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Research and Practice on Equilibrium Theory of Road Capacity

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Abstract

The main problems of traffic at present are low design and over design, and this paper puts forward equilibrium theory of road capacity based on the main problems and then puts forward corresponding model based on equilibrium theory for the purpose of guiding and improving the design of road, The paper takes Zhouzhuang Road in Wuhan as example, and conducts capacity equilibrium test based on different traffic organization optimization scheme. Meanwhile, the paper will evaluate the model with VISSIN, and then demonstrates the feasibility and effectiveness of capacity equilibrium model.

Key Words: Capacity; Traffic Volume; Equilibrium Theory; VISSIM

1. Introduction

In recent years, traffic problem has become one of the most puzzling social problems in every big city in the world. Traffic problems are mainly reflected in two aspects, which are low design and over design. Low design mainly displays in that road construction cannot keep pace with the growth of traffic volume. This leads to the low level of service and lack of traffic supply capacity. Therefore, this compounds traffic congestion in cities. Over design mainly displays in that road construction level and speed are far larger than the increasing speed of traffic volume. This leads to the low utilization rate of road and over supply of capacity. As a result, there appears wasting of resources. Therefore, the paper puts forward equilibrium theory of road capacity, which can be used for measuring the rationality of road design. Besides, Capacity equilibrium model can provide a theoretical foundation for future road design.

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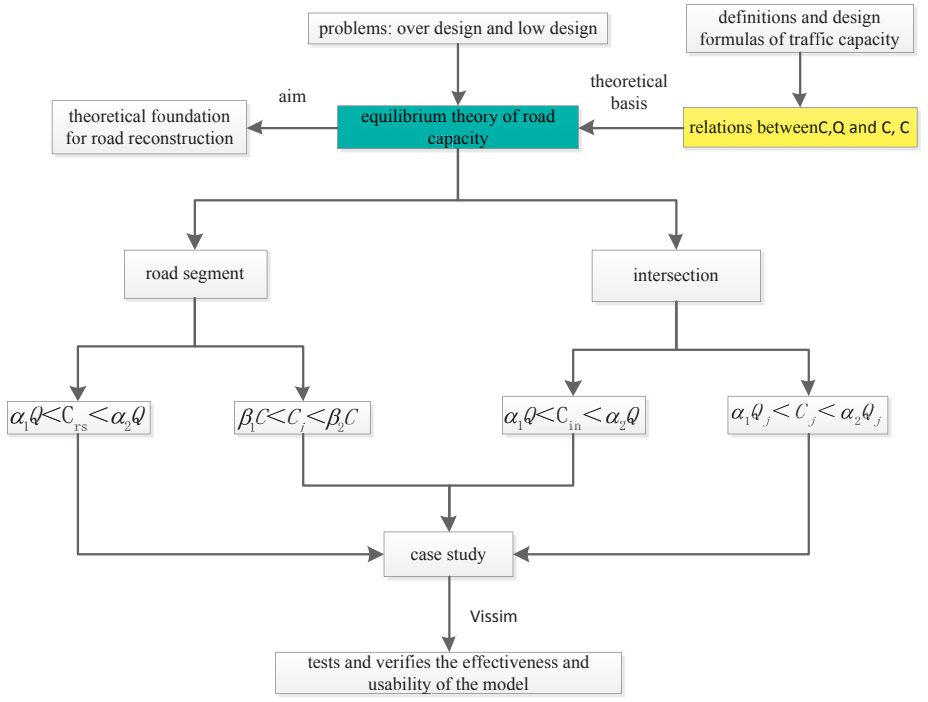

Fig.1.Technical Route

2. The Concept of Capacity

The current definition of capacity is not exactly the same with home and abroad. This paper uses the definition of capacity in General Theory of Traffic Engineering.

Capacity can be divided into basic capacity, possible capacity and design capacity.

Basic capacity means that the maximum traffic volume each lane can pass in unit time under the perfect condition of road and traffic.

Possible capacity means that the maximum traffic volume the certain point of road can pass in unit time under the actual condition of road and traffic.

