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A SIMPLE METHODOLOGY FOR ESTIMATION OF QUEUE LENGTH

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ABSTRACT

Urban arterials are characterized by frequent intersections. Queue length and delay are the two primary measures of performance of intersection. These measures play a primary role in determining the arterial performance. This article presents a methodology to determine the number of vehicles in queue at a signalized intersection for under saturated traffic conditions. The results obtained were validated using actual values that are manually extracted. The root-mean-square error is of the range 1.3 vehicles for estimation of number of vehicles in queue. The various aspects that have to be considered in accurate estimation of performance measures are also discussed.

1.INTRODUCTION

The typical characteristics of urban traffic are frequent stops due to congestion and intersections, and associated delays and pollution. One of the major reason for this is the presence of signalized intersections. Signalized intersections, while helping to make the traffic more organized and safe, may lead to more delays, especially during off-peak hours. The major parameters that are used to quantify the performance of a signal are the queue length and delays. Thus, the information of number of vehicles in queue and associated delay are useful for devising traffic management strategies that would help in improving the performance of traffic network. This study presents a simple approach to estimate the queue length using the data that are collected by automatic detectors for real time applications.

The most commonly used and widely employed sensors for automatic detection of vehicles are the loop detectors. The loop detector produces an electric pulse when a vehicle passes over it. The produced pulse is digitized by setting all values higher than a threshold equal to one and others equal to zero. Loop detector data dominates the traffic detection systems due to its low costs. Automatic detectors however suffer from associated errors in detections. The present study employs traffic data collected from loop detectors for estimation of number of vehicles in queue at intersections. The data that are collected from the loop detectors include the stop bar and advanced detector actuations which gives the traffic count, time occupancy as well as the time headway. These traffic parameters are used in this study to develop suitable estimation schemes for finding out the number in queue.

2. LITERATURE REVIEW

The number of vehicles in queue at any instant of time is a spatial parameter, the direct measurement of which is difficult. Hence, it is usually estimated from other location based data such as flow. The flow based methods are simple and effective but there are various limitations associated with these methods. A commonly used method to estimate queues is to use the simple Input-Output model. The Input-Output model based on conservation of vehicles equation determines traffic queues based on the difference between the total arrivals and the total departures of a traffic facility. There are various drawbacks associated with these methods. The primary drawback is that the method requires the initial number of vehicles inside the section to estimate the number of vehicles in queue. Secondly, this approach is very sensitive to the accuracy of the flow measurements. Numerous research has been reported on estimation of performance measures of signals and some of them are discussed below.

Sharma *et al*., [1] presented two techniques, input-output method and hybrid technique for real-time measurement of vehicle delay and queue length at a signalized intersection. The methods used the data from advance and stop bar detectors along with signal timing information suitably for determining the performance measures of the intersection. The possible application and advantages of the developed models in various scenarios were described. Chang *et al*., [2] presented a simple methodology to estimate queue length on an approach to a signalized intersection. This method has a minimal set of data requirements specifically flow, occupancy, cycle length, and detector setback. The key element of the algorithm is the estimation of two baseline occupancies that correspond to the relative position of the queue with respect to the detector location. The results of the algorithm have been evaluated using traffic simulation and also compared to field observations. Liu *et al*., [3] estimated intersection queue length by using shockwave theory. The approach could estimate time-dependent queue length even when the signal links are congested with long queues.

Model based approaches have also been widely employed for the reliable estimation of traffic parameters. Vigos and Papageorgiou [4] developed a Kalman-filter-based real-time estimator for the vehicle count within signalized links, using three detector cross stations, to allow for reliable estimates on the basis of one single time-occupancy measurement that is typically available in urban signalized links. Lee *et al.,* [5] developed a robust queue estimation algorithm for three motorway on-ramps based on the Kalman filter framework. The fundamental conservation model was used to estimate the queue size with the flow-in and flow-out measurements. This projection results were updated with the measurement equation using the time occupancies from mid-link and link-entrance loop detectors. Wu *et al.,* [6] evaluated three different methods namely Kalman filter using a simplified model using linear occupancy and by Highway Capacity Manual (HCM) back of queue method, for estimation of on-ramp queue length. It was concluded that the Kalman Filter estimation scheme and model based on linear occupancy are suitable for real world operations.

