Intelligent Traffic Safety Evaluation of Urban Road Intersections Based on Analytic Hierarchy Process and Fuzzy Theory

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Abstract: Since the evaluation of traffic safety status of urban road intersections is fuzzy and hierarchical, this paper analyzes the occurrence mechanism of traffic accidents at urban road intersections, constructs an evaluation index system for smart traffic safety status of urban road intersections, and proposes an index system based on the analytic hierarchy process and fuzzy theory. Smart traffic safety evaluation method at urban road intersections. The fuzzy theory is used to modify the weights calculated by the analytic hierarchy process to obtain the membership value of each indicator in the evaluation system, and the fuzzy comprehensive evaluation results of the traffic safety status of urban road intersections are determined based on the principle of maximum membership. The study takes an intersection in Chongqing Hi-tech Zone as an example, and uses the index system and fuzzy comprehensive evaluation method in this article to evaluate its traffic safety status. Comparing the results with the actual results, it was found that the two are basically consistent, which verifies the effectiveness of the index system and evaluation method proposed in this article, and can provide reference and reference for the smart traffic safety evaluation of urban road intersections.

Keywords: Urban Road Intersections; Intelligent Transportation Safety State Evaluation; Fuzzy Theory; Hierarchical Analysis

1. Introduction

Urban road intersections are important nodes in the urban road network where various modes of transportation (e.g. motorized vehicles, non-motorized vehicles, and pedestrians) meet. Due to the differences in the driving characteristics of different modes of transportation, intersections are prone to different degrees of interference and conflict, and have become black spots for road traffic accidents. According to statistics, about 25% of fatal accidents occur at intersections [1]. Therefore, the establishment of an effective safety evaluation method for urban intersection traffic safety problems will be beneficial to the prevention of intersection traffic accidents and the reduction of losses caused by traffic accidents.

In terms of intelligent transportation safety evaluation, due to the fuzzy randomness of the safety evaluation factors of traffic accident-prone road sections, the mathematical method based on fuzzy theory can be used for effective treatment [2], the mathematical method based on fuzzy theory can be used for effective treatment; the hierarchical analysis method (AHP) can divide a large number of indexes into multiple levels according to the nature and importance of the indexes, so as to construct a highly reliable multilevel evaluation system. Therefore, it is very appropriate to combine the fuzzy theory with hierarchical analysis to establish a fuzzy hierarchical comprehensive evaluation model based on fuzzy theory and combine it with hierarchical analysis to evaluate the intelligent traffic safety of accident-prone intersections [3]. This paper takes the intersection of South University City Road and West University City Road in Hi-Tech Zone of Chongqing Municipality as an example, and establishes and applies the model to comprehensively evaluate the safety of the operation phase of accident-prone sections of urban road intersections.

2. Traffic Safety Evaluation Index System for Urban Road Interswctions

A set of intelligent traffic safety evaluation factors for urban road intersections is established by searching archival materials and on-site investigation to solve the hierarchy and ambiguity of the index system. Construct a multi-level evaluation index system to clarify the affiliation and parallelism between the indicators.

2.1 Set of Factors for Intelligent Transportation Safety Evaluation of Urban Roadway Intersections

Based on the analysis of a large amount of data on the causes of traffic accidents at urban road intersections, the main factors affecting traffic safety at urban road intersections were identified and categorized to form a factor set. According to the theory of fuzzy mathematics, let $U=\{U_1,U_2,\cdots,U_m\}$ be the evaluation index of the evaluation object. In this paper, $U=\{U_1,U_2,U_3,U_4,U_5\}=\{People,\ Vehicles,\ Roads,\ Environment,\ Management\}$, the allocation of weights can be effectively optimized by grading the evaluation indexes, i.e., setting the subordinate second-level evaluation indexes under the first-level evaluation indexes, in which $U=\{U_{i1},U_{i2},\cdots,U_{in}\}$. $u_{ij}=\{i=1,2,\cdots,m;j=1,2,\cdots,n\}$ is the J factor of the subordinate second-level indicator corresponding to the I factor in the first-level evaluation J indicator [4].

The intelligent traffic safety evaluation index system for urban road intersections is divided into three levels from top to bottom: target level, criterion level and index level. This paper takes the "cross" intersection as the evaluation object, and based on the principles of systematic, hierarchical and operability, the five main factors affecting the traffic safety of the intersection are taken as the criterion layer. The evaluation index system is modified and improved according to the influencing factors of urban road intersections, and a total of 18 evaluation indexes are established [5].The evaluation indicator system is shown in Figure 1.

