Study on Evaluation of Cooperative Vehicle Infrastructure System Roadside Facilities based on the Analytic Hierarchy Process

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Abstract. In this study, we established a fuzzy evaluation model for the deployment of vehicle road collaborative roadside equipment based on the Analytic Hierarchy Process. By selecting evaluation indicators, determining the weights of each indicator, and establishing an evaluation set, we established a multi-level indicator system. On the basis of fuzzy mathematics, we used the fuzzy comprehensive evaluation method to introduce in detail the fuzzy comprehensive evaluation method for the deployment of vehicle road collaborative roadside equipment. The research content is conducive to the development and promotion of vehicle road collaborative systems in China, and is of great significance for improving road traffic safety and efficiency, as well as achieving sustainable development of road traffic systems.

Keywords: Cooperative vehicle Infrastructure system, Roadside facilities, evaluation method, Indicator system

1 Introduction

The vehicle road collaboration system (CVIS) is to adopt advanced wireless communication and new generation Internet technology, implement dynamic real-time information interaction among people, vehicles and roads in an all-round way, and carry out active safety control of vehicles, collaborative management of road traffic and pedestrian safety assistance on the basis of full time and space dynamic traffic information collection and integration, fully realize the effective collaboration between people, vehicles and roads, ensure traffic safety, improve traffic efficiency, and thus form a safe, efficient and environmentally friendly road traffic system[1]. The vehicle road collaborative system, as an important means to promote the empowerment of new technology to improve the quality and efficiency of transportation development, is the future direction of China's transportation system and is increasingly valued by the government and research institutions [2-3].

In the vehicle road collaboration system, roadside equipment is a highly intelligent embedded information platform that undertakes important functions such as infor-

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mation collection and transmission. Roadside equipment is generally deployed at intersections and important special road sections. By managing and controlling attached communication devices and sensors (such as cameras, radars, temperature sensors, humidity sensors, etc.), real-time traffic and environmental information within the road section can be detected. After analyzing and processing this information, the application program inside the roadside equipment sends the processed traffic environment information to the vehicle and vehicle networking cloud platform through communication devices, completing the collection and sharing of information, thereby achieving intelligent collaboration between the roadside equipment and the vehicle and cloud platform. As an important infrastructure under the smart road system, the type, quantity, and deployment location of roadside equipment have a significant impact on the accuracy of traffic information collection. Therefore, it is particularly important to conduct research on evaluation methods for roadside equipment deployment in a vehicle road collaborative environment.

This study is based on the Analytic Hierarchy Process (AHP) to determine evaluation principles, select appropriate evaluation indicators based on different principles, and construct an evaluation indicator system [4]. Based on this, using the fuzzy comprehensive evaluation method and fuzzy data as the basis, an evaluation model is proposed by applying the fuzzy transformation principle and the principle of maximum membership degree to achieve the evaluation of vehicle road collaborative roadside equipment layout based on the Analytic Hierarchy Process [5]. The evaluation method helps to ensure the reasonable layout of roadside equipment and maximize its role in traffic management and vehicle safety, thereby improving the urban traffic environment and enhancing the travel experience of residents.

2 Evaluation Index System

2.1 Principles for Selecting Evaluation Indicators

The comprehensive evaluation of vehicle road collaboration system is a complex task, and the determination of evaluation indicators and evaluation system is the core foundation for comprehensive and accurate evaluation. Different indicator system structures may lead to completely different evaluation conclusions. Therefore, designing an effective and reasonable evaluation indicator system for vehicle road collaboration system is of great significance.

From the perspective of functional decomposition of each subsystem of the vehicle road collaborative system, combined with existing research results, establish an evaluation index system for the vehicle road collaborative system according to the following principles.

1. Comprehensiveness

The evaluation of vehicle road collaborative roadside equipment is also a complex system, and it is quite challenging to comprehensively evaluate its performance and effectiveness. A single indicator is difficult to fully reflect its characteristics, so the evaluation system needs to cover multiple aspects, including technical performance, safety, reliability, communication efficiency, data accuracy, etc., in order to comprehensively evaluate the quality of the system.

