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Calculation Method of Unblocked Reliability Based on Random Arrival of Vehicle

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Abstract: Road traffic is a random and dynamic system while it is difficult to describe the traffic flow characteristics correctly, through the existing non-probability parameters. Evaluating the road network with such parameters will produce difficulty in traffic system management and planning. This paper guided by the theories of probability and traffic flow with primary consideration of random arrival of vehicle, aiming at the shortcomings of the past evaluation method, the unblocked thresholds in the urban roads of different levels are determined according to field survey of large numbers of drivers. On this basis, the parameter values of the BPR and the regression function are calibrated combined with road conditions in Tianjin of China and this paper gets the probability model of unblocked flow based on the random arrival of vehicle. Besides, the model is verified with simulation software Paramics. It is a new idea about the calculation method of unblocked reliability.

Key words: Threshold, unblocked reliability, impedance function, velocity model

INTRODUCTION

Whether traffic is unblocked is usually an important basis for evaluation and optimization of urban traffic management and planning level. In order to quantify the unblocked degree of road, provide decision support for the traffic managers to make real-time, accurate analysis and evaluation of traffic flow running state. The reliability has been adopted in many research in three class: The first class comprises connectivity reliability methods (Asakura, 1996), whereby an probabilistic, binary mode of operation is made link of network. The second class consists of travel time reliability methods (Du and Nicholson, 1997; Bell *et al*., 1999; Clark and Watling, 2005), whereby travel times of network is assumed to have an continuous probabilistic treatment. The third class encompasses methods to study capacity reliability (Chen *et al*., 2002, 2013). Above all, the indicators are mostly restricted to saturation, travel impedance, capacity and other non-parametric probability measure. Basis on this, Chen *et al*. (2006) firstly suggests unblocked reliability which is the probability on the condition that vehicles can travel under the unblocked service level. It takes full account of the relationship between supply and demand. Furthermore, produce three evaluation methods for basic road. Then, Xu and Fu (2012) and other researchers have some research of improving the method of calculation based on different circumstances. In summary, the present study is mainly from the traffic characteristics of network, link as macroeconomic factors but fewer in microscopic view. It is lack of relationship between unblocked standard and model. This study from the sighting of microscopic perspective will analyze the issues and make unblocked standards based on arrival of vehicles and improve the veracity and rationality of unblocked reliability which presents a new idea for road evaluation.

ANALYSIS OF ROAD UNBLOCKED THRESHOLD

Division of unblocked road: The levels of unblocked road are commonly divided into five grades. This method has more classifications which often causes the dividing line between each phase blur, not easily calibrated and so on. Therefore, the article intends to take the form of digital coding: 0-1 state grading, as shown in Table 1.

Determination of unblocked threshold

Speed threshold: Speed is one of traffic flow parameters which is the most sensitive and easily to obtain for people. Thus speed is selected as one of the division standards of studying the unblocked state. The unblocked threshold of expressway urban arterial road, urban secondary trunk road are, respectively 35, 20,15 km h^{-1} (Ministry of Public Security, 2012; Beijing Municipal Commission of Transport, 2011) combined with 0-1 state grading.

Table 1: Division of unblocked and congestion

Unblocked(0)	Congestion(1)
Very unblocked, the standard unblocked, unblocked	Not very unblocked, not the basic unblocked

