Research on Traffic Operation State Evaluation Model of Urban Road Network based on Point, Line and Surface

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Abstract. With the development of China 's social economy and the improvement of people 's living standards, the number of cars is increasing, and the original transportation infrastructure is difficult to keep up with the development of the situation, resulting in serious traffic congestion in various large and medium-sized cities in China.Reasonable traffic congestion evaluation methods are of great benefit to solving urban congestion. Most of the existing traffic congestion evaluation methods only study single congestion points such as intersections, toll stations, and local road sections, and lack the connection between each unit. In this paper, the average delay time and road speed are used as the core indicators, and the evaluation models of traffic operation status are established for intersections and road sections respectively. Subsequently, based on the evaluation results of these individual intersections and sections, combined with the traffic congestion index (TCI), the traffic operation efficiency and status of the entire regional road network are comprehensively measured and evaluated. It provides a reference for experts and scholars in urban traffic congestion research.

Keywords: congestion evaluation; intersection; road section; road network; traffic operation status

1 INTRODUCTION

China is in a period of rapid economic growth, on the one hand, the process of urbanization is in a period of rapid development, rapid growth of motor vehicles, urban road traffic surge ; on the other hand, the level of traffic management is backward, and traffic awareness is difficult to develop with the situation. Two factors lead to traffic congestion in China 's major cities. Congestion will undoubtedly bring us a lot of social and environmental problems. It will not only affect our daily life, but also affect the speed of social and economic development. In the context of economic globalization, urban traffic congestion has become an urgent problem to be solved in every city.

Zainab Ahmed Alkaissi [1] used Arc GIS for spatial analysis to obtain geographic reference and digital congested street maps. The fuzzy inference system (FIS) is applied to solve the uncertainty and random variation of traffic speed, and the fuzzy concepts of different levels of congestion are described. Feifei He et al. [2] used the

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speed performance index to evaluate the congestion status of the existing road network, and then introduced the road section and network congestion indicators to measure the congestion degree of urban road sections and road networks. Mahmudah N [3] et al used quantitative methods to evaluate the operating status of intersections by considering delays, vehicle queuing, congestion costs, and level of service (LOS). Hou Liping [4] pointed out that the evaluation of urban road traffic congestion can be divided into two levels : road travel time $TTI_{networkt}$ and road network travel time index, which can not only reflect the weighted congestion intensity of different grades of road sections, but also reflect the speed and delay time of traffic sections. Based on Wardrop 's weaving theory model, Wang Min et al. [5] calculated the traffic capacity of each weaving section of the Optical Valley Ring Island, and used Vissim microscopic traffic simulation software to simulate the operation of the Roundabout of the Optical Valley Square ; starting from the evaluation of regional real-time traffic congestion, Zhou Qi et al. [6] proposed a set of regional real-time road traffic congestion evaluation index to realize the objective and accurate evaluation of traffic congestion at the same time in different regions and at different times in the same region. By studying the traffic conditions of the roads around the school during the school period and the non-school period, Jingpeng [7] and others used the map open platform to obtain big data, established the discriminant index of road congestion in the school area, and screened out the roads that were greatly affected by school travel.

Most of the existing traffic congestion evaluation methods only study single congestion points such as intersections, toll stations, and local road sections, and lack the connection between each unit. Based on the feelings of traffic travelers, this paper selects the indicators closely related to time to establish the model, and selects the average delay value and the interval speed value to establish the traffic operation state evaluation model of intersections and road sections respectively. Based on the traffic operation state evaluation value of each intersection and each road section, the traffic congestion index TCI is introduced to evaluate the traffic operation state of the regional road network, which provides a reference for experts and scholars in urban traffic congestion research.

2 EVALUATION INDEX OF URBAN ROAD TRAFFIC OPERATION

2.1 Evaluation Index Selection

At present, the evaluation of road traffic congestion in China is mainly based on the two standards of ' Urban Traffic Operation Status Evaluation Specification ' (GB / T 33171-2016) and ' Road Traffic Congestion Evaluation Method ' (GA / T 115-2020). These two standards are based on the point, line and surface to establish the congestion evaluation index and index system of intersection, interval road and road network, mainly including ' maximum vehicle delay ', ' maximum queuing time index ', ' average travel speed ', ' serious congestion mileage ratio ', ' urban traffic operation index ' and other indicators.

