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Study on the Status Evaluation of Urban Road Intersections Traffic Congestion Base on AHP-TOPSIS Modal

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Abstract

Through the analysis and comparison of influence factors for the intersections traffic congestion status, it is determined that the status evaluation of urban road intersection traffic congestion is actually a complex and multi-objective decision problem. On this basis, it will be established that is the status evaluation index system of urban road intersections traffic congestion by application of Analytic Hierarchy Process (AHP), then the traffic status of intersections will be evaluated and decided by Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) method. Finally the algorithm is verified by the actual example about the urban road intersection traffic congestion; the results prove that the model is able to use the information given to correctly evaluate the actual traffic status of intersection and provide the references to make appropriate management measures for the traffic managers.

Keywords: Intersection; Traffic Congestion; Evaluation Index; AHP; TOPSIS

1. Intruduction

Urban road intersection is an important part of the road network and traffic flow pooled and dispersed place. It can easily cause traffic congestion, traffic delay and traffic accidents. Foreign statistics show that traffic delays of intersection traffic congestion accounted for more than one-third of total delay of urban road traffic and that incidents in the intersection represents more 50% of the traffic accidents. So studying intersection traffic flow phenomena, exploring the intersection traffic laws and analyzing the root cause of impacting the intersection traffic congestion have a very important significance to improve traffic situation, ensure traffic safety and increase traffic efficiency.

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Some scholars at home and abroad have made some research in the evaluation field of intersection traffic running status. The technique, economy, environment and other indicators were selected as influence factors in during of the comprehensive evaluation of intersection traffic state (Wu, H.Y., 2000). The point of traffic flow conflict and the angle of traffic flow conflict were considered to explain reason of urban traffic congestion and how to relieve traffic congestion (Ning, L.R., 2007). The key technologies of urban road congestion forecast was studied in a doctoral dissertation, however the research on intersection traffic congestion evaluation was little in paper(Feng, J.Q., 2008). Method of AHP was used to evaluate intersection improvement program (Zhang, J.X., 2011). Under the substantial increase of the level of the motorization and especially tremendous changes of the traffic status of urban road intersection in China in recent years, Although deferent scholars study intersection traffic status from deferent sides, it is the major problems facing our urban traffic congestion that how to adapt to the new situation facing China's urban traffic problems and how to correctly evaluate intersection traffic congestion. The paper looks for the reason of causing traffic congestion, establishes evaluation index system and evaluates traffic congestion of intersection by AHP-TOPSIS base on the traffic congestion characteristics of urban road intersections under the new situation.

2. The establishment of the evaluation index system

The evaluation index system that will be established should comply with the actual traffic status of the intersection. Its fundamental goal is to find the reasons of causing traffic congestion, and to provide the ideas and methods to resolve the traffic congestion problem that is facing in the vast majority cities. Therefore, the following principles about establishing evaluation system of intersection traffic state should be followed: (1) practicality; (2) representation; (3) operability. In addition, the evaluation index system should have certain characteristics of adaptability, flexibility and comparability and so on.

2.1. The selection of evaluation index

The choice of the evaluation index should take into account the following aspects by comprehensive analyzing the road intersections planning and traffic flow running characteristics in accordance with the above principles.

(1) Design rationality. Selection of intersection form and channelization model has a great impact on traffic flow running of intersection. Once there are unusual problems, the traffic flow would be greatly the impact. By compared, the paper selected some typical factors to measure traffic congestion index of intersection, such as the intersection traffic conflict situation C_1, splitting the case of Motor vehicles and non-motorized C_2.

(2) Facilities perfection. Imperfectness of traffic facilities is one of the reasons of causing traffic congestion in intersection. However, traffic facilities of many urban road intersections are not perfect or unreasonable by survey. Therefore the paper selected some typical factors those can reflect imperfectness of traffic facilities to measure traffic congestion index of intersection, such as intersection guide lanes facilities C_3, signal timing C_4.

(3) Management science. When intersection design and facilities are reasonable, scientific management is an important means to solve the intersection traffic congestion. So the paper selected some typical factors those can reflect management level to measure traffic congestion index of intersection, such as Management methods adaptability C_5, state of complying with the rules C_6.

2.2. The evaluation index system

The six indexes above described can reflect reason of causing intersection traffic congestion comprehensively. However the six indexes involve many influencing factors; so it is difficult to precisely quantifying them. The

paper adopts interval values to express these indicators will more comply with the actual situation. It follows that establishes AHP-TOPSIS hybrid multi-attribute decision problems.