Design capacity means that according to different usage requirement and different service level, capacity that road has. In other words, design capacity is road undertaking service traffic volume and it is generally used as the basis of road planning and design.

3. Research on Equilibrium Theory of Road Capacity

3.1. Equilibrium Theory

According to the two main traffic problems on current, the paper puts forward the theory of measuring the rationality of traffic organization optimization, that is the equilibrium theory of capacity, which is used for measuring whether traffic organization optimization Scheme is rational or not. The equilibrium model of capacity is as follows.

$$\alpha_1 Q < C < \alpha_2 Q \tag{1}$$

In which: C =Design capacity (pcu/h);

Q =Traffic volume (pcu/h);

α_1、α_2 =equilibrium coefficient of road capacity.

$$\beta_1 C < C_i < \beta_2 C \tag{2}$$

In which: C_i =design capacity of any segment (pcu/h);

C =design capacity (pcu/h);

β_1、β_2 =equilibrium coefficient of road capacity.

For any road, when any segment or Intersection meets the requirement of two formulas (1)and (2)above, this road will be suitable for equilibrium theory of road capacity.

This theory can be applied to transport planning on urban road, engineering feasibility research; urban road design, assessment after construction and other aspects, and it can provide more scientific theoretical foundation for all the aspects above. When $C < \alpha_1 Q$, and design capacity is less than α_1 times design capacity, it is called low design. When $C > \alpha_2 Q$, and design capacity is greater than α_2 times design capacity, it is called over design. Over design and low design should be avoided during the design process.

3.2. Equilibrium Model of Road Segment

Ⅰ. Equilibrium Model of Road Segment

Equilibrium model of road segment capacity is as follows:

$$\alpha_1 Q < C_{rs} < \alpha_2 Q \tag{3}$$

In which: α_1、α_2 =equilibrium coefficient of road segment, and the value of α_1 is 0.8， and the value of α_2 is 2. （α_1、α_2 calculates based on saturation temporally. And the range of saturation value based on road service level assessment index[1] is 0.35~0.9. The specific value of equilibrium coefficient has yet to be studied further）.

$$C_{rs} = C_o \times K_1 \times K_2 \times K_3 \times \nu/C \tag{4}$$

$$\alpha_1 Q < C_o \times K_1 \times K_2 \times K_3 \times \nu/C < \alpha_2 Q \tag{5}$$

In which: C_o =basic capacity (pcu/h);

K_1、K_2、K_3 =reduction coefficient of road segment, K_1 is reduction coefficient of road conditions, and K_2 is reduction coefficient of traffic condition, and K_3 is reduction coefficient of traffic management condition.

ν/C =saturation to certain service level;

Q =traffic volume (pcu/h);

α_1、α_2 =equilibrium coefficient of capacity, and the value of α_1 is 0.8, and the value of α_2 is 2.

Previous research on possible capacity didn't take various kinds of influence factors into full consideration or ignored some complicated conditions. The paper holds the view that the influence factor of possible capacity includes road conditions, transportation conditions and traffic management conditions. In the present analysis of road capacity, any influence factors cannot be ignored, especially on traffic management conditions.

$$\beta_1 C < C_i < \beta_2 C \tag{6}$$

In which: C_i =design capacity of any segment on one road (pcu/h);

C =design capacity (pcu/h);

β_1、β_2=equilibrium coefficient of capacity. The value of β_1 is 0.8 and the value of β_2 is 1.2. （The calculation of β_1、β_2 bases on intersection distance temporally.The specific value of equilibrium coefficient has yet to be studied further）.

Ⅱ.Equilibrium Model of Intersection

Equilibrium model of intersection capacity is as follows:

$$\alpha_1 Q < C_{in} < \alpha_2 Q \tag{7}$$

In which: α_1、α_2 —equilibrium coefficient, and the value of α_1 is 0.9 and the value of α_2 is 1.4. (The calculation of α_1、α_2 bases on saturation temporally. And the range of saturation value based on intersection service level assessment index is 0.6~0.9. The specific value of equilibrium coefficient has yet to be studied further）.