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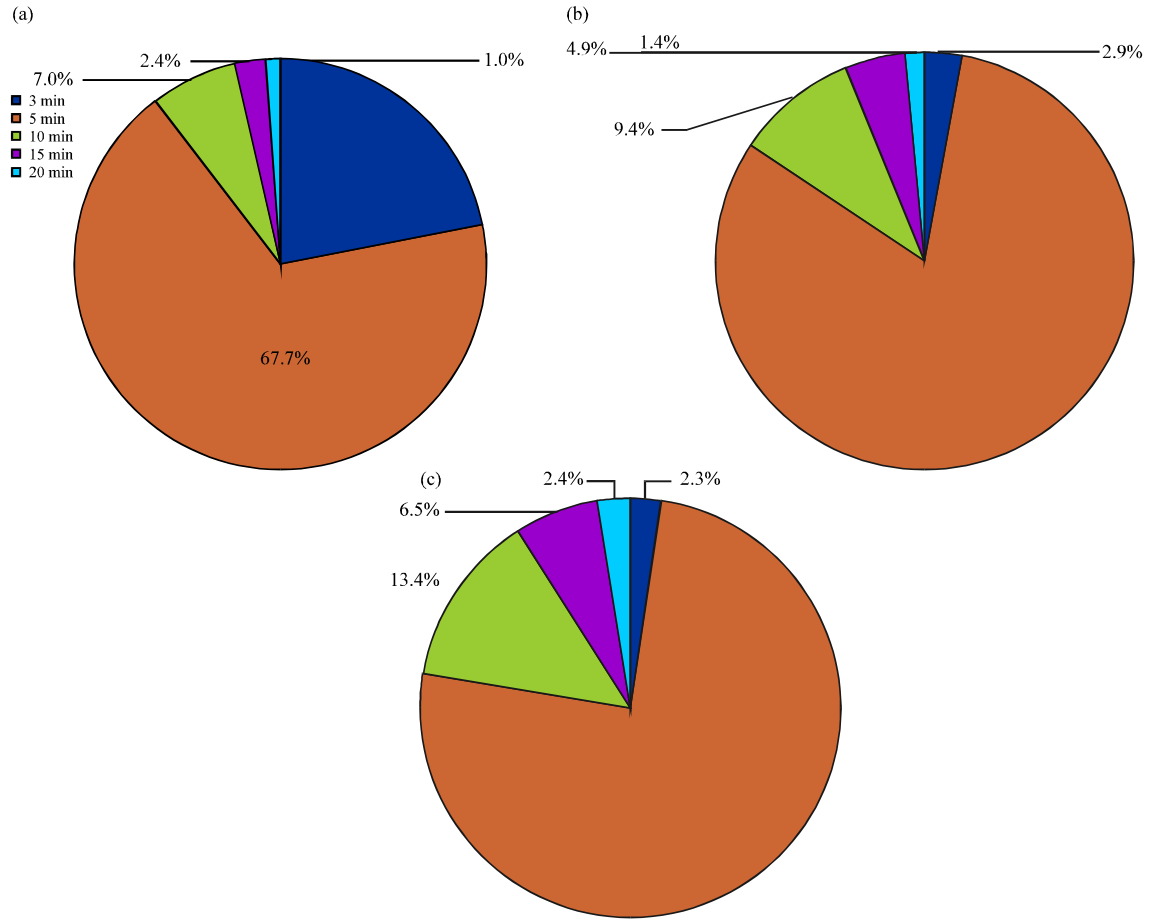

Fig . 1(a-b): Drivers' duration, (a) expressway, (b) Arterial road and (c) secondary trunk road

Time threshold: Congestion is the condition that speed of traffic flow reaches a certain level and lasts for some time. Field surveys are conducted towards drivers which have 10 years driving experience about the unblocked threshold in different road. The Statistics results of the survey are shown in Fig. 1.

Figure 1 shows that 67.7, 81.4, 75.4% of traffic participants felt blocked when duration on the basis of speed of 35, 20, 15 km h^{-1} in expressway, arterial road, secondary trunk road reach beyond five minutes. Thus, The unblocked threshold in expressway, arterial road, secondary trunk road is continuous 5 min (35, 20, 15 km h^{-1}).

PARAMETER CALIBRATION

The road impedance function is the functional relationship between travel time and traffic load which is the basis for transportation network analysis. It is found that BPR function is road impedance function for current urban expressway and arterial roads while the regression function is that for secondary trunk road in China.

Function

BPR function: The BPR function is proposed by the U.S. Federal Highway Administration. The formula is as follow:

$$t = t_0[1+\alpha(\frac{Qu}{c})^{\beta}] \quad (1)$$

Where:

- t = Travel time between sections of intersections (min)
- t_0 = Travel time between sections of the two intersections when traffic volume is equal to 0 (min)
- Q_u = Traffic volume of the section(pcu h^{-1})
- C = The capacity of the actual sections(pcu h^{-1})
- α-β = Parameters.