Table 1 Evaluation index of urban road intersection traffic congestion

Target layer	Criteria layer	Index layer
Status of traffic congestion A	Design rationality B_1	the intersection traffic conflict situation C_1
		splitting the case of Motor vehicles and non-motorized C_2
	Facilities perfection B_2	intersection guide lanes facilities C_3
		signal timing C_4
	Management science B_3	Management methods adaptability C_5
		state of complying with the rulesC_6

3 The basic principles of the AHP and TOPSIS

3.1. Analytic Hierarchy Process

The analytic hierarchy method (AHP) was founded by Professor T.L. Salty in the early 1970s. The basic idea is: the complex problems will be decomposed into goal level, guidelines level, program level and so on, decision makers decide relation of each factor pair wise independence on several levels in much simpler than the original problem, and result of the judgment will be expressed and treated, and target relative importance of decision program will be sorted, and then qualitative and quantitative analysis of the decision-making will be in progress.

AHP requires evaluators to give the important level of factors by pairwise comparisons according to the function table of the relative importance. So it has the advantages of high reliability and a small error. In addition, it can be found whether fore-and-aft judgment of the decision-makers on the issue is the contradictions, then decision-maker can modify judgment in time by those prompt message.

3.2. TOPSIS

Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) is a multi-attribute decision-making method, and uses to resolve multi-objective and multi-program decision problem. It's the basic idea is: the basic for estimation will be decided by constructing positive ideal solution and negative ideal solution of evaluation indicators and compare with the close and away degree of the ideal solution.

3.3. The standardization decision-making matrix

In the actual multi-objective decision-making process, because of different dimensions and different changes in scope for each index, so each index need to take dimensionless in order to better reflect the actual changes of various indicators. The standardized decision matrix will be established by the following specification decision matrix.

$$B = (b_{ij})_{m \times n} \cdot b_{ij} = \overline{a}_{ij} / \sqrt{\sum_{i=1}^{m}(\overline{a}_{ij})^2} \tag{1}$$

where：

$$b_{ij} = [b_{ij}^{L}, b_{ij}^{U}]$$

$$b_{ij}^{L} = a_{ij}^{L} / \sqrt{\sum_{i=1}^{m} (a_{ij}^{U})^2}$$

$$b_{ij}^{U} = a_{ij}^{U} / \sqrt{\sum_{i=1}^{m} (a_{ij}^{L})^2}$$

3.4. The calculation of the weight vector

The weight vector of the evaluation index is determined by Analytic Hierarchy Process (AHP), the steps are as follows:

Step 1: To construct the judgment matrix B-C. The relationship between the criterion layer and the project layer are established by 1-9 scale method, and then judgment matrix is constructed.

Step 2: To normalize judgment matrix. The calculation method of the general items sees formula (2).

$$b_{ij}^{'} = b_{ij} / \sqrt{\sum_{i=1}^{5} b_{ij}} \qquad (i = 1, 2, 3, 4, 5, 6) \tag{2}$$

Step 3: To add each row of the judgment matrix which has been normalized.

$$\beta_i = \sum_{i=1}^{6} b_{ij} \qquad (i = 1, 2, 3, 4, 5, 6) \tag{3}$$

Step 4: The calculation of the weight vector. That is a normalization process. See (4).

$$\omega_j = \beta_i / \sum_{i=1}^{6} \beta_j \tag{4}$$

Step 5: The calculation of the largest eigenvalue of the judgment matrix.

$$\lambda_{\max} = \sum_{i=1}^{6} \frac{(B\omega_1)_i}{n\omega_j} \tag{5}$$

Step 6: The consistency test. For judgment matrix B-C, the lager value of CI, the worse consistency of the judgment matrix is to be explained.

$$CI = \frac{(\lambda_{\max} - n)}{(n-1)} \tag{6}$$

When CI<0.1, the satisfaction with judgment matrix can be accepted. When order n of judgment matrix is large, the satisfying consistency meets more difficult. At this point, the random consistency index RI will be introduced, and a reasonable judgment index CR will be definite, that is consistency proportion indicators. CR=CI/RI, when CR<0.1, the consistency of judgment matrix can be accepted, otherwise the judgment matrix need to be make the appropriate modifications.

