Risk Assessment Research of Urban Road Traffic Safety Based on Extension Matter Element Model

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Abstract: In order to improve the urban road traffic safety early warning ability and traffic safety situation, this paper expounds the relationship between the main factors affecting traffic safety and traffic safety from macro and micro aspects. Then the evaluation index system of urban road traffic safety is constructed by selecting four factors including pedestrian, vehicular, road and environment. And the index weight are determined by the entropy weight method, the traffic safety evaluation model is established by extension theory, so it can make a qualitative and quantitative analysis of road traffic safety. Finally, Wuhan City is used as an example to verify the established index system and evaluation model, after determining the evaluation level according to the actual situation of urban road traffic safety, the constructed matter element model is applied to the evaluation of urban road traffic safety status in Wuhan. It is concluded that the safety level of the actual roads in Wuhan is three levels, and the safety is moderate and needs to be improved.

1. Introduction
In recent years, road traffic accidents have occurred frequently around the world, causing huge casualties and economic losses to the society. Faced with the severe traffic accident hazard situation, it is urgent to establish a scientific and efficient urban road traffic safety evaluation system to ensure the good management and improvement of urban road traffic and minimize the losses caused by disasters.

Road traffic safety assessment mainly analyzes the dangers, unfavorable factors and possible dangers, consequences and severity of road traffic. According to the analysis results, safety countermeasures are proposed to reduce or prevent accidents, thereby reducing the accident rate and reducing economic losses. Cheng Jinjun et al. used fuzzy comprehensive evaluation to evaluate the road factors in the road traffic safety influencing factors [¹]. Wang Yijing et al. proposed a grey evaluation model based on grey theory and established a road traffic safety evaluation system [²]. Qian Liang used the Delphi method and the analytic hierarchy process to establish a safety evaluation system and a safety evaluation model [³]. These methods are simple in analysis and subjective, and are more biased towards qualitative analysis. Cao Yinghao et al. used the combination of analytic hierarchy process and grey clustering method to establish a road traffic safety evaluation model and analyze the road traffic safety status [⁴]. Meng Lu et al. proposed the evaluation model of traffic conflict technology (TCT), which can quantitatively evaluate the safety status of road traffic [⁵]. Li Silao used the combination of DEA and AHP to evaluate traffic safety and analyzed it in 11 provinces and cities in the Yangtze River Economic Belt [⁶]. In the above study, there are few evaluation indicators for road traffic risk analysis, and only safety indicators such as death toll, number of accidents, mortality and fatality are evaluated, and cannot be from people, vehicles, roads, environment and management.
The above research results provide a good theoretical basis and method basis for the practice of road safety evaluation and early warning in China, but some methods have strong subjectivity, it is difficult to objectively quantify the evaluation index, and the extension matter element method is the calculation of quantitative indicators. A large number of raw data are used to completely overcome the shortcomings of the indicators that are not accurate enough to solve the problem of quality and quantity conversion between qualitative and quantitative indicators. Therefore, based on the above research, this paper selects 20 evaluation indicators to establish an index system from five aspects: human, vehicle, road, environment and management, and establishes a traffic safety risk assessment and early warning model based on extension theory.

2. Construction of a city road traffic safety risk assessment index system

2.1 Establishment of evaluation indicators

This paper reviews the domestic and international data and literature on urban transportation system safety evaluation, and summarizes the current domestic and international status of urban road system safety evaluation. Then, based on this, through survey and data processing analysis, we get a person and a car. Comprehensive dynamic system consisting of five factors: road, environment and management. When the entire safety network is in a stable normal state, it proves that the five safety influencing factors of people, vehicles, roads, environment and management are in a dynamic process of balanced coordination and mutual restraint.

Based on the selection principle of evaluation indicators, this paper expresses the urban road traffic safety evaluation system by three levels of indicators through the analysis of traffic safety factors. Among them, the urban traffic safety level is the first-level indicator; the second-level indicators include 5 factors affecting the traffic safety environment (people, vehicles, roads, environment, management); the third-level indicators are 20. The refined primary and secondary indicators are shown in Figure 1.