2. Scientificity

The selection of indicators should be based on recognized scientific theories, such as statistics, systems theory, management science, etc., to ensure that the evaluation system is scientific and objective. The evaluation indicators should accurately reflect the actual effects of vehicle road collaborative roadside equipment in improving traffic safety, optimizing traffic efficiency, reducing traffic congestion, etc., rather than based on subjective assumptions or unscientific inference. This can ensure the accuracy of the evaluation results, provide reliable reference basis for decision-makers, and support the application and promotion of vehicle road collaboration technology in traffic management and safety fields.

3. Feasibility

The designed indicators should have the characteristics of being collectible and quantifiable, and each indicator can be effectively measured and statistically analyzed. The establishment of an evaluation system is to provide comprehensive evaluation services, and its value can only be reflected in practical application. Therefore, each indicator should be defined clearly, simple and practical, with high reliability, and less affected by factors outside the evaluation system. The entire evaluation indicator system should be concise, easy to operate, and have practical application functions.

4. Economy

When evaluating roadside equipment for vehicle road collaboration, the principle of economy is crucial. The evaluation system should consider the cost-effectiveness of the equipment, including the costs of purchasing, installing, maintaining, and updating the equipment, and compare it with the economic benefits it brings. The principle of economy requires the evaluation system to comprehensively consider economic indicators such as investment return cycle, cost savings, resource utilization efficiency, etc., to ensure sustainable economic returns on investment, and to choose the most economical solution when resources are limited.

2.2 Evaluation Index Hierarchy Model

We refer to the set of factors that affect the deployment and evaluation of vehicle road collaborative testing equipment as the factor set. Here, this study adopts a three-level comprehensive evaluation model. The first layer is the target layer A, which is a comprehensive evaluation of the deployment of vehicle road collaborative roadside equipment; The second layer is criterion layer B. According to the overall goal requirements, the evaluation indicators of vehicle road collaborative roadside equipment to be studied are decomposed into four sub objectives, namely: comprehensiveness, scientificity, feasibility, and economy; The third layer is scheme layer C, which consists of a specific set of evaluation indicators and factors corresponding to each criterion layer.

Based on each sub objective and corresponding evaluation index of vehicle road collaboration, factors are aggregated and combined at different levels according to their interrelationships and membership relationships. A multi-level ordered hierarchical evaluation index hierarchical structure model is established as shown in Table 1.

Table 1. Evaluation index hierarchy model.

Target layer (A)	Criteria layer (B)	Plan layer (C)
Comprehensive evaluation of roadside equipment deployment for vehicle road collaboration.	Comprehensiveness	Types of data collection
		Functional integrity
		Facility coverage
	Scientificity	check the accuracy
		positioning accuracy
		Data processing accuracy
	Feasibility	Environmental adaptability
		Continuous operation rate
		Information responsiveness
	Economy	Average construction cost per kilometer
		Average operating cost per kilometer
		Average maintenance cost per kilometer

The meanings of each indicator are shown in Table 2:

Table 2. Meaning of evaluation indicators.

Indicator name	Meaning of indicators
Types of data collection	The richness of data types that roadside equipment can collect
Functional integrity	Complete functionality of roadside equipment
Facility coverage	The ratio of the coverage range that roadside equipment can detect to the road range
check the accuracy	Accuracy of roadside equipment detection data
positioning accuracy	Accuracy of roadside equipment positioning data
Data processing accuracy	Roadside equipment data processing accuracy
Environmental adaptability	Adaptation of roadside equipment to abnormal and adverse weather conditions
Continuous operation rate	Ratio of continuous running time to total time
Information responsiveness	The ratio of timely information notification times to the total number of times
Average construction cost per kilometer	The average construction cost per kilometer of roadside equipment during road construction
Average operating cost per kilometer	The average operating cost per kilometer of roadside equipment after road operation

Average maintenance cost per kilometer	The average maintenance cost per kilometer of roadside equipment after road operation

3 Calculation of Evaluation Index Weights Based on AHP

3.1 Building a Judgment Matrix

Establish reasonable and unified standards to represent the relative importance of pairwise elements. Propose each element in each level separately and compare it with other elements pairwise. Quantify the importance level based on the determined standards. The calculated comparison results of all elements will form a judgment matrix for each level. The scale and its definition are shown in Table 3.