3.5. To construct the weighted normalized decision matrix C_0

The weighted normalized decision matrix is

$$C = [\omega_j b_{ij}^L, \omega_j b_{ij}^U]_{m \times n} \qquad i \in M, j \in N \tag{7}$$

3.6. To determine the positive ideal and negative ideal point

If u_j^L and u_j^U meet $u_j^L = \max_i c_{ij}^L, u_j^U = \max_i c_{ij}^U$, the positive ideal point is

$$\overline{\mu} = [u_j^L, u_j^U](j \in N) \tag{8}$$

If v_j^L and v_j^U meet $v_j^L = \min_i c_{ij}^L, v_j^U = \min_i c_{ij}^U$, the negative point is

$$\overline{v} = [v_j^L, v_j^U](j \in N) \tag{9}$$

3.7. To determine the distance

The distance of each program to the ideal point are shown as following.

$$D_i^+ = \sum_{j=1}^n |\left(c_{ij}^L - u_j^L\right) + \left(c_{ij}^U - u_j^U\right)|, i \in M \tag{10}$$

The distance of each program to the negative ideal point are shown as following.

$$D_i^- = \sum_{j=1}^n |\left(c_{ij}^L - v_j^L\right) + \left(c_{ij}^U - v_j^U\right)|, i \in M \tag{11}$$

3.8. The relative proximity of each program to the ideal point

$$S_i^* = \frac{D_i^-}{D_i^+ + D_i^-}, i \in M \tag{12}$$

Finally, the program was sorted by from big to small, and the program to be ranked near the top is the most excellent.

4. Case Analysis

Five typical intersections, which were selected on the main road in a city, will be evaluated the level of congestion respectively. The main factors affecting the intersections are shown in Table 1. Range of values of the foregoing six indicators was determined by industry experts, traffic participants and traffic managers according to the actual situation. The corresponding range of value described by qualitative language is shown in table 2.

Table 2 Range of intersection traffic congestion evaluation index

Traffic state	C_1	C_2	C_3	C_4	C_5	C_6
Free	[8,10]	[8,10]	[8,10]	[8,10]	[8,10]	[8,10]
Mild crowded	[6,8]	[6,8]	[6,8]	[6,8]	[6,8]	[6,8]
Moderately crowded	[3,6]	[3,6]	[3,6]	[3,6]	[3,6]	[3,6]
Severe congestion	[0,3]	[0,3]	[0,3]	[0,3]	[0,3]	[0,3]

4.1. The establishment of decision matrix

The decision matrix A:

$$
\begin{Vmatrix}
[8,9] & [6,7] & [2,3] & [4,5] & [5,6] & [7,8] \\
[6,7] & [7,8] & [1,3] & [5,6] & [1,2] & [3,4] \\
[5,6] & [6,7] & [7,8] & [8,9] & [4,6] & [6,8] \\
[3,6] & [1,3] & [2,3] & [8,9] & [7,8] & [5,6] \\
[1,3] & [0,3] & [5,6] & [7,9] & [8,9] & [4,6]
\end{Vmatrix}
$$

4.2. Normative decision matrix

Decision matrix will be standard by the formula (1), results are as follows:

$$
\begin{Vmatrix}
[0.6,0.8] & [0.4,0.7] & [0.27,0.3] & [0.2,0.3] & [0.3,0.5] & [0.5,0.7] \\
[0.4,0.6] & [0.5,0.8] & [0.1,0.3] & [0.3,0.4] & [0.1,0.2] & [0.2,0.3] \\
[0.3,0.5] & [0.4,0.7] & [0.6,0.9] & [0.5,0.6] & [0.3,0.5] & [0.4,0.7] \\
[0.2,0.5] & [0.1,0.3] & [0.2,0.3] & [0.5,0.6] & [0.5,0.6] & [0.3,0.5] \\
[0.1,0.3] & [0.0,0.3] & [0.4,0.6] & [0.4,0.6] & [0.5,0.7] & [0.3,0.5]
\end{Vmatrix}
$$

4.3. The calculation of evaluation index weight

According to Table 1, the judgment matrix of evaluation index is obtained by a comprehensive evaluation of all categories of personnel. The specific value see matrix 13.