![Figure 1 Urban road traffic safety evaluation index system](image)

Among them, \( C_1 \) is the proportion of driving drivers under 3 years; \( C_2 \) is the number of traffic police for 100,000 people; \( C_3 \) is the average time for traffic accidents; \( C_4 \) is the time for medical accidents; \( C_5 \) is Large and medium-sized cars account for the total number of vehicles; \( C_6 \) is the proportion of vehicles using more than 15 years; \( C_7 \) is the accident rate of 10,000 vehicles; \( C_8 \) is the death rate of 10,000 vehicles; \( C_9 \) is the traffic sign and the line setting ratio; \( C_{10} \) is the road surface intact Rate; \( C_{11} \) is the intersection control rate; \( C_{12} \) is the illegal road occupation rate; \( C_{13} \) is the proportion of the route through the mountainous hills; \( C_{14} \) is the main division of the central separation zone; \( C_{15} \) is the annual bad climate Index; \( C_{16} \) is the ratio of the non-separated belt (column) of the road machine; \( C_{17} \) is the comprehensive economic loss ratio for traffic accidents; \( C_{18} \) is the safe traffic management plan; \( C_{19} \) is the case for the traffic accident escape case; \( C_{20} \) is the traffic safety investment ratio.
2.2 Evaluation level setting
In this paper, Wuhan City is taken as an example to classify the corresponding index system. The thresholds of various early warning indicators in each security level are mainly referred to the “Urban Road Traffic Planning and Design Specification” and “Urban Road Traffic Management Evaluation Index System”. The national, industry and local regulations on traffic safety quality standards, background and local standards, combined with existing research literature and the actual situation of traffic safety in China, determine the threshold value of early warning indicators. The threshold values are as shown in Table 1:

| Evaluation index                                      | First level | Second level | Third level | Level four | Five levels |
|-------------------------------------------------------|-------------|--------------|-------------|------------|-------------|
| Proportion of driving drivers under 3 years           | <3          | [3,6)        | [6,9)       | [9,12)     | ≥12         |
| the number of traffic police for 100,000 people       | >30         | [25,30)      | [20,25)     | [15,20)    | <15         |
| the average time for traffic accidents                | <200        | [200,220)    | [220,240)   | [240,260)  | ≥260        |
| the time for medical accidents                        | <600        | [600,700)    | [700,800)   | [800,900)  | ≥900        |
| the illegal road occupation rate                      | <5          | [5,8)        | [8,11)      | [11,14)    | ≥14         |
| Large sized cars account for the total number of vehicles | <5          | [5,8)        | [8,11)      | [11,14)    | ≥14         |
| the proportion of vehicles using more than 15 years   | <5          | [5,8)        | [8,11)      | [11,14)    | ≥14         |
| the accident rate of 10,000 vehicles                  | [30,80]     | (80,120)     | [120,160)   | (160,200)  | (200,320)   |
| the death rate of 10,000 vehicles                     | [2,5]       | (5,8)        | (8,12)      | (12,16)    | (16,30)     |
| the traffic sign and the line setting ratio           | [95,100]    | [90,95)      | [85,90)     | [80,85)    | (0,80)      |
| the road surface intact Rate                          | [80,100]    | [90,95)      | [85,90)     | [80,85)    | [0,80)      |
| the intersection control rate                         | [85,100]    | [75,85)      | [65,75)     | [55,65)    | [0,55)      |
| the proportion of the route through the hills         | <3          | [3,6)        | [6,9)       | [9,12)     | ≥12         |
| the main division of the central separation zone      | [90,100]    | [80,90)      | [70,80)     | [60,70)    | [0,60)      |
| the annual bad climate Index                         | <5          | [5,10)       | [10,15)     | [15,20)    | ≥20         |
| traffic safety investment ratio                       | ≥7          | [5,7)        | [3,5)       | [1,3)      | <1          |
| he case for the traffic accident escape case          | [70,100]    | [60,70)      | [50,60)     | [40,50)    | (0,40)      |
| the safe traffic management plan                      | 1.0         | 0.9          | 0.8         | 0.7        | <0.6        |
| the safe traffic management plan                      | <1          | [1,3)        | [3,5)       | [5,7)      | ≥7          |
| the ratio of the non-separated belt of the road machine | [90,100]    | [80,90)      | [70,80)     | [60,70)    | [0,60)      |

