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The comprehensive measure model for urban traffic congestion based on value function

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Abstract: According to the distribution characteristics of traffic congestion in time and space, a measure index system of urban traffic congestion is set up based on the spatial and temporal distribution. Based on the analysis of the main characteristics of traffic congestion and the generation process of traffic congestion, the measure model for urban traffic congestion is constructed by the value function. Moreover, based on the measure values of traffic congestion in urban road networks with defined different levels, a method to prevent and control traffic congestion is designed. The application results confirm that the proposed method is feasible in comprehensive measures for urban traffic congestion and they are consistent with the results of other methods. The measuring results can therefore reflect the actual situation. The comprehensive measure model is scientific and the process is simple, and it has wide application prospects and practical value.

Key words: urban traffic; congestion; measure matrix; value function

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The urban traffic congestion problem has become a global issue and it impacts normal urban functioning and sustainable development. Recently, scholars both domestic and abroad have done much research on it[1-7]. Developed countries began to study congestion indices since the 1950s[8]. Hwang[9] built the congestion indices in some cities, but he did not compare them when congestion occurred in different places or times[9]. Jabari et al.[10] compared the indices based on time, and they discussed the influences of various indices on congestion quantification. Also, from the perspective of the traveler, Schmidt-Daffy[11] designed congestion classification based on the time parameters and he put forward the concept of time reliability which means that travel time changes; moreover, he carried out an analysis with the collected data. He also proposed new principles of congestion evaluation, namely using a real-time evaluation method instead of a computer model. Besides, Bagdadi[12] proposed an evaluation index system for urban road traffic congestion. However, some measurements cannot be obtained easily. To remove these deficiencies, an efficient and systematic approach is required. Therefore, this paper proposes a determination model to reduce the occurrence of urban traffic congestion based on the value function.

1 Measurement Index System for Urban Traffic Congestion

The selection of the measure index directly affects the measure results. In order to make the measure conclusions more objective, comprehensive and scientific, there are some principles for choosing the indices, for example, maturity, objectivity, operability and comparability and so on. Based on the comprehensive analysis, the measure index system for urban traffic congestion is proposed (see Fig. 1). In Fig. 1, I_1 is the saturation; I_2 is the queue length; I_3 is the average delay; I_4 is the queuing duration; I_5 is the average travel speed; I_6 is the average stop number; I_7 is the vehicle hours of travel; I_8 is the lane occupancy; I_9 is the mobility index; I_{10} is the con-

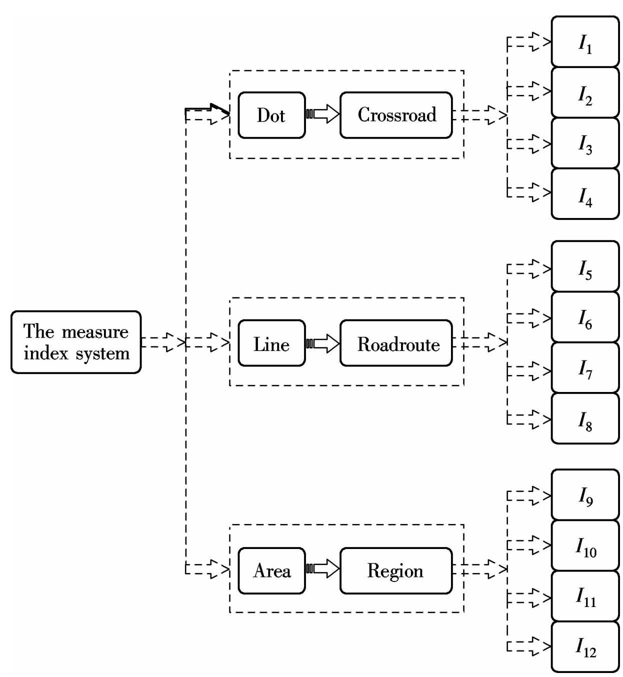

Fig. 1 The measure index system for urban traffic congestion

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gestion roadway; I_{11} is the level of service; and I_{12} is the congestion index.

2 Comprehensive Measure Model for Urban Traffic Congestion

2.1 The basic principle of the value function

The value function is a flexible and practical method proposed by operation researchers in the early 1970s for decision making science[12]. The main characteristic of this method is that it combines qualitative with quantitative methods in the decision making process. In this paper, we assume that A is the attribute set, G is the index set, d_{ij} is the measure value about attribute A_i under the index I_j, then the decision matrix is $\boldsymbol{D} = \{d_{ij}\}$. According to the characteristics of the urban traffic system, we combine the value functions to measure urban traffic congestion. Assume that the value function $f_{I_j}(d_{ij})$ of the measurement index I_j is

$$f_{I_j}(d_{ij}) = 0.5\mathrm{e}^{f_j(d_{ij})} \tag{1}$$

where $f_j(d_{ij})$ is the measure function about the measurement index I_j, and $f_j(d_{ij}) \in [0, 1]$.