Table 3. Judgment matrix scale and definition.

Scale	Definition
1:1	Equally important
3:1	Slightly important
5:1	important
7:1	More important
9:1	extremely important
2:1,4:1,6:1,8:1	Between the above two degree values

Assuming the judgment matrix is B=[b]. The weight coefficients of each factor are W_i, and the ratio of the importance of factor i to factor j is b_{ij}. Therefore, $b_{ij} = W_i/W_j$, $b_{ii} = 1$, $b_{ij} = 1/b_{ji}$, $b_{ij} = b_{ik} \times b_{kj}$.

3.2 Calculation and Verification

Calculate eigenvectors and maximum eigenvalues: After establishing a judgment matrix, solve for eigenvectors W and maximum eigenvalues λ _max. The relationship between the two can be expressed using mathematical formula (1).

$$\mathrm{BW} = \lambda_{max} W \tag{1}$$

Due to the fact that the judgment matrix is established through subjective comparison, it inevitably has a certain degree of subjectivity. In order to avoid excessive errors caused by the subjective quantitative process affecting the credibility of the weight coefficients, consistency testing is required after calculating the weight vector and maximum eigenvalue to test and measure whether the size of this judgment error is within a reasonable range. This is the so-called consistency testing method. Establish the average random consistency index CI for the multi-level judgment matrix, as shown in formula (2).

$$CI = \frac{\lambda_{max-n}}{n-1} \tag{2}$$

Establish consistency check formula (3):

$$C * I = (\lambda_{max} - n) / (n - 1) \tag{3}$$

In the formula, C * I is the consistency test indicator, λ_{max} is the maximum eigenvalue of the judgment matrix, N is the order of the judgment matrix. The larger the value of the consistency index C * I, the greater the deviation of the judgment matrix from complete consistency, and the less credible the weight coefficients. At this point, it is necessary to reestablish the judgment matrix until the value of C * I is small enough to approach complete consistency. The consistency ratio CR is shown in formula (4).

$$CR = \frac{C*I}{RI} \tag{4}$$

Generally speaking, when the consistency ratio CR<0.1, it is considered that the degree of inconsistency is within a reasonable range and passes the consistency test. Otherwise, the judgment matrix needs to be re established until the CR value is less than 0.1.

4 Fuzzy Comprehensive Evaluation Model

4.1 Model Building

Due to the numerous factors that need to be considered in the comprehensive evaluation of the vehicle road collaborative system, a single-layer evaluation layer is not convenient to establish a judgment matrix, and thus cannot determine weight allocation. Therefore, a multi-level fuzzy comprehensive evaluation model is more suitable for solving problems. As shown in Table 1, each factor is decomposed into two levels for two-level fuzzy comprehensive evaluation, and each level of factor is composed of the next level of factors. The first layer is the element in criterion layer B, U = $\{u_1, u_2, u_3, u_4\}$, The second layer is the element in criterion layer C, $u_1 = \{u_{11}, u_{12}, u_{13}\}$, $u_2 = \{u_{21}, u_{22}, u_{23}\}$,……, There are a total of 12 factor sets.

Scoring the layout of vehicle road collaborative roadside equipment through expert scoring or questionnaire survey methods. Due to the subjectivity of the expert scoring method, it is advisable to select experienced experts in the field as much as possible for scoring. It is divided into five evaluation levels: Very Good V1, Good V2, General V3, Poor V4, and Very Poor V5. V represents the evaluation set, V={V1, V2,V3,V4,V5}, Use the arithmetic mean method in formula (5) to process the data.

$$V_{ij} = m_{ij} / \sum_{j=1}^{n} m_{ij} \tag{5}$$

Among them, $V_{ij}$is the score of the i indicator belonging to the j evaluation set, m_{ij} is the number of people who scored the j evaluation set for the i indicator, and $\sum_{j=1}^{n} m_{ij}$ is the total number of people who scored the i indicator.

