Estimation of Queue Length at Signalized Intersections based on Electronic Police Data

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Abstract. Aiming at the problems of complicated traffic data detection environment in China and the larger calculation error of queue length at signalized intersections, a model of queue length estimation at signalized intersections based on electronic police data was studied. By analyzing the characteristics of travel time in the electronic police data, the jump position is extracted and the number of parking times is divided. Take the intersection of Zhongguan Road and Donghuan North Road in Ningbo as an example for simulation verification and analysis. Simulation results show that the accuracy rate of the model is over 83%, and the accuracy rate during peak hours is 90.8%, which has good adaptability.

1. Introduction

Signalized intersections are the key to the capacity of urban roads, and they are also frequent locations of traffic congestion [1] [2]. With the development of science and technology, a variety of new traffic control equipment and new traffic detection technology have been applied to the traffic management system, which provides a strong support for the optimization and development of traffic [3]. As an important factor in judging traffic congestion, queue length can reflect the congestion status of intersections in a timely manner, and plays a vital role in optimizing traffic signal control and evaluating signal timing schemes [4] [5]. Regarding the queue length at signalized intersections, most of the existing researches are mainly based on geomagnetic induction coils, GPS, and video processing technologies. Electronic police data is rarely used as a data basis. Sometimes, traffic conditions at consecutive intersections need to be considered. The amount of data required is huge and there are defects in practical applications. Electronic police data has the advantages of easy access, low cost, and high accuracy.

Based on the electronic police data, using the relationship between the vehicle travel time and the time when the vehicle leaves the intersection, the jump characteristics of the vehicle travel time are extracted, and the queue length model is established by the jump characteristics, and the queue length is finally calculated. Then take the actual intersection in Zhenhai, Ningbo as an example, and use VISSIM traffic simulation software for simulation verification.
2. Analysis of electronic police data

2.1. Data Characteristics
The electronic police can obtain the following data through real-time monitoring of road intersections: the location of the intersection, the lane number, the license plate number, the type of the license plate, and the moment when the vehicle leaves the intersection [6] [7]. The electronic police data only records the information of vehicles passing through the intersection, and it is recorded once when the vehicle’s head passes the intersection parking line position. Therefore, the recorded departure times of the vehicles are obviously cyclical.

![Figure 1. Periodic Distribution of Travel Time](image1)

2.2. Vehicle Queuing Analysis
The time interval and number of vehicles arriving at the intersection change randomly, in each signal period, the red light is blocked, and there may be blocked vehicles in front of the parking line. Especially during rush hours, a sudden increase in traffic volume will cause the intersection to be in a supersaturated state, resulting in a secondary parking phenomenon.

As shown in the figure below, $L_1$ is the vehicle arrival curve, $L_2$ is the vehicle emission curve, and $BB'$ is the cumulative number of vehicles before the parking line. When the number of arriving vehicles in a cycle is greater than the number of discharged vehicles, the intersection will be oversaturated, resulting in secondary parking. $AA'$ is the number of vehicles stranded before the parking line after the end of the first signal cycle. When the signal period changes, more vehicles are emitted in one cycle, reaching a point of saturation at point $C$, and all emissions from vehicles to $D$ are completed.

![Figure 2. Vehicle arrival-departure situation](image2)
3. Queue Length Model
Assume a trip time series:

\[ T_l, T_h, \ldots, T_{X-i}, T_{X-i+1}, \ldots, T_{X-1}, T_X \]  \hspace{1cm} (1)

Based on the electronic police data, this article takes the average of the first 5% of the least travel time in the one-day electronic police data as the free-flow travel time \( T_0 \) in this model. The travel time \( T \) is the difference between the time when the vehicle leaves the parking line at the intersection and the time when the vehicle leaves the parking line at the previous intersection. By analyzing the point distribution of the departure time-travel time distribution curve, it is possible to extract the travel time jump characteristics, which are divided into two types according to whether there are jumps. The rules for judging whether the transition is as follows:

Suppose that the transition occurs between \( x-i \) and \( x-i+1 \) points, then:

Jump up: \[
\begin{align*}
T_{x-i+1} & \geq r + T_{x-i} \\
t_{y+i} & \geq r + t_{x-i}
\end{align*}
\]

Jump down: \[
T_{x-i+1} \leq T_{x-i} - r
\]

All other cases are considered non-jumping.