Regression function: According to the basic form of BPR function, domestic scholars proposed the following empirical model considering the impact of the non-motor vehicle:

$$T = T0[1+\alpha\left(\frac{Qu}{Q_{max}}\right)^{\beta}+\alpha_2\left(\frac{Qb}{Q_{bmax}}\right)^{\beta 2}] \quad (2)$$

Where:

Q_{max} = The capacity of motor vehicle (pcu h^{-1})
Q_{bmax} = Non-motor vehicle capacity, typically 900-1000 (pcu h^{-1})
Q_U = Motor vehicle volume (pcu h^{-1})
Q_b = Non-motor vehicle volume (veh h^{-1})
$\alpha,\alpha_2,\beta,\beta_2$ = Parameter

Calibration of function: Considering the big difference in traffic flow of different urban road, parameter calibration is necessary.

Function converting: The principle of catastrophe theory found actual road capacity, $c = k_j v_f/4$ combined with $Q = k_j v - k_j v^2/v_b$, BPR function simplifies to:

$$In(V_f/v-1) = In^{\alpha}+\beta In[4(v/v_f - v^2 v_f^2)] \quad (3)$$

Where:

k_j = Blocking density
v_f = Free speed
v = Average speed

Hypothesis:

$$Y = In(V_f/v-1); X = In[4(v/v_f - v^2 v_f^2)]; a = In^{\alpha}; b = \beta$$

Thus:

$$Y = a+bX \quad (4)$$

Likewise, regression function is converted as:

$$In\left(\frac{V_f}{V_f}-1\right)In\alpha+\beta In[4(\left(\frac{v}{V_f}-v^2v_f^2\right)+In^{\alpha}2+ \beta_2 In\left[4\left(\frac{v}{vf}-v^2v_f^2\right)\right] \quad (5)$$

Hypothesis:

$$In\left(\frac{V_f}{V_f}-1\right)X_1 = In[4(\left(\frac{v}{V_f}-v^2v_f^2\right); X_2\left(\frac{Qb}{Q_{bmax}}\right);$$
$$a = In\alpha + In\alpha_2; b_1 = \beta; b_2 = \beta_2$$

Thus:

$$Y = a+b_1 X_1+b_2 X_2$$

Calibration: In order to ensure a representative parameter and sample volume, investigate traffic flow and vehicle speed in expressway, Arterial road and secondary trunk road during Weekdays of 7:00-9:00am in Tianjin. The Equipment is manual counting and radar The field investigation is shown in Fig. a:

Through analysis, Regression results about survey data of different types road, are shown in Fig. 2b-d.

Combined with formula 3-6,get the function parameter of Tianjin shown in Table 2.

CALCULATION METHOD OF UNBLOCKED RELIABILITY

Unblocked reliability methods in urban expressway and arterial road: Variables of BPR function are time and traffic capacity. Time is not easily observed, nor sensitive compared with the speed. Therefore, the function is converted into the relationship formula between speed and traffic capacity:

$$v_m = v_0\left[1+\alpha\left(\frac{Qu}{c}\right)^{\beta}\right]^{-1} \quad (7)$$

Where:

V_m = Driving speed, km h^{-1};
V_0 = Driving speed under link flow 0, km h^{-1}

From 1.2 known: 35k m h^{-1} for expressway, 20 km h^{-1} for trunk road. Take it as the value of V_m in equation 7. Then capacities of the sections are obtained under the unblocked threshold of v. That is to say, when vehicle speed is less than V_m, Q_u the upper limit of the section traffic volume, is:

$$Q_U = C\times\sqrt{\frac{V_0+V_m}{V_m}\div\alpha} \quad (8)$$

It is found that arrival of vehicles is close to the Poisson distribution. Therefore, the probability value on the condition that traffic volume is greater than Q_u during time T' is :

$$PT'(k<QU.T')\sum_{k=QUT}^{\infty}P(k) = 1-\sum_{k=0}^{QUT}P(k) \quad (9)$$

Where:

$PT'(k \geq QU.T')$ the Probability of reach k greater than or equal to QU.T:

