^2 | SEE |
|-------|-----------------------------|---------------------------|---|------|----|---------|-----|
|       | B   | Std. Error | Beta |       |  |       |     |
| Constant | -9.482 | 2.912 | -3.256 | 0.007 |  |       |     |
| v/c value | 18.223 | 4.488 | 0.571 | 0.002 | 0.868 | 0.846 | 3.1479 |
| Cycle | 0.051 | 0.016 | 0.449 | 3.195 | 0.008 |  |     |

The results of regression technique and selected developed model are shown in equation 2.

\[ q = 0.051 \cdot C + 18.223 \cdot \frac{v}{c} - 9.48 \]

The variables that have a significant impact on the queue are explained in table 4 for the linear regression model, with statistical characteristics. The minimum and maximum traffic parameters limits represent the range at which the model will be applicable.
Table 4. Data range and statistical characteristics for queue length model of left turn movement.
(by SPSS v.20)

| Variable          | Minimum | Maximum | Mean   | Std. Deviation |
|-------------------|---------|---------|--------|----------------|
| v/c value         | 0.500   | 1.172   | 0.75427| 0.251457       |
| Cycle (sec)       | 97.0    | 300.0   | 215.067| 70.1310        |

The correlation coefficients between all of the variables are calculated and the correlation matrix is set up. This matrix can be seen in Table 5.

Table 5. Correlation coefficient matrix for queue length of left turn movement.
(by SPSS v.20)

| Field Queue (veh) | g/C | v/c | Cycle (sec) |
|-------------------|-----|-----|-------------|
| Field Queue (veh) | 1.00|      |             |
| g/C               | 0.05| 1.00|             |
| v/c               | 0.870| 0.118| 1.00       |
| Cycle (sec)       | 0.829| 0.351| 0.666      | 1.00 |

4.2 Through Queue Model

The summary of the stepwise regression model for queue length of through movements can be seen in Table 6.

Table 6. Stepwise regression models summary for queue of through turn movements.
(by SPSS v.20)

| Model            | Unstandardized Coefficients | Standardized Coefficients | t     | Sig. | R²   | Adj. R² | SEE   |
|------------------|-----------------------------|---------------------------|-------|------|------|---------|-------|
| (Constant)       | -11.618                     |                           | -2.755| 0.025|      |         |       |
| 2 Cycle v/c value| 0.071                       | 0.540                     | 2.978 | 0.018| 0.853| 0.816   | 4.10304|

The results of the regression technique and selected developed models can be seen in equation 3.

\[ q = 0.071 \times C + 13.33 \times \frac{v}{c} - 11.618 \]  

(3)

The variables that have a significant impact on the queue length of through movements are explained in Table 7 for the linear regression model, with statistical characteristics. The minimum and maximum traffic parameters limits represent the range at which the model will be applicable.

Table 7. Data range and statistical characteristics for queue length model of through movement.
(by SPSS, v.20)

| Variable          | Minimum | Maximum | Mean   | Std. Deviation |
|-------------------|---------|---------|--------|----------------|
| v/c value         | 0.15    | 1.30    | 0.7607 | 0.33875        |
| Cycle (sec)       | 97      | 300     | 225.73 | 72.874         |
The correlation coefficients between all of the variables are calculated and the correlation matrix is setup. This matrix can be seen in table 8.

| Field Queue(veh) | v/c  | g/C  | Cycle(sec) |
|------------------|------|------|------------|
| Field Queue(veh) | 1.000|      |            |
| v/c              | 0.831| 1.000|            |
| g/C              | -0.144| -0.256| 1.000      |
| sec(Cycle)       | 0.854| 0.664| 0.292      |

5. Model Validation
The validation process is determining whether the model is appropriate for the local conditions; it compares model prediction with field measurements or observations [11]. The validation objective is to estimate the sufficiency of the proposed prediction models and measure the error or accuracy of the prediction for the validation period. There are different ways used for models validation. One of these ways is to compare the model with other data group that is excluding in model constructing [12]. The data used for validation is peak hour data abstracted from video records at different times for the same intersections in the network. The average field queue from peak hour is regressed with the queue time predicted by the model. The regression results are shown in figures 2 and 3 and table 9. It can be concluded from the models values of R^2 that, the predicted values from models can represent the actual field values of queue length.

| Model                | Model Fit                  | R^2-value | Adj.R^2-value | Sig.  |
|----------------------|----------------------------|-----------|---------------|-------|
| 1- Left Queue Model  | 1.139 * Field Queue – 2.24 | 0.906     | 0.874         | 0.013 |
| 2-Through Queue Model| 1.058 * Field Queue – 1.944| 0.956     | 0.942         | 0.004 |

Figure 2. Observed versus predicted queue length for the model of left turn movement. (by SPSS, v.20)

Figure 3. Observed versus predicted queue length for the model of through movement. (by SPSS, v.20)
6. Analysis of developed queue model parameters
Queue length depends on cycle length and degree of saturation. From the previous models of queue length, it is obvious that queue length increases as cycle time and v/c value increase. The increase in queue is attributed mainly to the increase in the effective red and hence in waiting time for vehicles before the start of green.

7. Field queue length comparison with SYNCHRO software model
SYNCHRO 8.0 software has been applied for these intersections. SYNCHRO is a macroscopic analysis and optimization program for modeling and optimizing traffic signal timings. The queue length results produced by SYNCHRO were compared with field queue. A comparison is made by using the paired samples t-test. The paired samples t-test is made by using SPSS V.20 program. The paired t-test results, as in table 10, with a P-value of 0.061 for left turn movement and 0.064 for through movement. So, the hypothesis is that there is no significant difference accepted at 95% confidence.

| Movement            | Pairwise Sample t-test | P-value |
|---------------------|------------------------|---------|
| Through Movement    |                        |         |
| t                   | -2.039                 | .061    |
| p                   | -2.080                 | 0.064   |

p-value greater than 0.05, so that there is no statistically significant difference

8. Conclusion
Within the limits of traffic and geometric features of the study area, the conclusions that can be summarized are as follows:
1. Regression model developed to estimate queue length shows good correlation with field values. This model can be used to estimate queue length at any intersections knowing signal timing, traffic volume. This model may not be suitable for the extreme range of input variable.
2. All signalized intersection suffers from long cycle length that it causes high delay time values and high queue length.
3. Queue length for signalized intersections produced by SYNCHRO has a no significant difference with the queue length measured at field with 95%.

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