# A New Method for Calculating Traffic Delay Based on Modified BPR Function Model

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**Abstract.**

With rapid economic, technological and industrial development, the transport network is under increasing load pressure. Making the best use of existing road network resources and traffic management resources, improving traffic and travel management, and increasing the efficiency of road use are essential issues we need to face. In this paper, the traditional BPR model is modified to take into account complications such as intersections, traffic accidents, road maintenance under congestion, and delay time due to queueing under congestion. The queueing time of a congested traffic flow is estimated using a trajectory tracking method using the cell phone signal of the driver and the base station data in the traffic network. The traditional BPR model was creatively modified to develop a modified BPR functional model for estimating traffic delay, which can be applied in transportation network planning. The final experimental model simulates the effect of traffic delay during vehicle movement, reflecting road flow and providing effect support for road network planning.

**Keywords:** modified BPR model, traffic delay,network resources

## 1. Introduction

The BPR model is the most influential and widely used model in transportation planning[6,7]. However, the BPR model is based on free flow. It aims to calculate the delay time caused by complex scenarios that do not take into account intersections, traffic accidents, road resurfacing, etc. This model is suitable for continuous highway flows, but not for complex urban road network planning networks considering congested queueing and waiting situations[5,12].

To overcome the limitations of the above BPR model, the invention takes into account the delays caused by road congestion and queues[15]. In this paper, the road is divided into two parts: free flow and queuing flow. Using mobile phone signal and base station data of drivers in the Chinese traffic network[1,2,9,11,14], we estimate the queueing delay of congested traffic flow using the trajectory tracking method[3,4,8,10,13]. The traditional BPR model is creatively modified, and the modified BPR function traffic delay model (FTD) is established to obtain the traffic delay.

Specifically, we divide the traffic into free-flow and waiting-flow segments, modify the parameters of the BPR function, and calculate the traffic delay in the non-congested segments. The traffic delay of congested sections is then obtained by using the vehicle trajectory data to label the stopping points of vehicles through the trajectory tracking method, and extracting the road speed values through the trajectory tracking method. Finally, the traffic delay calculated by FTD is obtained by cumulative calculation and the model effect is verified by simulation. The flow chart of FTD model is shown in Figure 1.

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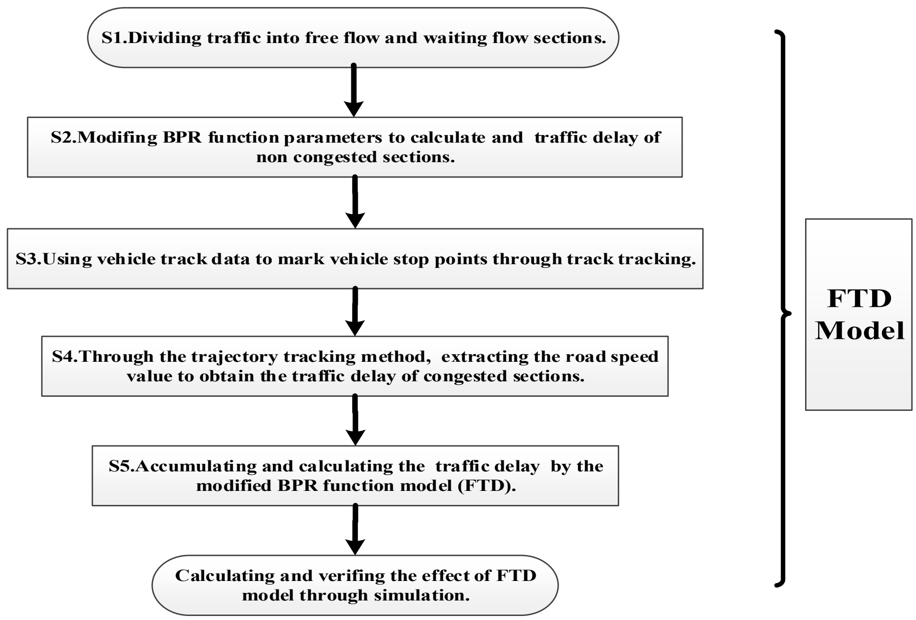