The most direct manifestation of road congestion is the decrease of speed and the increase of travel time. For travelers, indicators based on travel time are easy to be recognized and accepted. Furthermore, the travel time index is applicable to all traffic models and can compare different travel modes. Therefore, this paper mainly selects the index based on travel time (travel time, speed, delay) as the evaluation index of urban road traffic operation. In order to eliminate the differences between different evaluation indicators, it is necessary to normalize the indicators. In order to unify the comparison criteria, it is decided to use the inverse indicators for evaluation. Therefore, it is necessary to perform inverse processing and standardization on the positive indicators. The processing of these indicators is shown in Figure 1.

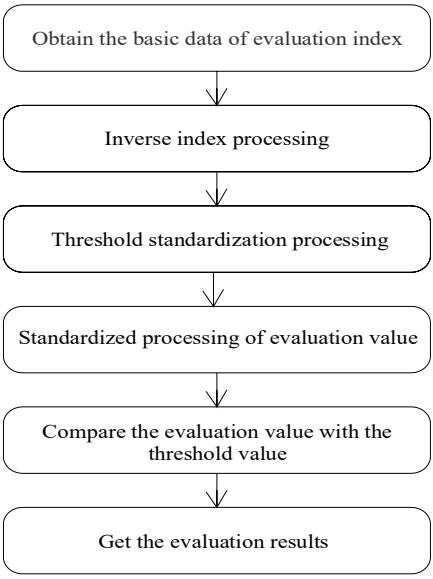

Fig. 1. Index processing flow.

2.2 Points, Line Traffic Running State Evaluation Index Processing

At intersections controlled by signal lights, saturation and delay are important indicators to measure their service levels. There is a monotonous correlation between the two. Therefore, in traffic engineering, delay is often used as an indicator to measure the service level of intersections. Delays not only reflect the extra time that travelers spend on the road, but also reflect the traffic state of the road. When the vehicle delay is small, the vehicle is in good condition. According to the existing research results, the intersection traffic operation state evaluation standard table is shown in table 1.

Table 1. Intersection traffic operation state evaluation standard table.

Running state at intersection	Smooth	Mild congestion	Moderate congestion	Severe congestion
Average delay (s)	(-∞,10]	(10,35]	（ 35,60]	(60,+∞)

The delay index itself is an inverse index, so there is no need for inverse processing, and the standardized processing method of extreme value processing method is directly used to standardize the threshold of evaluation index. After processing, the evaluation index threshold standardized value table 2 is obtained.

$$x^* = \frac{x - m}{M - m} \tag{1}$$

In the formula, M and m are the minimum and maximum values in the sample x , respectively, and x^* is the standardized value.

Table 2. Intersection evaluation index threshold standardized value table.

Running state at intersection	Smooth	Mild congestion	Moderate congestion	Severe congestion
x^*	(0,0.043)	[0.043,0.261)	[0.261,0.478)	[0.478,1)

The main road of the city is the aorta of urban traffic, and its traffic operation state directly affects the traffic operation of the whole region. Combined with the characteristics of the main road of the city, according to the applicability analysis of the index and the use probability and recommendation probability of each department, combined with the actual situation of this paper, the interval speed is selected as the evaluation index of the traffic operation state of the basic road section. The evaluation criteria of traffic operation status of urban road main roads are shown in Table 3.

Table 3. Evaluation standard table of urban trunk road operation status.

Running state at intersection	Smooth	Mild congestion	Moderate congestion	Severe congestion
Average travel speed V (km / h)	[35，+∞)	[25，35)	[15,25)	(-∞,15)

Speed is a positive index, which needs to be inversed. The inverse processing formula is as follows : the value of the speed evaluation index after inverse processing is too small, so it is standardized by expanding it by 100 times, and the standardized value Table 4 of the evaluation index threshold of the urban main road is obtained.

$$V_1 = 1 / V \tag{2}$$

Table 4. .Standardized value table of evaluation index threshold of urban main road.

Running state at intersection	Smooth	Mild congestion	Moderate congestion	Severe congestion
$x*$	(0,0.167)	[0.167,0.3)	[0.3,0.611)	[0.611,1)

(Note : M is 70km / h, m is 10km / h)

Traffic Congestion Index (TCI) is an inverse index, which refers to the quantitative value of the congestion degree of road sections, intersections and road networks in a

certain area during a certain period of time. It is expressed in the form of relative values and can reflect the road traffic congestion at different levels such as road sections and intersections in the study area. Under normal conditions, the range of traffic congestion index is usually 0 ~ 10. The traffic congestion level corresponding to the range of traffic congestion index is shown in Table 5.

Table 5. .Traffic congestion index range table.