3.1. In the Case of Transition (When there is a jump, \( T_h \) and \( T_x \) may not be in the same cycle)

Figure 3. Travel time distribution in the case of jump

When \( T_x = T_0 \), it must be an upward transition, and \( x \) has no queue.

When \( T_x > T_0 \), determine the number of parking times at \( T_x \):

If \( T_x \in (T_0 - \alpha, T_0 + \alpha) \), then \( x \) has no parking (\( \alpha \) is the delay value when the vehicle is not in a queue, usually between 5 and 10).

Suppose \( T_x \in T_0 + (n_1 - 1)C, T_0 + n_1 C \) (referred to as interval a), the number of parking stops for \( x \) is \( n_1 \), \( T_x \in T_0 + n_2 C, T_0 + g + n_2 C \) (referred to as interval b) The number of parking stops for \( x \) is \( n_2 \).

If \( n_1 = n_2 + 1 \), the number of parking times of \( x \) is \( n_1 \). At this time, the maximum number of vehicles queued by \( x \) is:

\[
X = \left[ \frac{(t_x - t_h) + (n_1 - 1)(t_{x-i} - t_h)}{3600} + 1 \right] \cdot \frac{1}{m} \]  \hspace{1cm} (2)

If \( n_1 = n_2 \), the number of parking times of \( x \) may be \( n_1 \) or \( n_1 + 1 \).

Go forward from \( T_h \):

- If \( T_l \leq T_h \), then \( n_1 \)
- If \( T_l > T_h \), then \( n_1 + 1 \)

When the number of stops is \( n_i \), the maximum number of vehicles queued by \( x \) is the same as in formula (2).

When the number of stops is \( n_i + 1 \), the maximum number of vehicles queued by \( x \) is:
\[ X = \left[ \frac{(t_x-t_h)+(t_x-i-t_h)}{3600} S + 1 \right] \cdot \frac{1}{m} \] (3)

3.2. Without Transition (At this time, the default Th and Tx are the same period.)

When \( T_s = T_0 \), then \( x \) has no queue.

When \( T_s > T_0 \), determine the number of parking times of \( T_h \) and \( T_x \):
- If \( T_h \) and \( T_x \) belong to interval \( a \), then the maximum number of vehicles queued by \( x \) is the same as (2).
- If \( T_h \) belongs to interval \( b \), \( T_x \) belongs to interval \( a \), then traverse from \( x \). When traversing to \( T_{x,i} \), \( T_{x,i+1} \) belongs to interval \( b \), then \( T_{x,i+1} \) is experienced by \( x \). The largest number of queued vehicles is the leader of the cycle. The maximum number of vehicles queued by \( x \) is:

\[ X = \left[ \frac{(t_x-t_{x,i+1})+(n-2)(t_{x,i+1}-t_i)+(n-1)(t_{x,i+1}-t_{i+1})}{3600} S + 1 \right] \cdot \frac{1}{m} \] (4)

If \( T_h \) and \( T_s \) belong to the interval \( b \), it is determined whether \( T_h \) and \( T_l \) meet the conditions of the upward transition.

If so, the maximum number of queued vehicles that \( x \) has experienced is:

\[ X = \left[ \frac{(t_x-t_h)+(t_l-t_x-i+1)}{3600} S + 1 \right] \cdot \frac{1}{m} \] (5)

If not, traverse forward through \( T_l \) to find the position of the upward transition (from \( T_{x,i} \) to \( T_{x,i+1} \)), then the maximum number of vehicles queued by \( x \):

\[ X = \left[ \frac{(t_x-t_l)+(t_{x,i+1}-t_{x,i+1})n(t_{x,i+1}-t_{i+1})}{3600} S + 1 \right] \cdot \frac{1}{m} \] (6)

There is no case where \( T_h \) belongs to interval \( a \) and \( T_x \) belongs to interval \( b \).

3.3. Queue Length Calculation

The vehicles at the intersection are composed of cars: trucks = 19: 1, so the maximum queue length \( L \) is finally calculated:

\[ L = 6 \times 0.95 \times X + 12 \times 0.05 \times X = 6.3X \] (7)
4. Simulation experiments

4.1. Simulation modeling

In order to verify the validity of the model, a VISSIM simulation model was established using the straight lane at the intersection of Zhongguan Road-Yifu Road to the intersection of Zhongguan Road-Donghuan North Road in Zhenhai District of Ningbo City as the research object, as shown in Figure 5. At the same time, in order to verify the adaptability of the model at different times, different signal timings are performed on the peak and peak hours based on the true timing scheme of Zhenhai District, as shown in Figure 6.