2.2 Fuzzy Theory and Scoring Criteria

Classical set theory cannot describe uncertain and fuzzy domains, and fuzzy theory fully overcomes the shortcomings of classical set theory and provides a new way to deal with uncertainty and imprecision problems. In conducting the assessment of the city's smart transportation safety status, the affiliation of the factor set to the rubric set is filled with continuous intervals, i.e., {0,1}→ [0,1] [6].Among the influencing factors of smart traffic safety conditions at urban road intersections, it is necessary to quantify the score range of the single-factor index comment set to construct a membership function, and then use the quantitative values provided by expert ratings to obtain the calculated interpolation points [7].The traditional evaluation of the state of transportation safety often uses the method of expert survey, but the limitation of this method is that it ignores the experts' own deficiencies and level of expertise [8], Therefore, in order to ensure the objectivity of the scoring process and the reliability of the scoring results, the expert scoring group in this paper was formed by comprehensively considering factors such as the years of service and titles of the panel experts. The expert scoring team consisted of 18 experts, including road designers, construction engineers and road maintenance managers. Based on the set of rubrics shown in equation (1), the expert rating intervals were categorized as follows: level 1 is safer, rating [100, 90); level 2 is safe, rating [90, 70); level 3 is basic danger, rating [70, 50); and level 4 is more dangerous, rating [50, 0) [9].

$$u=\{u_1,u_2,\cdots,u_m\}=\{\mathrm{I}，\mathrm{II}，\mathrm{III}，\mathrm{IV}\} \tag{1}$$

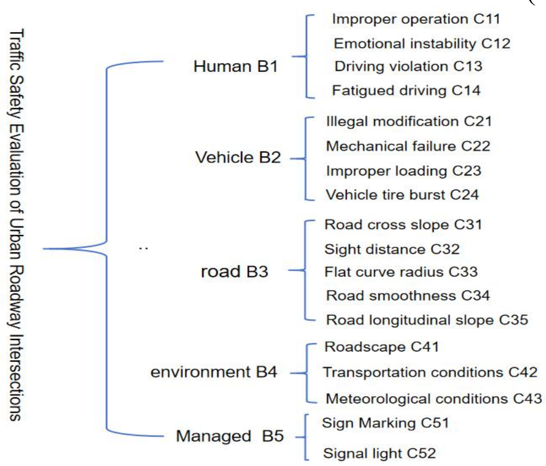

Figure 1. Traffic Safety Evaluation Index System for Urban Road Intersections

2.3 Construct Fuzzy Membership Matrix

Since there are many detailed factors involved in the evaluation process, a two-level comprehensive evaluation model is usually used. According to this principle, the steps to establish a mathematical model are as follows [10]:

2.3.1 Determine the evaluation factor set U

According to the comprehensive index system set up in this article, the evaluation factor set U is established: U:
$U=\{U_1,U_2,U_3,U_4,U_5\}=\{People,\ Vehicles,\ Roads,\ Environment,\ Management\}$, Secondary evaluation index $U_n=\{U_{n1},U_{n2},U_{n3},U_{n4}\}$.

2.3.2 Determine the comment set V

Set: $V=\{\mathrm{I}，\mathrm{II}，\mathrm{III}，\mathrm{IV}\}$, the rubric set reflects the different safety states of traffic at urban road intersections. Comment set V: V= { I(safer), II(safe), III(dangerous) , IV(more dangerous) }.

2.3.3 Determine the judgment matrix Ri composed of single-factor judgments, and find the first-level judgment vector

As the fuzzy matrix Ri from sub-factor set Ui to judgment set Vi,

$$R_i = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1\sigma} \\ \cdots & & & \\ r_{\sigma 1} & r_{\sigma 2} & \cdots & r_{\sigma\sigma} \end{bmatrix} \quad (2)$$

The fuzzy matrix synthesis operation is performed to obtain the first-level judgment vector $B_i = A_i \odot R_i = (b_{i1}, b_{i1}, \cdots, b_{i5})(i = 1, 2, \cdots, 6)$.