**Figure 1.** Flow Chart of FTD Model.

# 2. Methodology

## 2.1 The traffic is divided into free flow and waiting flow segments.

We calculate the total traffic delay of a road by splitting it into two parts: the first part is the travel time of the non-congested free-driving section. The remaining part is the queue delay time in complex situations such as intersections, traffic accidents and road resurfacing. We use to express the actual driving time of the vehicle when it enters the road. Therefore, T is calculated as

$$T=T_f+T_c \tag{1}$$

Where, $T_f$ is the free travel time of vehicles in the free-flow section and the waiting time of vehicles in the congested section. $T_f$ can be expressed as

$$T_f=(t_e-t_s)\cdot\left[1+\alpha\cdot(\bar{v}/v_f)^{\beta}\right] \tag{2}$$

Among them, $(t_e-t_s)$ refers to the time stamp attached to the base station in the free driving section, $\bar{v}$ refers to the average speed of this part of vehicles, and $v_f$ refers to the open speed of the road, $\alpha$ and $\beta$ are regression parameters.

## 2.2. Modification of the parameters of the BPR function to compute the and traffic delays for non-congested segments.

For the travel time of free flow vehicles, we no longer use a simple linear model (divide the length of the road section by the average speed of the vehicle) to roughly estimate it, but regard the driving state of this part of vehicles as the free running state. Then, based on the BPR function model and its parameters are modified, instead of relying on the road traffic flow that is very difficult to obtain, the vehicle travel time model of this part is obtained according to the time stamp, average speed, and road unblocked speed of mobile phone signalling data. $T_f$ can be expressed as

$$T_f=(t_e-t_s)\cdot\left[1+\alpha\cdot(\bar{v}/v_f)^{\beta}\right] \tag{3}$$

Where, $(t_e - t_s)$ refers to the time stamp attached to the base station in the free running road section, $\bar{v}$ refers to the average speed of this part of vehicles, and $v_f$ refers to the open speed of the road.

### 2.3. The vehicle stopping points are marked by track tracking using vehicle tracking data.

Based on the characteristics of vehicles driving at road intersections, traffic accidents, and road repair segments, we classify vehicle stopping points into three types: stop points, defect points, and hover points,as shown in Figure 2.

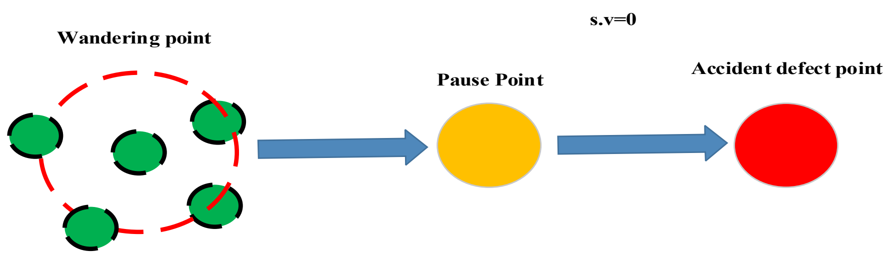


**Figure 2.** Schematic Diagram for Inspection of Dwell Point.

As shown in the figure above: We mark the pause point as: $s.v = 0$ and the duration is within the timestamp $\nabla T_r$; $s.v = 0$ and the duration is within the timestamp $\nabla T_r$;Accident defect points: $s.v = 0$ and the duration is greater than the timestamp threshold $T_r$;Wandering point mark: a dwell point $S$ refers to a subset $P$ of the set $T_P$. Through the data tracking method, the speed of the tracking points is lower than the speed threshold $V_r$, but the number of points exceeds the point threshold $N_r$,therefore, the wandering point is expressed as

$$s=(x,y,t_a,t_l,v),s.x=\sum_m^k P_i.x/|P|,s.y=\sum_m^k P_i.y/|P|,s.t_a=p_m.t,s.t_l=p_k.t,s.v=s.y=\sum_m^k P_i.v/|P| \quad (4)$$

Where, $s.t_a$ is the time when the user arrives at the collection $P$, $s.t_l$ is the time when the user leaves the collection $P$, and $s.v$ is the average speed of the collection $P$.