$$\begin{vmatrix} 1 & 2 & 3 & 3 & 5 & 5 \\ \dfrac{1}{2} & 1 & 2 & 3 & 4 & 5 \\ \dfrac{1}{3} & \dfrac{1}{2} & 1 & 3 & 5 & 5 \\ \dfrac{1}{3} & \dfrac{1}{3} & \dfrac{1}{3} & 1 & 2 & 3 \\ \dfrac{1}{5} & \dfrac{1}{4} & \dfrac{1}{5} & \dfrac{1}{2} & 1 & 3 \\ \dfrac{1}{5} & \dfrac{1}{5} & \dfrac{1}{5} & \dfrac{1}{3} & \dfrac{1}{3} & 1 \end{vmatrix} \tag{13}$$

4.4. The calculation of the weight

The weight can be calculated by the previous step 2 to step 4, results are as follows: $\omega_j = (0.349, 0.243, 0.198, 0.100, 0.068, 0.042)^T$

4.5. The calculation of the largest eigenvalue and check of the consistency

The largest eigenvalue λ_{max} can be obtained according to the equation (5), that is λ_{max}=6.337. And then consistency test of judgment matrix can be done by using the principle described above.

$$CI = \frac{\lambda_{max} - n}{n - 1} = 0.067$$

When n=6, RI=1.24, $CR = \dfrac{CI}{RI} = 0.054 < 0.1$

The Consistency of the judgment matrix can be accepted and the weight ω_j is determined to be $\omega_j = (0.349, 0.243, 0.198, 0.100, 0.068, 0.042)^T$.

4.6. The construction of the weighted normalized decision matrix C_0

It, weight normalized decision matrix C_0, can be constructed by the formula (7). That is

$$\begin{vmatrix} [0.19,0.27] & [0.09,0.16] & [0.05,0.06] & [0.02,0.03] & [0.02,0.03] & [0.03,0.05] \\ [0.14,0.21] & [0.13,0.18] & [0.02,0.06] & [0.03,0.04] & [0.00,0.01] & [0.01,0.02] \\ [0.12,0.18] & [0.11,0.16] & [0.12,0.17] & [0.05,0.06] & [0.02,0.03] & [0.03,0.05] \\ [0.07,0.18] & [0.02,0.07] & [0.04,0.06] & [0.05,0.06] & [0.03,0.04] & [0.02,0.03] \\ [0.02,0.09] & [0.00,0.07] & [0.09,0.13] & [0.04,0.06] & [0.04,0.05] & [0.02,0.03] \end{vmatrix}$$

4.7. To determine the positive ideal and negative ideal point

The positive ideal point and negative ideal point can be determined according to equation (8), (9). Specific results are u_j={[0.19,0.27],[0.13,0.18],[0.12,0.17],[0.05,0.06],[0.04,0.05],[0.03,0.05]} , v_j={[0.02,0.09],[0.00,0.07],[0.02,0.06],[0.02,0.03],[0.00,0.01],[0.01,0.02]} .

4.8. To calculate the distance of target G to the ideal point and negative ideal point

The distance of target G to the ideal point and negative ideal point can be obtained according to equation (10) and (11), results are

$$D_1^+ = 0.315, \; D_2^+ = 0.468, \; D_3^+ = 0.243, \; D_4^+ = 0.659, \; D_5^+ = 0.700, D_1^- = 0.648, \; D_2^- = 0.495, \; D_3^- = 0.721,$$
$$D_4^- = 0.305, \; D_5^- = 0.264.$$

4.9. The calculation to the relative closeness degree

The relative closeness degree between objective and optimal target can be calculated by formula (12), that is $S_1^* = 0.673 \; S_2^* = 0.514 \; S_3^* = 0.748 \; S_4^* = 0.316 \; S_5^* = 0.274$. It can clearly be seen $S_3^* > S_1^* > S_2^* > S_4^* > S_5^*$, and the order of intersection traffic congestion is $S_3^* > S_1^* > S_2^* > S_4^* > S_5^*$. Traffic congestion of intersection 3 is lighter than other intersections, while intersection 5 is the most crowded, so it needs be governed as soon as possible.

5. Conclusion

The paper combines AHP and TOPSIS methods to construct a comprehensive evaluation model and evaluates the intersection traffic congestion status by above model. The evaluation results are basically consistent with the actual situation of the selected intersections; it indicates that we can use the model to evaluate the intersection traffic congestion. However, some problems need to be further research in the evaluation process, such as the selection of evaluation index and the establishment of judgment matrix and so on.

6. Acknowledgments

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