The present study is aiming for an accurate and efficient queue length estimation method using the data reported by the automated sensors.

3. DATA COLLECTION AND METHODOLOGY

The main focus of the study is in the estimation of number of vehicles in queue at signalized intersections under low volume conditions. In order to achieve this objective, data collection was carried out at two signalized intersection in Lincoln city, Nebraska, USA namely 17G and 27G Cornhusker. The traffic condition that exist in the study site is low volume with lane disciplined and homogeneous traffic. There are three lanes in both directions at each of these intersections. Loop detectors are installed at the entry to the intersection, which is 90 m and 100 m behind the stop line for 17G and 27G intersections respectively and at the exit from the intersection, which is just ahead of the stop line. Data were analyzed for one hour each from 17G intersection and 27G Cornhusker in peak and off-peak hour. The actual number of vehicles entering and exiting was observed manually from video for estimation of actual number of vehicles in queue.

The data is obtained in the form of digital pulses (0 and 1) along with the time stamps. The required data for the study which are the vehicle counts for time intervals of 10 seconds were extracted from the advance and stop bar detector actuations. The signal timing information was also analyzed.

The present study uses vehicle count from the advance and stop bar detectors and the signal information to evaluate the performance measures of the intersection namely number of vehicles in queue over an analysis period of every 10 seconds. The conservation of vehicles equation was proposed to formulate the expression for number of vehicles in queue. The conservation of vehicles necessitates that the number of vehicles in a given section at the next instant of time is equal to the sum of the number of vehicles at the current instant of time and the difference between the number of vehicles that have entered and exited that section in this time interval.

Equation (1) shows the equation for input-output method which uses the conservation principle to estimate the number of vehicles in the next instant of time N(k+1)

$$N(k+1) = N(k) + (N_{entry}(k) - N_{exit}(k)). \quad (1)$$

where, $N(k)$ is the number of vehicles in the section between the stop line and the advance detector during the current time instant, N_{entry} (k) and N_{exit} (k) are the number of vehicles that have entered and exited the intersection during the time interval from k to k+1.

The data obtained from the loop detector namely the entry count and exit count at 10 seconds interval was used to estimate the number of vehicles in queue. The initial number of vehicles in queue was found from video, which was used to start the estimation. Figure 1 shows the estimated queue by using Input-Output method for 27G Cornhusker intersection in peak hour.

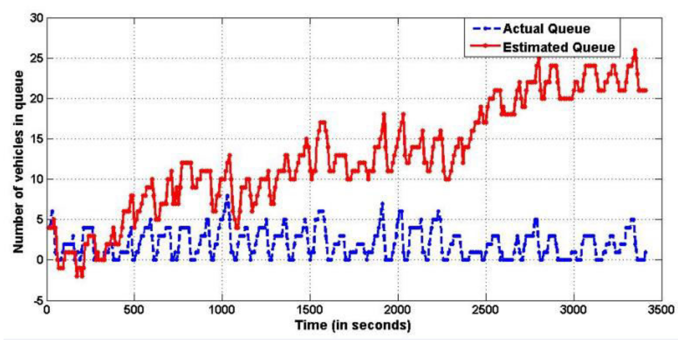

FIGURE 1. QUEUE ESTIMATED BY INPUT-OUTPUT METHOD

It can be observed that the Input-Output method do not estimate the number of vehicles in queue. The reason behind this is the inaccuracy in the count data that are obtained from the loop detectors. However, Sharma *et al*., [1] used multiple constraints to overcome this problem for every cycle. Further, a suitable approach that can be used for the estimation with such errors in data was developed.