### 2.4. The road speed value is extracted from the traffic delay in congested sections by trajectory tracking.

It is estimated that the traffic delay of the congested road section, as long as we can find the last vehicle waiting in the queue on the downstream road before the end of the congestion, we will mark the actual position of the vehicle as the stop point, and $L_c$ is available. Let $v_c$ be the average speed of the congested road section, and the queuing delay time $T_c$ is as follows:

$$T_c = \frac{L_c}{v_c} \quad (5)$$

We can divide the congested road sections into two situations: road defect congestion caused by road accidents and repair, and normal traffic light queuing, length of the congested road section.Assuming that the probability of occurrence of road defects such as road accidents and road repair is $\eta$,In this case, the average speed of the vehicle is $\bar{v}_a$,the intersection probability is $1-\eta$,the queuing delay time $T_{c1}$ of the defect point is

$$T_{c1} = \frac{\eta \cdot L_c}{\bar{v}_a} \quad (6)$$

Equation 6 assumes that the probability of red light at the intersection is $\delta$, The probability of green light is $1-\delta$ (Ignore the yellow light). During the red-light period, vehicles at the intersection wait in line. If we record their velocity, then it is zero. When the green light comes, the vehicles in the queue start to accelerate into the next section. Considering the convenience and feasibility of the experiment, we neglect the complexity of vehicle velocity shift when the green light is on. Here, we only consider the simple case of vehicle acceleration as shown in Figure 3.

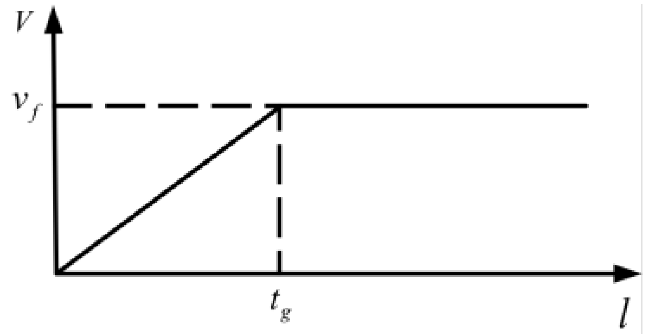


**Figure 3.** Simple traffic mode.

In Figure 3, $t_g$ represents the duration of the green light. For the convenience of calculation, we approximate the $v_f$ of two adjacent roads to be equal. Figure 4 shows that at the green light, the vehicles in the queue accelerate until they reach $v_f$ and enter the next adjacent road. Therefore, the $\frac{1}{2}v_f$ during acceleration is $\overline{v_g}$ . Therefore, the average speed of vehicles queuing at the downstream intersection is

$$\overline{v_b} = \delta \cdot \overline{v_r} + (1 - \delta) \cdot \overline{v_g} = \delta \cdot 0 + (1 - \delta) \cdot \frac{1}{2} v_f = \frac{1 - \delta}{2} \cdot v_f \tag{7}$$

We get $T_{c2}$ as follows:

$$T_{c2} = \frac{(1 - \eta) \cdot L_c}{\overline{v_b}} = \frac{2}{1 - \delta} \cdot \frac{L_c}{v_f} \tag{8}$$

Finally, the queuing delay time $T_c$ of the whole congested road section is as follows:

$$T_c = T_{c1} + T_{c2} = \frac{\eta \cdot L_c}{\overline{v_a}} + \frac{(1 - \eta) \cdot L_c}{\overline{v_b}} = \frac{\eta \cdot L_c}{\overline{v_a}} + \frac{2}{1 - \delta} \cdot \frac{L_c}{v_f} \tag{9}$$