The present formulas of intersection capacity are relatively clear and definite. The calculation method used in this paper is from code for design of urban road engineering.

$$\alpha_1 Q_j < C_j < \alpha_2 Q_j \tag{8}$$

In which: C_j = capacity of arbitrary direction j (pcu/h);

Q_j =traffic volume of arbitrary direction j (pcu/h);

α_1、α_2 =equilibrium coefficient, and the value of α_1 is 0.6 and the value of α_2 is 0.9.

$$C_{in} = \sum_i C_i \tag{9}$$

$$\alpha_1 Q < \sum_i C_i < \alpha_2 Q \tag{10}$$

In which: C_i =capacity of lane i (pcu/h);

Q =traffic volume (pcu/h);

α_1、α_2 =equilibrium coefficient, and the value of α_1 is 0.6 and the value of α_2 is 0.9.

4. **The Application of Road Capacity Equilibrium**

4.1. The Analysis of Traffic Organization

The example used in this paper is based on the design what we have done, that is Zhouzhuang Road. The paper has analyzed traffic organization optimization for local segment (Gaoxin Road to Shangda Road).

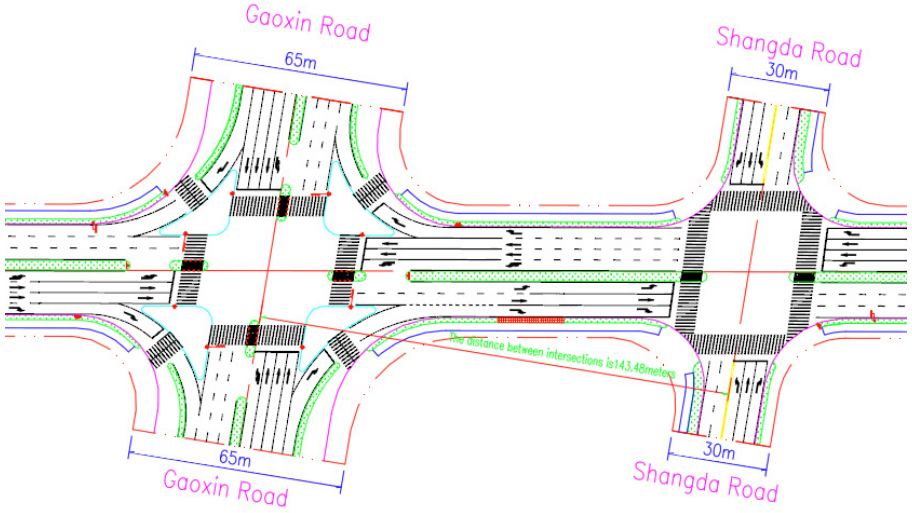

Fig.2. Planning Schemes

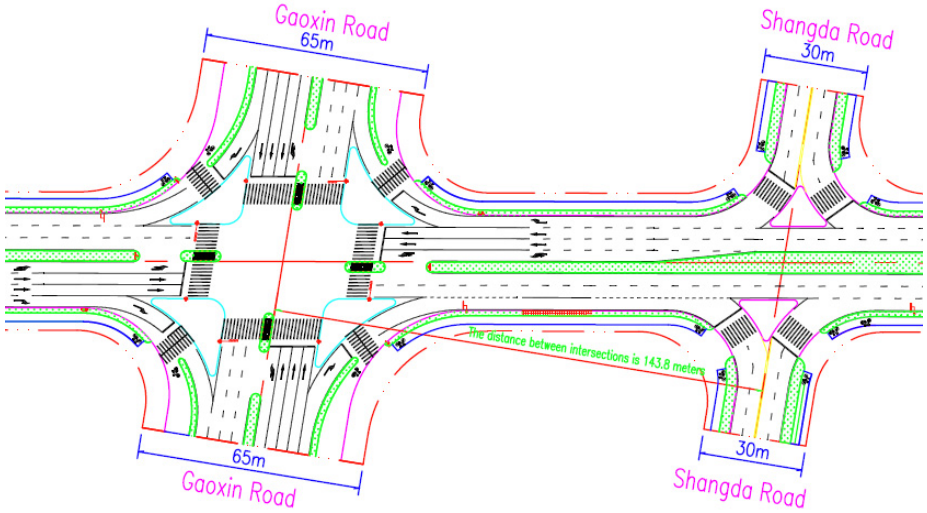

Fig.3. Optimization Scheme

4.2. Calculation on Equilibrium of Road Capacity

Ⅰ. Calculation on Capacity of Road Segment

This road belongs to city secondary road and its design speed is 50km/h. There are many at-grade intersections along the road and the capacity is based on aforementioned correction coefficient, that is K_1 (road-grade α_1 ,lane position α_2 ,and intersection influence α_3), K_2 (visual system of driver β_1), K_3 (reduction coefficient of pedestrian crossing γ_1). Therefore, the calculation of road segment capacity will base on the following formula.

$$C_{rs}=C_o \times \alpha_1 \times \alpha_2 \times \alpha_3 \times \beta_1 \times \gamma_1 \times \nu/C \quad (11)$$

In which: C_o=basic capacity. When design speed is 50km/h, basic capacity is $1690(pcu/h)$;

α_1=reduction coefficient of road classification level in design capacity, and its value is 0.75 based on expressway; the value of main road is 0.8; the value of secondary road is 0.85; the value of branch is 0.9.

α_2=reduction coefficient of lane position and its value is 1.0, 0.8, 0.65, and 5 in turn from center line to outside.