A queue polygon, which gives the number of vehicle in queue at any instant is developed using an algorithm that employs the information from field such as the exit detector actuations and signal timing information. The algorithm requires only simple input such as the vehicle actuations from the detector at the stop line and the signal timing information. The algorithm process these input at the end of every cycle to generate a queue polygon that estimates the number of vehicles in queue for the previous cycle. The algorithm uses the signal timing information to determine the points such as the cycle start time, end of red and end of green for every signal cycle. As the exit detector is located ahead of the stop line there are no actuations in the detector, during red time. As the signal turns green, the detector records the actuations continuously at a minimum headway after an initial start up lost time. The count of the number of vehicles that has time headway around the minimum headway, are taken as the number of vehicles in queue during that cycle. Knowing the number of vehicles in queue during the red and duration of red time, the algorithm develops the arrival part of the queue polygon.

The queue clearance time is determined by finding a cut-off point when the time headway between vehicles exceeds a threshold value, selected as four seconds which is based on the actual observation from the video, when the queue actually gets cleared. Hence, the vehicles that pass the exit detector after the queue clearance time are the vehicles that arrive during the green time of the cycle and pass freely without any delay. By knowing the maximum number of vehicles in queue at the end of red and the queue clearance time, which is the time elapsed between the start of green and the time when the queue clears, the departure part of the queue polygon is also developed. This process is repeated for every cycle, which generates the queue polygon for every cycle. Since the arrival and departure part of the queue polygon is generated from the information that are obtained from the end of green and red, it is required to wait till the end of the cycle to estimate the queue lengths at each point. This method can be applied only for under saturated conditions where the queue gets completely cleared off in the green time.

The developed method was tested by comparing with the actual number of vehicles in queue. Figure 2 shows the comparison of the estimated queue with the actual queue for 27G Cornhusker intersection in peak hour. It can be observed that the estimation scheme estimates the number in queue reasonably well. The results were evaluated for all the study sections by the estimation scheme by analyzing the Root Mean Square Error (RMSE) by comparing with the actual queue.

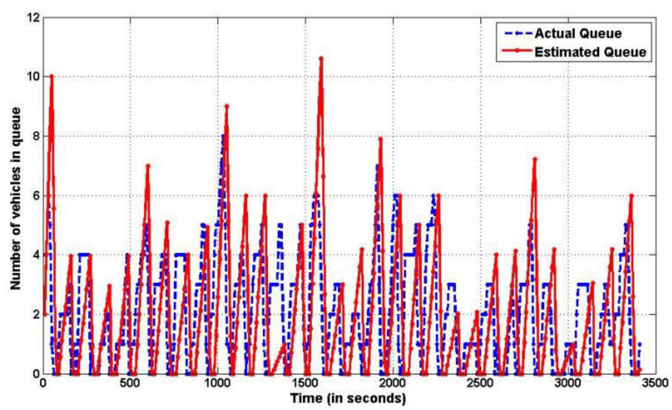

FIGURE 2. QUEUE ESTIMATED BY QUEUE POLYGON METHOD

RMSE is a measure of estimation stability. The lesser the value of RMSE, the better is the forecast obtained.

$$\text{RMSE} = \sqrt{\frac{1}{\text{N}}\sum_{k=1}^{\text{N}}\left[\text{N}_{\text{meas}}(k)\text{-}\text{N}_{\text{est}}(k)\right]^2} \qquad (2)$$

where $N_{meas}(k)$ and $N_{est}(k)$ are the estimated and the actual number of vehicles in queue during the k^{th} interval of time with N being the total number of time intervals. Table 1 shows the RMSE obtained for queue and delay for different conditions at two intersections. It can be observed that the RMSE are low indicating the usefulness of the developed schemes.

TABLE 1.EVALUATION OF ESTIMATION SCHEME

Intersection and Traffic Condition	**RMSE**
	Queue (veh)
17G off-peak	1.2
17G peak	1.3
27G off-peak	1.5
27G peak	1.3

4.CONCLUSIONS

The study investigated the reliability of flow based estimation scheme for the estimation of performance measure of intersection. Analysing the drawbacks in the flow based methods, the study developed a suitable estimation scheme for reliable estimation of number of vehicles in queue at signalized intersections. The proposed method has shown sucessful results in estimating the number of vehicles in queue by using the data obtained from loop detectors and signal timing information.

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