### 2.5. Accumulating and calculating the traffic delay by the FTD.

We add the traffic delay of non congested sections and the delay time of congested sections obtained from 2.2 and 2.4 to get the total traffic travel time of FTD model vehicles

$$T = T_f + T_c = (t_e - t_s) \cdot [1 + \alpha \cdot (\overline{v}/v_f)^{\beta}] + \frac{\eta \cdot L_c}{\overline{v_a}} + \frac{2}{1 - \delta} \cdot \frac{L_c}{v_f} \tag{10}$$

It can be seen from equation 10 that the results of the FTD model are independent of the traffic flow, which avoids the difficulty of obtaining traffic flow data. The key of FTD model is to find the stopping point. Once a dwell point is found, LL and VV can be easily calculated. For defect point of the roads $\overline{v_a}$ ,, the $v_0$ and $v_f$ of specific roads are fixed, while the sum of different roads is different. We need to set different $v_0$ and $v_f$ values according to the number of roads.

## 3. Results

### 3.1 Computation and validation of the effects of the FTD model through simulations

The well-known effect of the FTD model is verified by calculations. There are many factors that affect vehicle travel time, including road width, pedestrians, weather conditions, etc. The velocity values can represent all uncertainties, so the FTD model with the average velocity of the running part as input can cover all uncertainties.Through the message of roads in Table 1, Figure 4 shows simulation results based on the FTD model using real road data of a city in China.

**Table 1.** The Message of Roads.

| Road ID | 22090 | 31721 | 48712 | 46823 | 46478 | 66618 | 50320 | 22562 | 22562 | 65940 | 46116 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Length (m) | 66 | 725 | 919 | 1200 | 1307 | 1416 | 1671 | 1671 | 1929 | 2077 | 2186 |

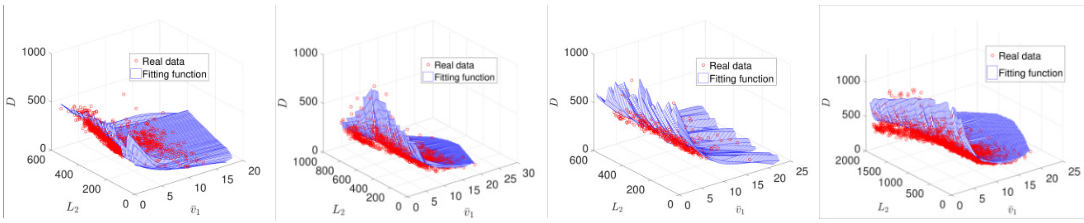


**Figure 4.** 22090 46823 50320 46166 Simulation effect of four channel data.

As shown in Figure 4, it is the simulation effect of four channel data. The red circle represents the real track point data, the blue box represents the model simulation results, the X coordinate represents the queue length $L_c$ of the congested section, the $Y$ coordinate represents the speed $\bar{v}$ of the travel and the $Z$ coordinate represents the travel delay $T$. This model models the effect of traffic delays during driving, reflects the traffic flow situation, and provides effective support for highway network planning.

## 4. Conclusion

The FTD model in this paper creatively modifies the traditional BPR model to establish an FTD and finally obtain the traffic delay. First, the road is divided into a free-running section and a congested section. The congested segments are divided into pause points, defect points, and wandering points. The BPR function parameters are modified to calculate the traffic delay in the non-congested section. Then, using the trajectory tracking method, the road speed values are extracted to obtain the traffic delay in congested sections. Finally, the traffic delay calculated by FTD is obtained from the cumulative calculation and the FTD model effect is verified by simulation. On the one hand, this model avoids the difficulty of obtaining traffic flow data for the BPR model, and on the other hand, it uses various complex cases of roads. Considering that the situation is closer to the actual situation of the road, the relevant data is easy to obtain and the computational method is simple, which considerably reduces the computational complexity.

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