Oversaturation Overflow Detection at Intersections Based on Electric Police Data

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Abstract. Traffic congestion is still an important problem that plagues the city. The “Deadlock” of the road network caused by the queuing overflow has a more serious for traffic. In the past, the overflow research was based on fixed detectors or floating car data with low sampling rate. It can only make rough judgments on queue overflow, and it is difficult to effectively support refined queue management. In recent years, the coverage of electronic police has become higher and higher, and the data has the characteristics of high sample rate and trajectory. Therefore, this paper is based on the electronic police's license plate identification data to obtain travel time delay and vehicle relationship and building a queuing overflow model. Secondly, by constructing a VISSIM simulation model, and then judging the oversaturated queue overflow at the intersection library through the delay time, the validity of the model was verified by combining with the traffic data of Ningbo Zhenhai District. The research results provide theoretical basis and method support for road traffic queuing management.

1. Introduction

Signalized intersections are an important part of urban traffic. The design of intersections, signal control, and phase design all affect the efficiency of traffic efficiency. With the increase of vehicles, the contradiction between the demand for peak motor vehicles and road resources is increasing in the morning and evening. Traffic overflows often occur, causing the road network to "lock up". If the overflow is not controlled, it will spread from a single intersection to an adjacent intersection, causing the entire road network to be paralyzed. Therefore, the timely control of traffic overflow is the research focus of traffic control.

Some scholars have long studied traffic overflow. Gazis studied the optimal control of over-saturated intersections, he considered traffic overlap as an over-saturated phenomenon [1]. In response to this over-saturated phenomenon, Qiao Henning established a parking position and vehicle delay model based on GPS data [2]. Other scholars have studied vehicle queue length and queue overflow based on traffic wave theory [3-4]. Some scholars analyze the phenomenon of traffic queue overflow based on shock wave theory [5]. Zhang Lidong, L. Jia, and W. X. Zhu proposed a fuzzy recognition algorithm for traffic overflow based on intelligent fuzzy theory [6]. Li Mengmeng described and analyzed the phenomenon of queue overflow, divided the vehicle queue into two types, modeled the
queue length using traffic wave theory, and performed simulation verification [7]. Based on this, a solution is proposed. Yang Xiufeng, Wang Dong, Ye Kaifeng and Hao Siyuan Real-time control of the cyclic phase, restricting the traffic of vehicles in the overflow direction, and achieving management of traffic overflows at urban intersections [8]. Daganzo gives empirical and theoretical methods to control traffic overflow [9].

Based on the principle of starter kinematics, this paper proposes a linear model of delay and queuing length. Combining the relationship between queuing length and queuing overflow, a model of delay and queuing overflow is proposed. The accuracy of the model is verified by VISSIM simulation experiments.

2. Problem Description

2.1. Traffic overflow phenomenon description
The vehicle enters the upstream intersection from the downstream intersection and encounters a red light to form a queue from the parking line position. After a number of cycles of vehicle accumulation, the vehicle accumulates to the upstream intersection at a certain time. The queue length is greater than the link length $L$, that is $L_q > L$, resulting in traffic overflow. The physical phenomenon of overflow indicates that the queue length of vehicles at intersections is longer than the length of road sections, causing vehicles to line up at upstream intersections, causing congestion. As shown below.

![Overflow schematic](image_url)

Figure 1. Overflow schematic

2.2. The following assumptions need to be made
- Research objects are three-phase intersection and four phase intersection, and the vehicle is directly overflowed.
- The queuing overflow is oversaturated queuing overflow, and the vehicle is discharged at the saturated flow rate of the inlet road, regardless of the blockage caused by the accident. Overflow and Delay Model.
3. Overflow and Delay Model

3.1. Electric police data source and collection

Taking Figure 2 as an example, take the section L from intersection O1 to O2 as an example. Car exits the parking line from intersection O2 and exits the parking line at intersection O1. The travel time of the section of the vehicle \( T = T_{O1} - T_{O2} \). Control delay is the difference between travel time and free flow time.

3.2. Delay and queue length model

![Figure 3. Queue Length and Delay](image)
Signalized intersections can reflect road conditions in the lane, and vehicle delays are an important part of the intersection. There are many factors involved in the delay of signalized intersections, such as accidents, timing, traffic volume, and road segment design. In this paper, we study the delay and queue length in the case of saturation.

The model uses electric police data to combine the vehicle's trajectory with actual operational delays. The horizontal line is uniformly expressed as the delay time of the vehicle, and the vertical line is the queue length of the vehicle at different instants. Area I represents the arrival-emission curve area, and II represents the vehicle delay-queue length relationship. The broken line of area II represents the trajectory of the two-dimensional plane of each vehicle, and the horizontal part is the delay time of the vehicle. The horizontal distance of the two-fold line represents the headway between two adjacent cars.