After constructing a hierarchical fuzzy subset, the evaluated items are quantified one by one from each element u_i, that is, the membership degree $(R|u_i)$ of the evaluated items to the hierarchical fuzzy subset is determined from a single factor perspective. The fuzzy relationship matrix is shown in formula (6).

$$R = \begin{bmatrix} (R|u_1) \\ \vdots \\ (R|u_i) \end{bmatrix} = \begin{bmatrix} r_{11} & \cdots & r_{1m} \\ \vdots & \ddots & \vdots \\ r_{p1} & \cdots & r_{pm} \end{bmatrix}_{p \times m} \tag{6}$$

The element r_{ij} in the i row and j column of matrix R represents the membership degree of the evaluated object from factor u_i to the v_j subset. In summary, the fuzzy comprehensive evaluation model is (U, V, R).

4.2 Model Evaluation

The basic principle of multi-level fuzzy comprehensive evaluation is to start from the lowest indicator layer for comprehensive evaluation, and then comprehensively evaluate the results of the previous layer, layer by layer up to the highest level, and obtain the final evaluation result through operation.

(1) First level comprehensive evaluation

Firstly, evaluate the single factor within the lowest level system, and score the degree to which each factor belongs to the evaluation set through subjective surveys. Establish an evaluation matrix R_j for the single factor in the u_i layer, and use the Analytic Hierarchy Process to obtain the weight vector W_j corresponding to the factor. Operate with R_j to obtain the comprehensive evaluation vector corresponding to the u_i layer. The calculation process is shown in formula (7).

$$u_i = W_j \bullet R_j \tag{7}$$

(2) Secondary fuzzy evaluation

After the completion of the first level fuzzy evaluation, each subset of the aforementioned u_i subset is evaluated, and its evaluation result is used as the evaluation matrix R_i of the previous layer. R_i is calculated with the weight vector W_i corresponding to the factors in that layer to complete the second level comprehensive evaluation. The calculation process is shown in formula (8).

$$U = W_i \bullet R_i = W_i \bullet u_i = \{u_1, u_2, u_3, u_4\} \tag{8}$$

In multi-level fuzzy comprehensive evaluation, it is necessary to select appropriate relationship synthesis operators based on specific evaluation objects. The weighted average operator (•,+) comprehensively considers the weights of all factors in the calculation process, which is more suitable for the fuzzy comprehensive evaluation of vehicle road collaborative roadside equipment deployment. Therefore, the operator "•" in the above operations all use this fuzzy operator.

5 Conclusion

This study is based on the Analytic Hierarchy Process and establishes a fuzzy evaluation model for the deployment of roadside equipment in vehicle road collaboration. Firstly, determine the principles for selecting evaluation indicators and establish an evaluation indicator system by selecting evaluation indicators; Next, based on the Analytic Hierarchy Process, calculate the weights of evaluation indicators; Finally, using the fuzzy comprehensive evaluation method, a multi-level fuzzy comprehensive evaluation model is established. Through the evaluation system established by this research institute, the evaluation and feedback of roadside facilities deployment in vehicle road collaboration can be achieved, which is a necessary prerequisite for establishing an effective and safe vehicle road cloud integrated vehicle road collaboration system. It is of great significance for improving road safety and efficiency.

References

1. Fu S , Wenhong L , Ge J ,et al.Review on the application of freeway CVIS communication technology[J].MATEC Web of Conferences, 2020.DOI:10.1051/matecconf/202032501006..
2. Ekram Hossain, Garland Chow, Victor C.M. Leung, Robert D. McLeod,JelenaMimics,Vincent W.S. Wongc, Oliver Yang, Vehicular telematics over heterogeneous wirelessnetworks: A survey [J],Computer Communications 33 (2010): 775-793.
3. S. Olariu and M. C. Weigle, Vehicular Networks: From Theory to PracticelM]. London, UK:Chapman & Hall/CRC press, Mar. 2009.
4. Cao Maolin, Analytic Hierarchy Process for Determining Evaluation Index Weights and Excel Calculation [J]. Jiangsu Science and Technology Information, 2012 (2): 39-40
5. Tian Jingjing, Li Shiwu, Sun Wenchai, et al., Dynamic Vehicle Safety Status Evaluation Model Based on Vehicle Road Collaboration [J]. Journal of Harbin Institute of Technology, 2012 (4): 131-135.