Therefore, the value function of urban traffic congestion is defined as

$$U(A_i) = \sum_{j=1}^{12} w_j f_{I_j}(d_{ij}) \tag{2}$$

where w_j is the weight coefficient of the measurement index I_j.

2.2 The value function of urban traffic congestion

In order to reflect reality as much as possible, this paper deals with the data of measure value by the principles of standardization and normalization. Then, we define J^+ as the benefit-type indicators such as I_5, I_9, I_{11} set, J^- is the cost-type indicators such as I_1, I_2, I_3, I_4, I_6, I_7, I_{10} set, and J^{fix} is the fixing-type indictors such as I_8, I_{12} set. Define r_j as the fixing-type indicator value, and $I_j \in J^{\text{fix}}$. Then, the standardization function of urban traffic congestion $f_j(d_{ij})$ is

$$f_j(d_{ij}) = \begin{cases} \dfrac{d_{ij}}{\max\limits_j d_{ij}} & I_j \in J^+ \\ 1 - \dfrac{d_{ij}}{\max\limits_j d_{ij}} & I_j \in J^- \\ \dfrac{d_{ij}}{r_j} & I_j \in J^{\text{fix}}, d_{ij} < r_j \\ 1 - \dfrac{d_{ij}}{\max\limits_j d_{ij}} & I_j \in J^{\text{fix}}, d_{ij} \geqslant r_j \end{cases} \tag{3}$$

The value function for urban traffic congestion is unique. Also, the value function $f_{I_j}(d_{ij})$ is written as

$$f_{I_j}(d_{ij}) = \begin{cases} x^*\left(\dfrac{\bar{x}}{x^*}\right)^{2k_1} \exp\left\{d_{ij}(\max\limits_j d_{ij})^{-1}\ln\left(\dfrac{\bar{x}}{x^*}\right)^{-2k_1}\right\} & I_j \in J^+ \\ x^*\left(\dfrac{\bar{x}}{x^*}\right)^{2} \exp\left\{(\max\limits_j d_{ij} - d_{ij})(\max\limits_j d_{ij})^{-1}\ln\left(\dfrac{\bar{x}}{x^*}\right)^{-2k_1}\right\} & I_j \in J^- \\ x^*\left(\dfrac{\bar{x}}{x^*}\right)^{4k_2} \exp\left\{d_{ij}(r_j)^{-1}\ln\left(\dfrac{\bar{x}}{x^*}\right)\right\} & I_j \in J^{\text{fix}}, d_{ij} \leqslant r_j \\ x^*\left(\dfrac{\bar{x}}{x^*}\right)^{2} \exp\left\{(\max\limits_j d_{ij} - d_{ij})\max\limits_j d_{ij}\ln\left(\dfrac{\bar{x}}{x^*}\right)^{-4k_2}\right\} & I_j \in J^{\text{fix}}, d_{ij} > r \end{cases} \tag{4}$$

where $k_1 = \max\limits_j d_{ij}/(\max\limits_j d_{ij} - \min\limits_j d_{ij})$; $k_2 = r_j/(\max\limits_j d_{ij} - \min\limits_j d_{ij})$; x^* is the value of the optimal indicator for urban traffic congestion; $\bar{x}$ is the average value of indicators for urban traffic congestion.

2.3 The weight coefficient of the measure index

The weight coefficient of urban measurement indicators I_j is

$$w_j = \left(\sum_{i=1}^{m} d_{ij}\right)\left(\sum_{i=1}^{m}\sum_{j=1}^{12} d_{ij}\right)^{-1} \tag{5}$$

2.4 The comprehensive measurement level of urban traffic congestion

The comprehensive value $U(A_i)$ of traffic congestion represents different traffic situations and congestion degrees. The greater the comprehensive value $U(A_i)$, the worse the road conditions, and the greater the congestion degree. On the contrary, the better the road network, the less the congestion. Congestion levels are classified into five groups based on the calculated values (see Tab. 1).