The wave velocity calculation of the starting wave model established by Qu Zhaowei Wang Dianhai and Yao Ronghan differs from the actual observation by about 5% [10]. The kinematic formula of the start wave is:

\[ t_q = - \frac{u}{h k_j u - 1} = - \frac{1}{Q \times n} - \frac{1}{L_i} \quad (1) \]

\[ t_q = - \frac{L_i}{Q \times n} - \frac{1}{u} = - \frac{1}{Q \times n_i} - \frac{1}{u \times L_i} \quad (2) \]

Where: \( u \) is the free-flow speed, \( h \) is the saturation headway distance, \( k_j \) is the blocking density, \( L_i \) is the queue length, and \( n \) is queued for the number of vehicles. \( n_i \) is the number of cars.

3.3. Overflow and delay models

1) Analysis of overflow mechanism

According to the vehicle spillover mechanism, the overflow type of the supersaturated intersection is divided into two types: the \( O_1 \) signal is green or red.

In order to calculate the value of the vehicle overflow interval of the road section, it is necessary to determine the state of the traffic light at the upstream intersection \( O_1 \) when the tail-end vehicle reaches the target section. Under the assumption that the vehicle has overflowed, if the team arrives, the \( O_1 \) is green. \( t_r^m = t_q \), the lower limit of the overflow. If the team arrives at the end of the red light. \( t_r^m = I \), the upper limit of the overflow. The upstream road \( O_2 \) overflow vehicle delay can be expressed as \( t_y = t_r + t_q \), \( t_r \) is the waiting red light duration.

Considering the length between two adjacent signal intersections, the running time of the vehicle between the \( O_1 \) and \( O_2 \) intersections is generally divided into one cycle or more cycles. Therefore, it is necessary to consider two cases of \( m=0 \) and \( m=1 \). When \( m=0 \), the maximum vehicle capacity of the road section is less than the number of green light discharge vehicles. \( L<\text{Lc}^{*}Q \), \( m=1 \) is the maximum vehicle capacity of the road section is greater than or equal to the number of green light emission vehicles. \( L\geq\text{Lc}^{*}Q \).

\[ Q = S \times g / 3600 \quad (3) \]

When \( m=0 \) and \( t_r^m = 0 \).
When \( m = 0 \) and \( t_0^m = 1 \)

\[
t_I = \left[ \frac{L \times Q}{L_c \times g} \right] \times r + t_q
\]  

When \( m = 1 \) and \( t_1^m = 0 \)

\[
t_I = \left[ \frac{L \times Q}{L_c \times g} \right] \times r + t_q
\]  

When \( m = 1 \) and \( t_1^m = 1 \)

\[
t_I = \left( \left[ \frac{L \times Q}{L_c \times g} \right] + 1 \right) \times r + t_q
\]

In summary, the calculation formula for the queued vehicle overflow interval is:

Lower limit interval:

\[
T_{X1} = \begin{cases} 
\frac{1}{\frac{1}{2n} \frac{1}{u \times L_{\text{max}}}}, & n < Q \\
\left( \left[ \frac{L \times Q}{L_c \times g} \right] + 1 \right) \times r + \sum_{i=1}^{\left| \frac{t \times Q}{L_c \times g} \right|} \left( L - L_c \times Q \times i \right) \frac{1}{u_q}, & n \geq Q 
\end{cases}
\]

Upper limit interval:

\[
T_{X2} = \begin{cases} 
\left[ \frac{L \times Q}{L_c \times g} \right] \times r + \frac{1}{\frac{1}{2n} \frac{1}{u \times L_{\text{max}}}}, & n < Q \\
\left( \left[ \frac{L \times Q}{L_c \times g} \right] + 1 \right) \times r + \sum_{i=1}^{\left| \frac{L \times Q}{L_c \times g} \right|} \left( L - L_c \times Q \times i \right) \frac{1}{u_q}, & n \geq Q 
\end{cases}
\]
2) Analysis of vehicles queued in the interval

In order to determine whether a certain vehicle is overflowing, it is necessary to determine the departure time $t_n'$ of the first vehicle that queues the vehicle during the overflow period $N$ and the arrival time $t_n^2$ of the random vehicle at the end of the team. $t_n^2 = t_n - t_s$. Where $t_s$ is the vehicle departure time, $t_n$ is the vehicle travel time.