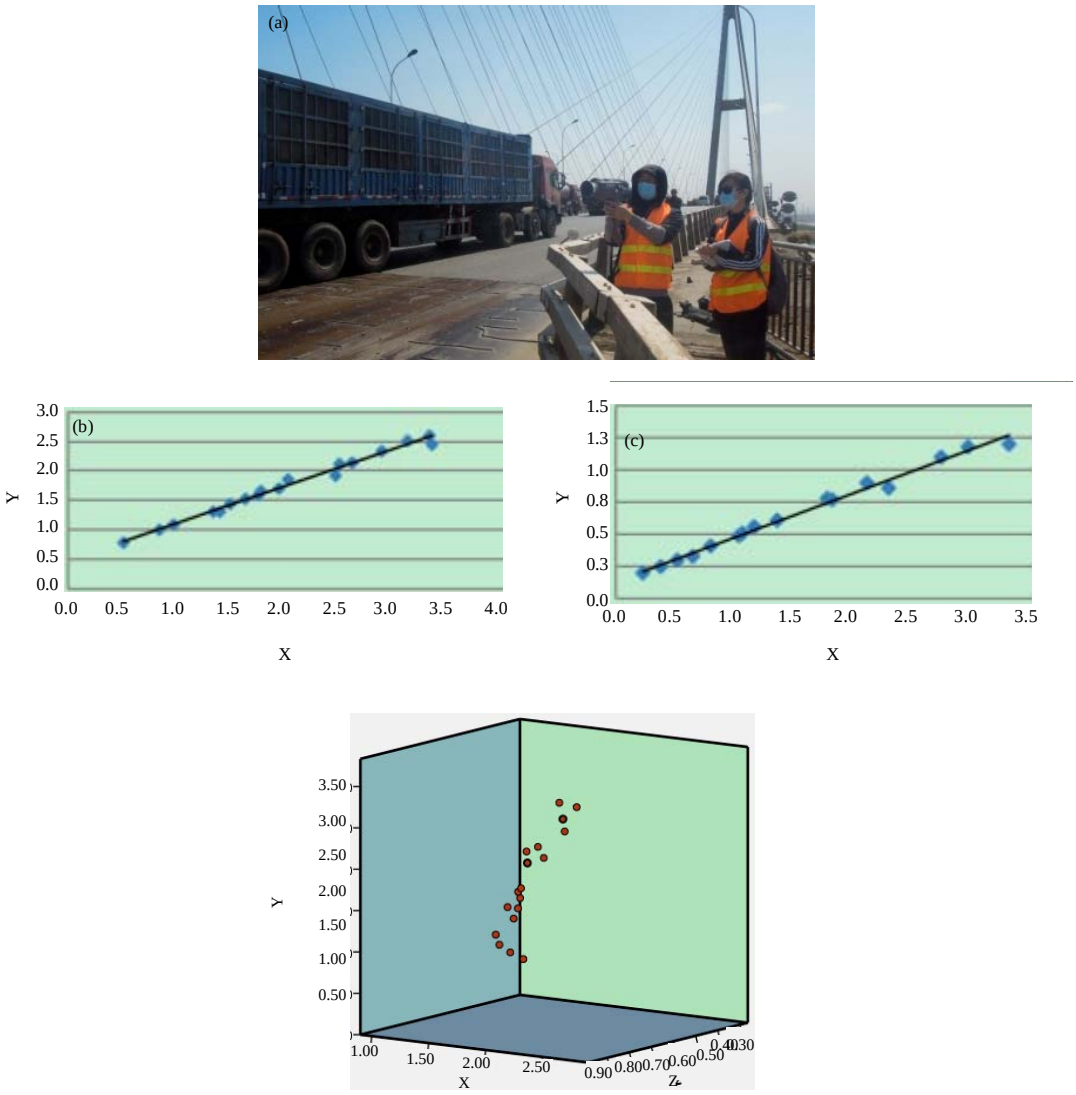

Fig. 2(a-d): (a) Survey schematic of Binhai avenue; (b-d) Regression: (b) Expressway, (c) Arterial road, (d) secondary trunk road

Table 2: Function parameter

Type	α	β	α_2	β_2	R^2
Expressway	0.726	2.741	-	-	0.988
Arterial road	0.5	1.522	-	-	0.99
Secondary trunk road	0.461	1.555	1.11	0.225	0.981

$$PT'(k < QU.T') = 1 - PT'(k \geq QU.T) = \sqrt[B_1]{\frac{V_0 - V_m}{V_m}} \div \alpha \left(\frac{QU.T'}{K!}\right)^k e - QUT' \quad (10)$$

The above formula is equivalent to the probability on the condition that the average traffic flow is Q_u while section speed is faster than V_m (35 or 20 km h^{-1}) and the duration is less thanT' (5 min). In other words, the Equation is the model of unblocked sections.