2.3.4 Determine the secondary judgment vector

Consider each Ui as a factor, denoted as $U = \{U_1, U_2, \cdots, U_6\}$, then the one-factor judgment matrix R of the factor set U is.

$$R = \begin{pmatrix} B_1 \\ \cdots \\ B_4 \end{pmatrix} = \begin{pmatrix} b_{11,} & b_{12,} & \cdots, & b_{15} \\ & \cdots & & \\ b_{\sigma 1,} & b_{\sigma 2,} & \cdots, & b_{\sigma 5} \end{pmatrix} \quad (3)$$

2.3.5 By AHP method

The weight assignment $A = \{a_1, a_2, \cdots, a_6\} \sum a_i = 1$ can be given according to the importance of Ui. Thus, the secondary judgment vector $B_i = A_i \odot R_i = (b_1, b_1, \cdots, b_5)$ is obtained and normalized.

2.3.6 Using the maximum affiliation criterion

The safety level is attributed to $b_{i\max} = (i = 1, 2, \cdots, m)$ according to the principle of maximum affiliation, to obtain the traffic safety status of the road intersection.

3. Determination of the Weights of the Indicators at Erch Level

Hierarchical analysis introduces quantitative analysis into the qualitative decision-making process in order to reduce the influence of subjective judgments on the outcome of decisions [11].The calculation process requires the participation of experts with extensive theoretical and practical experience as evaluators in decision-making [12].Experts evaluate the relative importance of the standard layer indicators in the decision-making indicator system and the indicator layer indicators under the same standard layer. On this basis, the comparative judgment matrices of the indicators in the standard and indicator layers are calculated, and then the consistency test is performed on the largest eigenvalue of each matrix, and the weights of the indicators that pass the consistency test are ranked to determine the decision-making results [13].

3.1 Constructing a Comparative Judgment Matrix

Qualitative and quantitative analysis based on the constructed evaluation index system (Figure 1), first of all, it is necessary to compare each element of the same criterion layer in pairs and calculate the quantitative value of the relative importance of the indicators, i.e., the comparative judgment matrix, in order to eliminate as much as possible the influence of the cognitive limitations of the decision-making on the results, to reduce the difficulty in comparing the elements of different natures, and to improve the accuracy of the evaluative judgment [14]. In this paper, the 1-9 scale method was used to construct a comparative judgment matrix, and the meaning of each scale is listed in Table 1 [15].

Table 1. 1-9 Scale Method Meaning Table

scale	meaning
1	Both factors have the same importance
3	The former is slightly more important than the latter
5	The former is significantly more important than the latter
7	The former is more strongly important than the latter
9	The former is extremely more important than the latter
2, 4, 6, 8	Intermediate values of the above adjacent judgments
reciprocal	If the importance ratio of factor I to factor J is aij then the importance ratio of factor j to factor i is aji =1/ aij.

In the urban road intersection traffic safety evaluation system, this paper takes the environmental factors comprehensive index B4 as an example, and constructs a comparative judgment matrix for the three sub-indicators of B4, namely, "road landscape C41", "meteorological conditions C42", "traffic conditions C43", and "traffic conditions C42", as shown in Table 2. "The comparison judgment matrix is constructed as shown in Table 2. Similarly, we can get the comparison judgment matrix between the indicators of the guideline layer and the indicators of the indicator layer under the same guideline layer.

Table 2. B4-C Comparative Judgment Matrix

B4	C41	C42	C43
C41	1	1/3	5
C42	1	1	7
C43	1/3	1/7	1

3.2 Weight Vector Calculation and Consistency Test

In this paper, the root method is used to calculate the indicator weight vector W. The procedure is as follows.

•Compare each row of the judgment matrix by concatenating the rows and then squaring them m times to obtain the vector.

$$W^*=(w_1^*,w_2^*,\cdots,w_m^*) \tag{4}$$

$$w_i=\sqrt[m]{\prod_{j=1}^{m}a_{ij}} \tag{5}$$

•Normalize W* to obtain the weight vector.

$$W=(w_1,w_2,\cdots,w_m)^{T} \tag{6}$$

$$w_i=\frac{w_i^*}{\sum_{i=1}^{m}w_i^*} \tag{7}$$

•Sum the elements of each column in the comparison judgment matrix to obtain the vector.

$$S=(s_1,s_2,\cdots,s_m) \tag{8}$$

$$s_1=\sum_{i=1}^{m}a_{ij} \tag{9}$$

•Calculate the maximum eigenvalue λ max:

$$\lambda_{\max}=\sum_{i=1}^{m}s_iw_i=S\bullet W=\frac{1}{m}\sum_{i=1}^{m}\frac{(A\bullet W)_i}{w_i} \tag{10}$$

•The steps to check the consistency of the judgment matrix are as follows:

Consistency index CI

$$CI=\frac{\lambda_{\max}-n}{n-1} \tag{11}$$

•Random consistency index RI

RI is used to measure CI. Usually, its value is positively correlated with the order of the comparison judgment matrix.

$$RI=\frac{CI_1+CI_2+\cdots+CI_n}{n} \tag{12}$$

•Consistency ratio CR

When CR≤ 0.1, the consistency of the judgment matrix is considered acceptable, otherwise the judgment matrix should be appropriately corrected. CR > 0.1 indicates that the matrix fails to meet the consistency requirements and needs to be reconstructed.

$$CR=\frac{CI}{RI} \tag{13}$$

Follow the above steps to calculate the weight of each comparison judgment matrix and conduct consistency testing.

4. Example Analysis

This example is located at the intersection of South University Town Road and West University Town Road in Hi-Tech Zone, Chongqing, as shown in Figure 2.The intersection is a cross intersection, The speed limit on both roads is 40Km/h. The longitudinal slope of University Town South Road is 2%, and the road gradient of University Town West Road is 1.5%.The surveyed peak hourly flows at this intersection are shown in Figure 3.

Figure 2. Intersection of Chongqing University Town South Road and University Town West Road

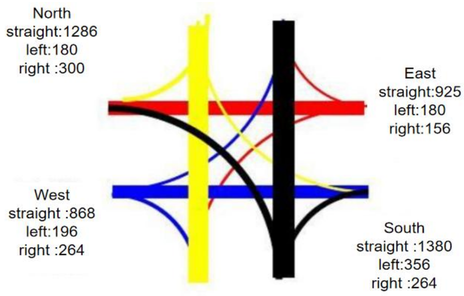

Figure 3. Peak Hourly Flow at Intersections

4.1 Calculate the Membership Degree of Each Factor

According to the established comprehensive evaluation method for traffic safety at urban road intersections, experts were organized to carry out expert scoring on the identified indicator layers, and the scoring results are shown in Table 3.

Calculate the degree of membership of each indicator in the indicator layer to each evaluation level. The results are shown in Table 4.

Table 3. Scores of Various Safety Evaluation Indicators at Intersections

parameterization	index	Score
Human B1	Improper operation C11	79
	Emotional instability C12	76
	Driving violation C13	73
	Fatigued driving C14	80
Vehicle B2	Illegal modification C21	81
	Mechanical failure C22	82
	Improper loading C23	88
	Vehicle tire burst C24	79

road B3	Road cross slope C31	90
	Sight distance C32	84
	Flat curve radius C33	90
	Road smoothness C34	88
	Road longitudinal slope C35	86
environment B4	Roadscape C41	84
	Transportation conditions C42	85
	Meteorological conditions C43	79
Managed B5	Sign Marking C51	89
	Signal light C52	92

4.2 Calculation of the Weights of the Indicators

Based on the constructed urban road intersection traffic safety evaluation index system (Fig. 1), the comparative judgment matrix is constructed using the 1-9 scale method, and then according to equations (5) to (14), the weights of the indicators of the guideline layer and the indicator layer are calculated as shown in Table 5.

4.3 Calculation of Intersection Traffic Safety Status Evaluation Results

Calculate target-level evaluation results based on single-factor affiliation, expert ratings and guideline-level indicator weights： $A=W\times B$ = [0. 548, 0.406, 0.041, 0.005] .According to the principle of maximum affiliation, combined with the constructed rating interval V= { I(safer), II(safe), III(basically dangerous) , IV(dangerous) }, the intersection of the South Road of University City and the West Road of University City of Hi-Tech Zone of Chongqing Municipality is in a safe state.

Table 4. Single-Factor Membership Degree and Expert Rating of Various Traffic Safety Evaluation Indicators at Intersections

index	Expert Ratings	Membership			
		Level 1	Level 2	Level 3	Level 4
C11	79	0.703	0.377	0.068	0.002
C12	76	0.644	0.494	0.073	0.004
C13	74	0.602	0.504	0.091	0.004
C14	80	0.728	0.309	0.043	0.001
C21	81	0.790	0.298	0.028	0.001
C22	82	0.830	0.201	0.015	0.001
C23	88	0.962	0.042	0.000	0.000
C24	79	0.703	0.377	0.068	0.002
C31	90	0.878	0.031	0.000	0.000
C32	84	0.893	0.138	0.010	0.000
C33	90	0.878	0.031	0.000	0.000
C34	88	0.962	0.042	0.000	0.000
C35	86	1.000	0.054	0.000	0.000
C41	84	0.893	0.138	0.010	0.000
C42	85	0.912	0.104	0.006	0.000
C43	79	0.703	0.377	0.068	0.002
C51	89	0.946	0.033	0.000	0.000
C52	92	0.818	0.021	0.000	0.000