3. Urban road traffic safety risk assessment model based on extension matter element

3.1 The extension theory
The extension theory is an interdisciplinary subject that solves contradictions by exploring the laws and extensions of things, and integrates mathematics, systems, and thinking science \(^7\). Extension mathematics is based on extension sets. Unlike classical mathematics and fuzzy mathematics, it takes into account the quantity and spatial form of matter, taking into account not only the quantity of things...
but also the nature of things. It not only studies the matter elements combining quality and quantity, but also studies a large number of contradictions in life. The matter element is the basic element describing the thing, and its expression is expressed by the ordered triplet $R = (M, C, X)$. In the formula, $M$, $C$, and $X$ are called three elements of the matter element, $M$ is a thing; $C$ is the name of the feature; and $X$ is the magnitude of $M$ taken by $C$.

3.2 Determining the model classic domain and the model section

The security level of the object to be evaluated can be divided into $m$ standard modes or levels $N_1$, $N_2$, ..., $N_m$, then the classic domain of the $j$-th level is:

$$R_j = (N_j, C, V_j) = \begin{bmatrix} N_j & C_1 & V_{j1} \\ C_2 & V_{j2} \\ \vdots & \vdots & \vdots \\ C_n & V_{jn} \end{bmatrix} = \begin{bmatrix} N_j & C_1 & \{v_{jmax1}, v_{jmax1}\} \\ C_2 & \{v_{jmax2}, v_{jmax2}\} \\ \vdots & \vdots & \vdots \\ C_n & \{v_{jmaxn}, v_{jmaxn}\} \end{bmatrix}$$

(1)

equation (3). $W_j$ represents the object element of the $j$ level; $C$ is the feature set of the matter element; $C_i$ represent the $i$ feature of the level $N_j$, the evaluation index $i=1, 2, \ldots, n$; The range of $V_{ji} = \langle v_{jini}, v_{jmaxi} \rangle$ of the characteristic $C_i$ of $N_j$, that is the data range of the relevant features of each level - the classical domain.

$R$ is used to represent all levels of matter-element models. $V_i = \langle v_{jini}, v_{jmaxi} \rangle$ is called the section of the matter element $N$ with respect to the value taken by $C_i$, and is expressed as:

$$R_i = (N_i, C, V_i) = \begin{bmatrix} N_i & C_1 & V_{i1} \\ \vdots & \vdots & \vdots \\ C_n & V_{in} \end{bmatrix} = \begin{bmatrix} N_i & C_1 & \{v_{imax1}, v_{imax1}\} \\ \vdots & \vdots & \vdots \\ C_n & \{v_{imaxn}, v_{imaxn}\} \end{bmatrix}$$

(2)

3.3 Objects to be evaluated

The object to be evaluated refers to an array of the magnitudes of the various evaluation indicators obtained through field surveys and software interpretation. If $N_e$ is used to represent the object to be evaluated, and $V_{ei}$ is the feature value of $N_e$ with respect to feature $C_i$, the detection data about each feature to be evaluated is represented by matter element model $R_e$ as:

$$R_e = (N_e, C, V_e) = \begin{bmatrix} N_e & C_1 & V_{e1} \\ \vdots & \vdots & \vdots \\ C_n & V_{en} \end{bmatrix}$$

(3)

3.4 Safety Correlation Calculation

For the warning object $P_i$, first, the magnitude $V_{ik}$ of the necessary feature is used to evaluate $C_k$. If $V_{ik}$ does not belong to $V_{jk}$, it is considered that the early warning object $P_i$ does not satisfy the non-satisfiable condition and is not evaluated; otherwise, the degree of association of the object to be alerted with respect to each level is calculated. Usually, the correlation function of the $i$-th indicator value field belonging to the $j$-th security level is:

$$K_i(v_i) = \begin{cases} K_i(v_i) = \frac{\rho(v_i, V_{i})}{\rho(v_i, V_{i}) - \rho(v_i, V_{i}) \neq \rho(v_i, V_{i})} & \text{if} \rho(v_i, V_{i}) \neq \rho(v_i, V_{i}) \\ \rho(v_i, V_{i}) / |V_{i}|, & \text{if} \rho(v_i, V_{i}) = \rho(v_i, V_{i}) \end{cases}$$