![Simulation model](image)

**Figure 5. Simulation model**

**Table 1. Signal timing scheme**

| Intersection                  | period         | Signaling scheme |
|--------------------------------|----------------|------------------|
| Zhongguan Road-Yifu Road       | Rush hour      | ![Signal timing](signal timing) |
|                                | Stationary hour| ![Signal timing](signal timing) |
| Zhongguan Road-Donghuan North Road | Rush hour     | ![Signal timing](signal timing) |
|                                | Stationary hour| ![Signal timing](signal timing) |

4.2. Parameter calibration

According to the actual traffic situation at the intersection of Zhongguan Road and Donghuan North Road, four different time periods were selected for simulation verification. A is the Rush hour, and B and C are Stationary hour. The simulation duration is 3600s, the simulation data sampling interval during Stationary hour is 98s, and the simulation data sampling interval during Rush hour is 118s, which is consistent with the signal period of the intersection. It is to collect the arrival flow, release flow and maximum queue of vehicles in each cycle. Length in order to achieve the prediction and analysis of the traffic volume and queuing length of the entrance channel [9]. The electronic police data is extracted with a step of 0.6s, and the data in the period of 2000 ~ 5600s is selected for model verification.
### Table 2. Intersection time and traffic allocation

| Period number | Start and end time | Flow / hour |
|---------------|--------------------|-------------|
| A             | 9:30—10:30         | 700         |
| B             | 7:30—8:30          | 1400        |
| C             | 16:45—17:45        | 1100        |

### Table 3. Distance calibration

| Detector name                  | Relative distance from Zhongguan Road-Donghuan North Road parking line / m |
|--------------------------------|--------------------------------------------------------------------------------|
| Upstream parking line          | -358.7                                                                       |
| Inspection checkpoint 1        | 10.0                                                                          |
| Inspection checkpoint 2        | 12.0                                                                          |
| Travel time detector start     | -355.6                                                                       |
| Travel time detector end       | 3.1                                                                           |
| Queuing counter                | 2.7                                                                           |

Distance calibration was performed using the Zhongguan Road-Donghuan North Road parking line as a reference point, and the simulated free-flow speed $V_0 = 24.7s$ and the saturated flow rate $S = 1900pcu/h$ were determined.

Through simulation modeling, the data obtained by using the queue length model is verified, and the queue length is finally obtained. The accuracy of the model was evaluated using mean absolute error (MAE) and mean relative error (MAPE). The specific formula is as follows:

$$ MAE = \frac{1}{n} \sum_{t=1}^{n} |actual(t) - forecast(t)| $$  \hspace{1cm} (8)
$$ MAPE = \frac{1}{n} \sum_{t=1}^{n} \left| \frac{actual(t) - forecast(t)}{actual(t)} \right| \times 100\% $$ \hspace{1cm} (9)

4.3. Result analysis

Due to the influence of the timing of the upstream intersection, no overflow caused by long queues occurred during the simulation. The real data of Zhongguan Road-Donghuan North Road was imported into the VISSIM simulation. Compare the queue length result with the model calculation result, as shown in the figure below.

![Figure 6. Comparison of Queue Length in Period A](image.png)
5. Conclusion

In this paper, by studying the different travel time characteristics of vehicles with time distribution, a queuing length model at a signalized intersection is established. The real data at the intersection of Zhongguan Road and North East Ring Road of Ningbo City was used for simulation and the following conclusions were reached:

The accuracy of the queuing length models established in this article are all above 83%, which can accurately predict the queuing length at intersections and meet the actual traffic management needs. The errors of the model mainly come from two aspects. On the one hand, whether the ratio of cars and trucks is accurate. Due to the inconsistent length of different models, errors will occur in determining the length of the queue; on the other hand, the randomness of vehicle driving behavior, and the difference between different vehicles when parking and starting. The driving behavior can also cause errors in the queue length.

By comparing the average relative errors, it is found that the accuracy of the model will increase as the queue length increases.

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