Analysis of the unblocked reliability methods of secondary trunk road: The regression function is also converted into the relationship between speed and capacity:

$$QU = Q_{max} \sqrt[B_1]{\frac{V_0 - V_m}{V_m}} - \alpha_2 \left(\frac{Qb}{Q_{bmax}}\right) / \alpha \quad (11)$$

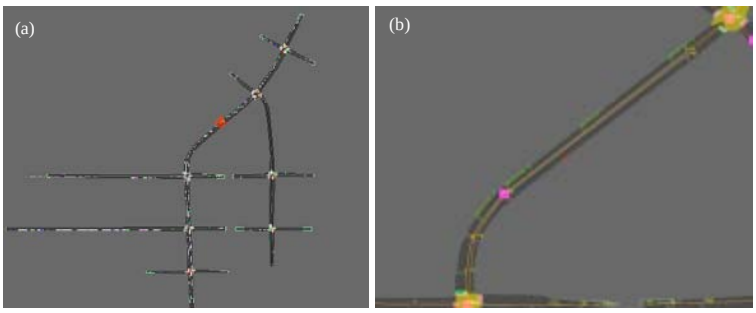

Fig. 3(a-b): (a) Schematic diagram of road and (b) The layout of induction coils

Poisson distribution is suitable for small traffic density and not influenced by interference factors. While urban road sections in this study are not subject to the interference of signal lights and other external factors. Thus, assume arrival of vehicles obeys Poisson distribution, the probability value is that traffic volume greater than Q during time T' is:

$$PT'(k \geq QU.T') = \sum_{k=QU}^{\infty} T'P(k) = 1\sum_{k=0}^{QU.T} P(k) \qquad (12)$$

$$PT'(k < QU.T')1 - P_T\ (k \geq QU.T) = Q_{max} \times \sqrt[B]{\frac{V_0 - V_m}{V_m} - \alpha_2}\left(\frac{Q_b}{Q_{max}}\right)\alpha\left(\frac{QU.T}{k!}\right)^k eQU.T$$

The formula is equivalent to the probability on the condition that the average traffic flow is Q while sections speed is faster than V_m (15km/h) and the duration is less than T'(5min), namely it is the model of unblocked sections.

MODEL SIMULATION

Paramics is a mature and reliable traffic simulation software. A single vehicle can be micro-processed in the interface. Its application areas include urban center district and a variety of primary and secondary trunk road. Take section of Tianjin Arterial road as an example. The road model of Paramics is constructed shown in Fig. 3a, for simulation validation. This section has six lanes and sets 4 induction coils in uniformity, shown as Fig. 3b.

The traffic volume measured by the induction coil and the speed values for each 5mins to analyze. It is found the speed values in the 27 of 72 group data are greater than or equal to 20 km h^{-1}. Therefore, the unblocked reliability is 0.375.Using the unblocked reliability calculation method of urban trunk road in this study (Equation10),the unblocked reliability is 0.37. Furthermore, the relative error is calculated:| Theoretical value -actual value| / theoretical value*100 = 1.2% which is the error in unblocked reliability model of Urban trunk road.

Table 3: Relative error

	Theoretical	Simulation	Error (%)
Expressway	0.48	0.476	0.83
Arterial road	0.37	0.375	1.35
Secondary trunk road	0.33	0.337	2.12

Similarly, simulation for expressway, secondary trunk road, get theoretical value, Simulation value, Relative error shown as follows in Table 3:

CONCLUSION

On the premise of random arrival of vehicle, from the microscopic perspective, the unblocked threshold in the urban roads of different levels are determined as the following:

- The determination of the unblocked threshold. This paper gives the unblocked threshold from both degree of congestion and duration, combined with survey of drivers
- Calibration BPR and Regression function. Combined with survey of different grade in Tianjin road, the parameter values are Calibrated
- Set up the unblocked reliability models. Combined with the unblocked threshold and probability distribution of vehicles arrival, models are set up for different levels of urban roads
- The model is verified with simulation software.

This research increases the rationality and accuracy of unblocked reliability and puts forward a new idea to evaluate the road.

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