α_3=The reduction coefficient of capacity of entry road segment affected by intersection along the upper reach, and its value is 0.40～0.70. If entry road segment is an main road, its value will be the higher one; if it is branch, then its value will be the lower one. When intersection distance along the upper reach is large, its value will be higher one. On the contrary, if the distance is small, then its value will be lower one.

β_1—The reduction coefficient of the visual system of driver and its value is 0.954.

γ_1—The reduction coefficient of pedestrian crossing. If there is no pedestrian crossing, then its reduction coefficient is 1.

ν/C—saturation, which is used for assessing road service level.

(1)The possible capacity of planning scheme is:

$$C_{pl}=C_o\alpha_1\alpha_2\alpha_3\beta_1\gamma_1=\begin{bmatrix}1690\times0.85\times0.5\times(1+0.8+0.65+0.5)\\+1690\times0.85\times0.4\times(1+0.8+0.65)\end{bmatrix}\times0.954=3363(pcu/h)$$

(2)The possible capacity of optimizing scheme is:

$$C_{op}=C_o\alpha_1\alpha_2\alpha_3\beta_1\gamma_1=\begin{bmatrix}1690\times0.85\times0.7\times(1+0.8+0.65+0.5)\\+1690\times0.85\times0.4\times(1+0.8+0.65)\end{bmatrix}\times0.954=4173(pcu/h)$$

Ⅱ.Traffic Volume Prognosis

The prediction about annual various segments' traffic volume in peak hour in Zhouzhuang Road can be seen in Table 1.

Table 1 Prediction table of annual traffic volume in peak hour in Zhouzhuang Road(pcu/h)

Road Section	2013 year	2015 year	2020 year	2025 year	2027 year
Gaoxin Rd-Shangda Rd	1598	1989	2641	3012	3204

4.3. Equilibrium Model Verification

$$\alpha_1 Q < C_{rs} < \alpha_2 Q$$

In which: α_1、α_2=equilibrium coefficient, and the value of α_1 is 0.8， and the value of α_2 is 2.

(1) The design capacity of planning scheme is:

$$C_{pl} = C_o\alpha_1\alpha_2\alpha_3\beta_1\gamma_1 = \begin{bmatrix} 1690\times0.85\times0.5\times(1+0.8+0.65+0.5) \\ +1690\times0.85\times0.4\times(1+0.8+0.65) \end{bmatrix}\times0.954 = 3363(pcu/h)$$

$$C_{rs}=C_{pl}\,V/C = 3363\times0.75 = 2522\,(pcu/h)$$

According to equilibrium model, the maximum traffic volume this road segment can contain is 2522pcu/h. Based on the result （3012pcu/h）of traffic volume prognosis, it can be seen that with the increase of traffic volume, the road will cannot meet the requirement of system equilibrium model, and then there will be traffic jam after 2025.