(4)
\( V_i \) is the actual value of the evaluation factor; \( |V_{ij}| \) is the length of the section interval; \( K_j(v_i) \) is the degree of association of each safety factor with respect to the security level; \( \rho(v_i, V_{ij}) \) is the distance between the point \( V_i \) and the finite interval \( V_{ij} = (a_{ij}, b_{ij}) \), and \( \rho(v_i, V_{ij}) \) is the distance between the point \( V_i \) and the finite interval \( V_{ip} = (a_{ip}, b_{ip}) \).

The formula for calculating the distance is:

\[
\rho(x, (a, b)) = \sqrt{(x-a)^2 + (b-x)^2}
\]

(5)

3.5 Early warning index weight coefficient

This paper uses the entropy weight method to determine the weight of evaluation indicators. The entropy is based on the sample data of each factor. The degree of influence of the factors on the system can be judged by calculating the entropy weight. The size of the entropy weight is proportional to the influence of the factors on the system. Since the information of the entropy weight method is derived from objective data, the objectivity and accuracy of the results can be well guaranteed. The basic steps are as follows:

(1) For the \( m \) evaluation objects and \( n \) evaluation index data of each object, construct a normalized matrix, and \( x_{ij} \) is the evaluation value of the \( j \)-th factor of the \( i \)-th object (\( i=1, 2, 3; j=1, 2, ..., m \));

(2) Find the factor entropy \( H_j \)

\[
H_j = -k \sum_{i=1}^{m} f_{ij} \ln f_{ij} (j=1,2,3,...,n)
\]

\( f_{ij} = x_{ij} / \sum_{i=1}^{m} x_{ij}, k = 1 / \ln m \)

(6)

(3) Find entropy weight \( W_j \)

\[
W_j = \frac{1 - H_j}{\sum_{i=1}^{m} (1 - H_j)} \quad 0 \leq W_j \leq 1, \sum_{i=1}^{m} W_j = 1
\]

(7)

3.6 Traffic Safety Rating

The value of the correlation function \( K(x) \) indicates the degree to which the warning object conforms to the food safety level. The degree of association of the warning object \( R_0 \) with respect to the security level \( j \) is:

\[
K_j(R_0) = \sum_{i=1}^{m} W_i K(v_i)
\]

(8)

If \( R_0 \) meets the following formula

\[
K_j(R_0) = \max_{j=1,2,..., m} K_j(R_0)
\]

(9)

Then it is rated that \( R_0 \) belongs to security level \( j \).

4. Case analysis and strategy research

4.1 Analysis of the current situation of road traffic safety in Wuhan

According to the data provided by the Wuhan Statistical Yearbook, the statistical data of the 2016 road traffic safety evaluation indicators of Wuhan City are shown in Table 2.

| Evaluation index                                         | unit  | value |
|----------------------------------------------------------|-------|-------|
| Proportion of driving drivers under 3 years              | %     | 6.4   |
| the number of traffic police for 100,000 people          | People| 28.4  |
| the average time for traffic accidents                    | s     | 220   |
| the time for medical accidents                            | s     | 510   |
| the illegal road occupation rate                          | %     | 5.0   |
4.2 Wuhan Road Traffic Safety Assessment

4.2.1 Constructing related matter elements
According to the traffic safety assessment index value of Wuhan, the classic domain and the domain of traffic safety in Wuhan can be constructed as follows:

\[
R_1 = \begin{bmatrix}
M & c_1 & [0,3] \\
& c_2 & [30,\infty) \\
& & \ldots \\
& c_{20} & [0.8,1]
\end{bmatrix}, \quad R_2 = \begin{bmatrix}
M & c_1 & [3,6] \\
& c_2 & [20,30] \\
& & \ldots \\
& c_{20} & [0.6,0.8]
\end{bmatrix}, \quad R_3 = \begin{bmatrix}
M & c_1 & [6,9] \\
& c_2 & [20,25] \\
& & \ldots \\
& c_{20} & [0.4,0.6]
\end{bmatrix}
\]