Tab. 1 The congestion levels determined by interval value

Congestion level	Definition	Interval value
1	Very clear	$0 < U(A_i) \leqslant 0.2$
2	Unblocked	$0.2 < U(A_i) \leqslant 0.4$
3	Slightly congested	$0.4 < U(A_i) \leqslant 0.6$
4	Moderate congestion	$0.6 < U(A_i) \leqslant 0.8$
5	Very congested	$0.8 < U(A_i) \leqslant 1.0$

The comprehensive measurement $U(A_i)$ can reflect the congestion degree and the travelers' acceptance of traffic congestion. The comprehensive measurement $U(A_i)$ belongs to the congestion level, and we can determine the degree of risk of urban traffic congestion. In order to prevent accidents, we should control traffic congestion earlier.

3 Example Analysis

The discrepancy between traffic supply and demand in many cities has been increasingly prominent and it has become an urgent problem to be solved. According to the constructed measurement models, this paper chooses three types of cities in China to study urban congestion. In September, 2013, we tracked the measure cities (City A_1, City A_2, City A_3) for a week and we collected much effective data. The inspection values are shown in Tab. 2.

Tab. 2 The inspection values of the measurement indicators

Indicator	Inspection value		
	City A_1	City A_2	City A_3
I_1/min	35.8	37.2	34.1
I_2/(km · h^{-1})	28.1	26.8	30.2
I_3	0.52	0.62	0.52
I_4/(pcu · km^{-1})	8.9	8. 5	7.9
I_5	0.85	0.97	0.89
I_6/min	5.7	6.8	5.3
I_7/min	12.1	11.7	9.8
I_8/m	10.8	12.7	9.8
I_9	0.72	0.83	0.91
I_{10}/km	0.98	1.12	0.76
I_{11}	0.83	0.91	0.93
I_{12}	0.97	0.92	0.89

The calculation process is presented as follows:

Step 1 The weight coefficient of the measurement indicators can be determined by Eq. (5).

$$\boldsymbol{W} = \{0.0831, 0.0837, 0.0833, 0.0837, 0.0835, 0.0836, 0.0829, 0.0837, 0.0828, 0.0838, 0.0831, 0.0835\}$$

Step 2 We can obtain the values of urban traffic congestion, such as x_1, x_2, x_3.

Step 3 The comprehensive measurement value of urban traffic congestion is determined by Eq. (1).

$$U(A_1) = 0.311\ 2,\ U(_2) = 0.310\ 5,\ U(A_3) = 0.301\ 7$$

Step 4 We can obtain the value of the urban congestion regarding City A_1, City A_2, City A_3. Moreover, they all belong to the 3rd congestion level; that is the congestion degree which is "slightly congested", which shows that the measure result may reflect the situation of traffic congestion accurately. According to the exponential value $U(A_i)$ of the comprehensive measurement, the rankings are City A_3, City A_2, City A_1, as shown in Fig. 2.

The results obtained can be used for investment priorities assignment in a practical manner. For example, it should urgently be concentrated on City A_3, City A_2, City A_1, which are at the 3rd congestion level (slightly congested). These results can be useful for decision makers who are trying to find an optimal investment assignment.

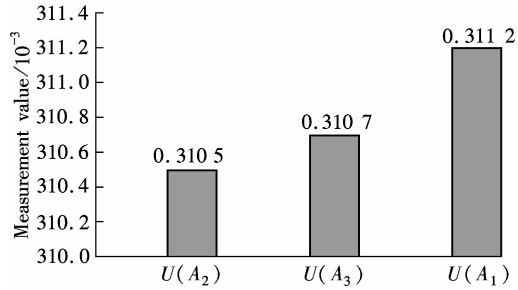

Fig. 2 Ranking results of the measure cities' traffic congestion

4 Conclusion

In this paper, the degree of urban traffic congestion is divided into five levels. The measure model of urban traffic congestion is constructed by the value function. This comprehensive measure method can overcome the defects of single index measure, and can reflect the congestion conditions much more scientifically, so it will have a broad application prospect in urban transportation management. Thus, the measurement model is of great theoretical and practical significance to research urban traffic congestion.

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基于价值函数的城市路网交通拥堵态势测定模型

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摘要:根据交通拥堵在时间和空间上的分布特性,建立基于价值函数的城市路网交通拥堵的测定指标体系.在分析交通拥堵的主要特征和交通拥堵生成过程的基础上,利用价值函数构建城市路网交通拥堵的测定模型, 并在城市路网交通拥堵测定值等级界定的基础上,设计交通拥堵预防和控制手段. 利用各态势的综合测定排序指数,对各态势进行排序和分类研究. 应用结果表明,所提方法的测定结果与其他方法的测定结果一致,能够较好地反映实际情况,且该方法计算科学、过程简单、易于实施,具有广泛的应用前景和实用价值.

关键词:城市交通;拥堵;测定矩阵;价值函数
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