(2) The design capacity of optimizing scheme is:

$$C_{op} = C_o\alpha_1\alpha_2\alpha_3\beta_1\gamma_1 = \begin{bmatrix} 1690\times0.85\times0.7\times(1+0.8+0.65+0.5) \\ +1690\times0.85\times0.4\times(1+0.8+0.65) \end{bmatrix}\times0.954 = 4173(pcu/h)$$

$$C_{rs}=C_{op}\,V/C = 4173\times0.75 = 3130\,(pcu/h)$$

According to equilibrium model, the maximum traffic volume can contain is $3204\,(pcu/h)$. Based on the result of traffic volume prognosis, it can be seen that the optimization scheme can meet the requirement of equilibrium model of system capacity within the design period.

4.4. VISSIM Simulation

By proceeding VISSIM traffic simulation 2027 on Gaoxin Road to Shangda Road, the result is as following:

Table 2 Queue length table of intersection (Planning Scheme)

Intersection	Intersection of Gaoxin Rd				Intersection of Shangda Rd			
Panel Point	East	West	South	North	East	West	South	North
Average Queue Length(m)	28	25	54	39	19	18	23	42
Maximum Queue Length(m)	45	49	86	58	39	37	54	82
Parking Times of Vehicle Queue (s)	13	12	16	18	15	13	18	14

Table 3 Table of travel time delay in Zhouzhuang Rd (Planning Scheme)

Road Segment		Travel Time (s)	Average Delay Traffic Time (s)	Average Parking Times(s)
Zhouzhuang Rd	GX Rd to SD Rd	75	53	0.54
	SD Rd to GX Rd	80	58	0.47

Table 4 Queue length table of intersection (Optimization Scheme)

Intersection	Intersection of Gaoxin Rd				Intersection of Shangda Rd			
Panel Point	East	West	South	North	East	West	South	North
Average Queue Length(m)	26	23	44	33	0	0	0	0
Maximum Queue Length(m)	34	31	62	54	0	0	0	0
Parking Times of Vehicle Queue (s)	19	16	21	17	0	0	0	0

Table 5 Table of travel time delay in Zhouzhuang Rd (Optimization Scheme)

Road Segment		Travel Time(s)	Average Delay Traffic Time (s)	Average Parking Times(s)
Zhouzhuang Rd	GX Rd to SD Rd	62	35	0.46
	SD Rd to GX Rd	59	43	0.35

Based on VISSIM simulation, the author gets the result as following: the maximum queue length of planning scheme is 86, and the maximum average stopped delay is 58, which has reached level 4. Therefore, it does not correspond to service level of road design. However, the maximum queue length of optimization scheme is 62, and the maximum average stopped delay is 43. Therefore, it corresponds to level three in road design. Simulation result corresponds to the calculation result of equilibrium model of system capacity, and these tests and verifies the effectiveness and usability of the system equilibrium model.

Table 6 Grading standard of service level

service level	level 1	level 2	level 3	level 4	level 5
Average Delay Traffic Time (s)	＜30	30~40	40~50	50~60	＞60
Queue Length(m)	＜30	30~60	60~80	80~100	＞100

5. Conclusion and Outlook

The paper puts forward a new concept based on present transportation problems, which is equilibrium theory of system capacity and establishes corresponding equilibrium model. However, the suggested equilibrium theory of capacity is still on preliminary stage. Besides, research methods and contents are insufficient, for example, the value of equilibrium coefficient and the design formulas of capacity are yet to be studied further. Meanwhile, the equilibrium model in the paper only aims for any one road, and the model has yet to be studied further. Lastly, its developing direction is from road equilibrium model to road network equilibrium.

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Acknowledgements

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