Cramping	Smooth	Mild congestion	Moderate congestion	Severe congestion
TCI *value*	[0,4]	(4,6]	(6,8]	(8,10]

3 ESTABLISHMENT OF REGIONAL ROAD NETWORK TRAFFIC OPERATION STATE EVALUATION MODEL

For the traffic operation state of the regional road network, each intersection and each road section are taken as the basic unit, and the traffic congestion index of the intersection, the traffic congestion index of the road section and the traffic congestion index of the road network are used to reflect the traffic operation state of the study area.

3.1 Calculation of Traffic Congestion Index at Intersection

The delay time of the intersection is an intuitive representation of the driver 's feeling of congestion at the intersection. The commonly used Webster delay model is only applicable to the case where the vehicle is undersaturated. When the road section is oversaturated, the calculation results of the model are quite different from the actual situation. In view of this, in recent years, many scholars have conducted in-depth research on the delay model in the case of undersaturation and oversaturation, and proposed some comprehensive delay models based on Webster delay model. Comprehensive delay model :

$$D = D_1 + D_2 \tag{3}$$

$$D_1 = \frac{0.5C(1-\lambda)^2}{1-[\min(1,x)\lambda]} \tag{4}$$

$$D_2 = 900T[(x-1)+\sqrt{(x-1)^2+(\frac{8ex}{CPA\times T})}] \tag{5}$$

Among them, D1 is the normal phase delay, D2 is the random delay and supersaturated delay, x is the saturation of the calculated lane, T is the duration of the analysis period, 0.25 h, CAP is the capacity of the calculated lane (pcu / h); e is the correction coefficient of signal control type at each intersection, taking 0.5; q is the arrival traffic

flow rate of the entrance; c is the signal cycle of intersection; λ is the corresponding phase green signal ratio.

For the traffic congestion index (TCI_{node}) of intersections, the traffic operation status evaluation results of each intersection are calculated based on the delay of intersections, and then the corresponding $TCI_{node\ i}$ values of different intersections are obtained by linear interpolation method. The weight is the vehicle delayed time (VDT) of all vehicles in the evaluation period. The value of VDT can be used as the product of the traffic volume in the evaluation period and the average delay of each intersection, which further reflects the congestion degree of all intersections in the study road network. The weighted calculation formula is as follows :

$$\mathrm{TCI}_{node}=\frac{\sum_i(\mathrm{VDT}_i\times\mathrm{TCI}_{nodei})}{\sum_i\mathrm{VDT}_i} \tag{6}$$

In the formula，$TCI_{node\ i}$ is the traffic congestion index of an intersection，VDT_i is the vehicle delay time of intersection i during the evaluation period.

For the traffic congestion index (TCI_{line}) of the road section, the traffic operation status evaluation result value of each road section is calculated based on the interval speed data, and the corresponding TCI_{linei} value of each road section is obtained by linear interpolation method. The weight is to evaluate the vehicle travel time VHT of the road section during the time period, and further reflect the congestion degree of all road sections in the road network. The weighted calculation formula is as follows :

$$TCI_{line}=\frac{\sum_i(VHT_i\times TCI_{linei})}{\sum_i VHT_i} \tag{7}$$

In the formula, TCI_{linei} is the traffic congestion index of a section i, and VHT_i is the vehicle travel time of section i during the evaluation period.

The road network traffic congestion index reflects the overall congestion degree of the road network and the quality of traffic operation. It is closely related to the operating status of intersections and road sections in the road network. In the calculation, all roads and nodes in the road network should be integrated. The traffic operation evaluation model of intersections and road sections has been constructed. The road network is a collection of intersections and road sections. The traffic operation status of the road network in the study area can be calculated by the weighted calculation method. The key problem is to determine the weight. The design of the weight is more subjective and can be set according to the actual situation. The calculation formula is as follows :

$$TCI_{network}=\alpha TCI_{node}+\beta TCI_{line} \tag{8}$$

$$\alpha+\beta=1 \tag{9}$$

4 CONCLUSIONS

There are many factors involved in the traffic operation state of the road network in the region, and the evaluation indexes are various. This paper focuses on the personal experience of traffic participants, selects key measurement standards from the time dimension, and constructs a traffic operation state evaluation model. Specifically, by calculating the average delay time and interval speed, a targeted traffic state evaluation model is established for intersections and road sections respectively. Furthermore, based on these refined evaluation results, a traffic congestion index (TCI) is introduced to comprehensively and systematically evaluate the traffic conditions of the entire regional road network.

The article is limited to the evaluation model of urban road traffic operation status, which provides some ideas for relevant researchers. For various reasons, its effectiveness has not been verified. The next step will be to combine the traffic data and the actual situation of traffic operation status to evaluate the effectiveness of the model studied in this paper.

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