Considering that there are two kinds of signals for the downstream intersection $O_1$ when the vehicle enters the road section, it is necessary to consider two cases where $m=0$ encounters green light and $m=1$ is red light. That is $t_n^2 \in t_n^g \cup t_n^r$.

When the target vehicle of the upstream intersection $O_2$ reaches the downstream intersection $O_1$ section, it is in the same cycle as the first vehicle departure time. The target vehicle must stop at the $O_2$ intersection once in the overflow interval.

3) Specific overflow discrimination in the interval

In order to calculate whether a vehicle has experienced a saturated queuing overflow, the vehicle's head vehicle data is queued in the known vehicle delay data.

Considering that the vehicle delay data may not have an overflow interval, it is necessary to consider that $m=0$ is not in the overflow interval and $m=1$ is in the overflow interval.

When $m=0$, that is, when $t_n^d$ is not in the overflow interval, it is necessary to discriminate the upper limit $T_{X1}$ or the lower limit $T_{X2}$ of the data in the overflow interval. If $t_n^d \leq T_{X1}$, then judged as not overflowing; if $t_n^d \geq T_{X2}$, then judged as overflowing.

When $m=1$, that is, when $t_n^d$ is in the overflow interval, considering the difference in the length of the link, it is necessary to consider both $n<Q$ and $n\geq Q$. First, you need to find the difference between the head car and the time of the vehicle you are driving. That is $t' = t_n^d - t_n^1$.

When $n<Q$, that is, when the road section capacity is less than the green light discharge amount, a green light can clear the road segment and queue the vehicle. Then need to determine whether $t > t_q + t_z$, is judged as overflow, otherwise it does not overflow.

When $n\geq Q$, that is, when the capacity of the road section is greater than or equal to the green light discharge amount, a green light cannot clear the queued vehicles in the road section. The way it is judged is:

$$X = \left[ \frac{L \times Q}{L_c \times g} \right]$$

$$t' > X \times (r + g) + \frac{L - L_c \times g}{Q} \times \left[ \frac{L \times g}{L_c \times Q} \right]$$

The difference between the departure time of the head vehicle and the target vehicle, the result is greater than the value of overflow, otherwise no overflow.

4. Experiment Analysis

Taking the intersection of Zhuang Nan Highway and Chuanpu Road in Zhenhai District as an example, due to the arrival of trucks from west to east at the intersection in the morning, the traffic volume is relatively large and overflows often occur, leading to deadlocks at upstream intersections. The actual
situation of the electronic police data and the micro-simulation software VISSIM are used to verify the micro-simulation model of the road. The simulation interface is shown in the figure below.

![Figure 4. Road simulation interface](image)

The parameters of the two different road lights are shown in the following table:

**Table 1.** Traffic parameters of case intersections

| Road       | Phase Sequence | Green light time |
|------------|----------------|------------------|
| short road | 0001           | 35, 26, 35, 24   |
| long road  | 0010           | 27, 16, 25, 15   |

The simulation parameters are set according to the actual traffic volume at the peak of the intersection.

**Table 2.** Starting wave estimates and real values

| Road     | Estimate m/s | real m/s |
|----------|--------------|----------|
| short road | 5.8          | 6.3      |
| long road | 5.5          | 5.84     |

**Table 3.** Comparison of judging spillover factors

| Road     | Estimate | Real   |
|----------|----------|--------|
| short road | 12.4     | 17.6   |
| long road  | 30.8     | 138.2  |

The simulation results of short roads and long roads include travel time maps of vehicle overflows and a table comparing the estimated and true values of queued overflows of vehicles on the same road with different periods, as shown below.

**Table 4.** Comparison table of short road values (0: no overflow; 1: overflow)

| cycle | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|-------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Over  |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| flow  |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
|       |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| estimate | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| real   |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
Table 5. Comparison table of short road values (0: no overflow; 1: overflow)

| cycle | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|-------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Over  | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 |
| flow  | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

Figure 5. Short Road Overflow Results

Figure 6. Long Road Overflow Results

5. Conclusion
The author's research mainly includes the content: 1 the queue length and delay research model based on electronic police data. Compared with traditional methods, this model uses the high sample rate and relational characteristics of electronic police data to more accurately distinguish between delay and queue length models. 2 Discriminant model of queue overflow. Compared with the traditional model, the method requires a simple data source, and the accuracy of queuing overflow for saturation is over 80%.

However, there are still some deficiencies in the research, such as the lag of electronic police data, and it is impossible to obtain the travel information of road vehicles in time. Further work will solve the above problems, using deep neural networks to improve the accuracy of the model. Based on this, the research of neural network prediction model based on electronic police data is carried out.
Acknowledgments
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