5. Conclusion

In this paper, for the characteristics of urban road intersection traffic safety evaluation system with complex levels and high fuzzy degree, the hierarchical analysis method and fuzzy theory are introduced, and the fuzzy mathematical theory is used to correct the hierarchical analysis method, which is used as the basis for constructing the urban road intersection traffic safety evaluation index system, and the method is used to analyze and evaluate the traffic safety situation of the intersection of the south road and the west road of the University City in Chongqing Hi-Tech Zone. It is verified that the evaluation results are basically consistent with the actual traffic safety condition, which proves that the method proposed in this paper is effective and feasible, and realizes a more objective quantitative evaluation of the traffic safety condition of urban road intersections.

Table 5. Index Weights of the Criterion Layer and Indicator Layer of the Traffic Safety Evaluation Index System at the Intersection of University Town South Road and University Town West Road

parameterization	weight	index	weight
Human B1	0.326	Improper operation C11	0.0869
		Emotional instability C12	0.0471
		Driving violation C13	0.0958
		Fatigued driving C14	0.0688
Vehicle B2	0.102	Illegal modification C21	0.0311
		Mechanical failure C22	0.0389
		Improper loading C23	0.0511

		Vehicle tire burst C24	0.0410
road B3	0.116	Road cross slope C31	0.0333
		Sight distance C32	0.0632
		Flat curve radius C33	0.0511
		Road smoothness C34	0.0298
		Road longitudinal slope C35	0.0407
environment B4	0.205	Roadscape C41	0.0227
		Transportation conditions C42	0.0698
		Meteorological conditions C43	0.0677
Managed B5	0.251	Sign Marking C51	0.0712
		Signal light C52	0.0898

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References

[1] Antonucci N D., Hardy K K., SLACK K L. 2004. A Guide for Reducing Collisions at Signalized Intersections. Washington D C: Transportation Research Board of the National Academies.

[2] Guo L., Yang S., Zhou L.2017. Comprehensive evaluation of highway traffic safety based on fuzzy analytic hierarchy process. Transportation Science and Technology and Economics.

[3] Yu Z., Zheng X. 2018. Research on operation safety evaluation of highway tunnels in mountainous areas based on fuzzy comprehensive evaluation method. Highway Transportation Technology.

[4] Yang L.2011.Principles and Applications of Fuzzy Mathematics (5th Edition).South China University of Technology Press

[5] Wang W. 2019. Analysis of influencing factors of urban road traffic accidents and traffic safety evaluation. Chang' an University.

[6] Zhong M. 2013. Multi-level fuzzy comprehensive evaluation of reservoir-induced earthquake risk based on association rules and cloud model. Wuhan: Huazhong University of Science and Technology.

[7] Chen C., Hua J. 2010. Application of improved analytic hierarchy process in safety evaluation of earth-rock dam. Progress in Water Conservancy and Hydropower Science and Technology.

[8] Zhang X. 2019. Research on safety risk assessment of highway maintenance construction based on fuzzy analytic hierarchy process—taking X project as an example. Guangzhou: South China University of Technology.

[9] Song H. 2016.Traffic safety evaluation in channel waters based on fuzzy comprehensive evaluation. Dalian Maritime University.

[10]Deng X., Li J., Zeng H.2012. Analysis and application research on weight calculation method of AHP. Practice and Understanding of Mathematics.

[11]Ma Z., Chen Y., Zhang L.2014. Analysis of factors affecting the severity of urban road traffic accidents. Journal of Chongqing Jiaotong University (Natural Science Edition).

[12]Zhang H., Li M. 2020. Research on application of fuzzy comprehensive evaluation of highway safety. Research and Exploration.

[13]Li X.2007. Research on risk assessment and risk management of hydropower station projects based on analytic hierarchy process. Kunming: Kunming University of Science and Technology.

[14]Li X., Li C., Li D. 2010. Research on dam safety evaluation based on multi-level fuzzy analysis method. People's Yangtze River.

[15]Jiang L. 1998. Application of fuzzy consistency matrix in analytic hierarchy process. Journal of Shanghai Maritime University.