\[
R_4 = \begin{bmatrix}
M & c_1 & [9,12] \\
& c_2 & [15,20] \\
& & \ldots \\
& c_{20} & [0.2,0.4]
\end{bmatrix}, \quad R_5 = \begin{bmatrix}
M & c_1 & [12,100] \\
& c_2 & [0,15] \\
& & \ldots \\
& c_{20} & [0,0.2]
\end{bmatrix}, \quad R_6 = \begin{bmatrix}
M & c_1 & [0,100] \\
& c_2 & [0,10000] \\
& & \ldots \\
& c_{20} & [0,1]
\end{bmatrix}
\]

4.2.2 Calculate correlation function and weight coefficient
Firstly, the weight coefficients of each evaluation index are calculated by equations (6) and (7). Through the identified traffic safety related matter elements, the road traffic safety of Wuhan City can be calculated by using the weight coefficient sets of equations (8) and (9). The relevance of the evaluation indicators for different evaluation levels is shown in Table 3.

| Table 3 Calculated values of road traffic safety evaluation indicators |
|---------------------------------------------------------------|
| Evaluation index | \( w_i \) | \( K_1(x_i) \) | \( K_2(x_i) \) | \( K_3(x_i) \) | \( K_4(x_i) \) |
| C_1   | 0.041 | 0.0276 | -0.0076 | -0.0693 | -0.0341 | -0.0238 |
| C_2   | 0.0406 | 0.0107 | -0.0023 | -0.0452 | -0.0726 | -0.0195 |
| C_3   | 0.0393 | 0.0017 | -0.0216 | -0.0543 | -0.0778 | -0.0205 |
| C_4   | 0.0373 | 0.0083 | -0.0051 | -0.0325 | -0.0782 | -0.0181 |
| C_5   | 0.0375 | -0.0004 | 0.0003 | -0.0204 | -0.0423 | -0.0054 |
| C_6   | 0.045 | 0.0012 | -0.0148 | -0.0407 | -0.0547 | -0.0231 |
| C_7   | 0.041 | -0.0035 | 0.003 | -0.027 | -0.0654 | -0.0152 |
| C_8   | 0.0544 | -0.0034 | 0.0049 | -0.0183 | -0.0505 | -0.0172 |
| C_9   | 0.0493 | -0.0307 | -0.0112 | -0.0023 | -0.0341 | 0.0013 |
| C_{10} | 0.0407 | -0.0112 | -0.0263 | -0.013 | 0.0123 | -0.0132 |
| C_{11} | 0.054 | -0.0102 | -0.0124 | -0.0076 | -0.0372 | 0.0026 |
| C_{12} | 0.0566 | -0.0062 | 0.0124 | -0.0135 | -0.0483 | -0.0058 |
4.3 Determine the rating and evaluation model results analysis

After calculating the matter-element model based on the extension theory, $k_j(x_i)$ is the largest. Therefore, the road traffic safety evaluation level in Wuhan belongs to the second level and is in a medium state. It also requires the local traffic control departments and units to strengthen the management and improvement of traffic.

The evaluation results of Wuhan road traffic safety using the urban road traffic safety evaluation model based on extension theory show that Wuhan is at the second level. At present, the traffic safety status in Wuhan is also at the level of the second level nationwide. From this, we can see that this paper is scientific and reasonable based on the idea of extension.

5. Conclusion

This paper first analyzes the characteristics of urban road traffic safety and the risk factors affecting traffic safety. It explores several typical factors that influence the road traffic safety in Wuhan, and finally establishes a risk assessment system based on five major components: people, vehicles, roads, environment and management. Secondly, this paper analyzes the advantages of extrinsic material element model evaluation method, and puts forward the idea of applying extensional decision material element model to evaluate urban traffic safety, and uses urban road traffic safety evaluation index. The entropy weight method is used to assign the elements in the index system, and finally the extension decision-making matter element evaluation model for road traffic accidents is established. Thirdly, taking Wuhan City as an example, collect all road traffic safety indicators and data of Wuhan City, and then build Wuhan's safety evaluation index system based on this, and analyze Wuhan City’s current road traffic safety conditions.

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