Resilience Evaluation Study of Urban Rail Transit Vehicle Base Schemes

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Abstract. An optimization method for evaluating urban rail transit vehicle base schemes based on resilience theory was proposed. A comprehensive evaluation index system was established based on four aspects: asset resilience, network resilience, user resilience, and social resilience. An optimization method for evaluating urban rail transit vehicle base schemes based on resilience theory was proposed. A comprehensive evaluation index system was established based on four aspects: asset resilience, network resilience, user resilience, and social resilience. weights were determined by combining expert opinions from different backgrounds using an improved AHP. The index values were standardized using the linear proportional transformation method. The generalized utility function was used to calculate the comprehensive evaluation value of the design scheme. The optimization method helps to promote the quantitative decision-making of the selection scheme. At the same time, it improves the shortcomings of the qualitative evaluation. The optimization method helps to promote the quantitative decision-making of the selection scheme. At the same time, it improves the shortcomings of the qualitative evaluation in the traditional program selection decision, which is easy to generalize. The evaluation method provides a reference for the actual decision-making of building a more resilient vehicle base project. The evaluation method provides a reference for the actual decision-making of building a more resilient vehicle base project.

Keywords: Urban Rail Transit; Vehicle Base; Resilience; Evaluation

1 Introduction

In recent years, the frequent occurrence of extreme weather and natural disasters has brought great challenges to the stable operation of urban infrastructure, and the improvement of infrastructure resilience has become a major topic of modern urban construction management, which has been paid attention by more and more scholars. The vehicle base is an important part of the urban rail transit system, which undertakes the important functions of urban rail transit operation vehicle management and utilization, overhaul and maintenance, and is an important infrastructure for many large and

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medium-sized cities. Since it will be used for a long time after completion, it is necessary to make a full argumentation and comparison of the design scheme of the vehicle base in the pre-construction period, and a set of evaluation methods with clear value orientation is needed. Existing vehicle base design program evaluation comparison studies are mainly for specific vehicle section engineering analysis. Existing evaluation studies take the construction cost, process and technical conditions as the main indicators, and qualitatively analyze the main technical indicators or quantitatively compare them with indicators such as engineering volume and cost. There are not many studies on resilience -oriented evaluation of vehicle base programs. This paper tries to explore the establishment of a resilience -oriented evaluation index system for urban rail transit vehicle base program, and establish a systematic quantitative evaluation model with the help of relevant methods. The evaluation research oriented to the value of resilience helps to improve the analysis and evaluation method of urban rail transit design and construction, and then promote urban rail transit to better cope with the impact of major safety risks.

The study of "resilience" has a long history, first originating in the physical sciences, and denoting the ability of a system or an individual to recover from shocks or perturbations [1-3]. In the 1970s, the concept of "resilience" was introduced to the ecological sciences by the American professor Holling [4], and since then, studies related to resilience have been carried out in many fields, such as environment, engineering, economy and psychology. It is used to describe the ability of systems to recover from the effects of shocks and perturbations and return to their pre-shock equilibrium state [5].

In the field of transportation, Murray-Tuite proposed the concept of transportation resilience in 2006 [6], and subsequent scholars have carried out urban transportation resilience research from the perspective of system or network and believed that urban transportation resilience should include preventive, robustness, redundancy, rapidity, resilience, and adaptability etc. [7-10]. Based on the understanding of the connotation and characteristics of resilient transportation, many scholars have adopted topological analysis, simulation, model optimization and data-driven methods to research the evaluation of resilient transportation [11-12]. From the infrastructure level, some scholars and organizations have constructed a resilient transportation evaluation index system. Yang Chao et al. [13] constructed a framework and index system for resilient transportation construction from six aspects, including organizational management, traffic risk, facility quality, network capacity, safety and security, and service provision. Bao Jashuo et al. [14] constructed the urban road traffic resilience evaluation index system from 4 aspects, including infrastructure asset resilience, network resilience, user resilience and organizational resilience. The construction of resilient transportation should focus on the three dimensions of infrastructure asset resilience, network resilience and user resilience. At present, former resilience evaluation studies for the transport field have mostly focused on urban transport systems, which are mesoscopic studies. Few studies have been conducted on the micro-functional units of transportation systems such as urban rail transit vehicle segments, and there is a need for specialized research.

2 Vehicle Base Design Program Resilience Evaluation Indicator System

The vehicle base belongs to the urban rail transit infrastructure monolith. We believe that a resilient vehicle base is able to adapt to changing external environments with a high degree of robustness and the necessary redundancy to withstand, respond to and recover quickly from unforeseen events. Vehicle base resilience value orientation should include 4 aspects. One is resistance, which indicates the ability to resist natural disasters such as floods, earthquakes and mudslides. The second is reliability, which indicates the ability to maintain good operation in daily and unexpected situations. Third, redundancy, which indicates the ability to have surplus vehicles for operation and maintenance. The fourth is resilience, which indicates the ability to recover quickly from emergencies. During the construction phase of the vehicle base, emphasis should be placed on the four aspects of asset resilience, network resilience, user resilience and social resilience of the base. That is to say, it should reduce the cost of the whole life cycle of assets, safeguard the emergency needs of urban rail transportation line network operation and have a certain amount of reservation, provide vehicle operation and maintenance services with higher reliability and convenience, and reduce the overall impact on the natural and social environments.

This paper establishes an evaluation index system for urban rail transit vehicle base program from four aspects: asset resilience, network resilience, user resilience and social resilience, as shown in Table 1.

Table 1. Urban rail transit vehicle base resilience evaluation index system

Guideline indicators	Evaluation indicators	Meaning of indicators and evaluation (calculation) methods	Type of indicators	Weights
Asset resilience D1 0.2662	Costs of land acquisition and relocation I1	Cost of land acquisition and relocation for the base program Product of base footprint and average cost of land acquisition and relocation in the site area	quant	0.1024
	Civil construction costs for access lines I2	Cost of laying access lines for the base option. Sum of the product of the length and average cost of access lines for underground, at-grade and elevated intervals.	quant	0.0477
	Station civil construction costs I3	Costs of civil construction of vehicle base station yards Sum of the costs used for excavation, filling, depot, and track laying	quant	0.0875
	Vehicle operation and maintenance costs I4	Product of the sum of routine maintenance and periodic overhaul costs per vehicle and the size of the vehicle fleet available for operation and maintenance	quant	0.0286

Network resilience D2 0.1648	Conditions for convergence I5	Base program entry and exit section line and the main line connection conditions Considering factors such as the way of connecting the entry and exit section lines, length, flat and longitudinal sections, and conditions of the crossing area, etc.	qual	0.0498
	Development space reservation I6	Considering factors such as the property development conditions of the base plan site, whether there is any reservation for the design vehicle maintenance scale, and the difficulty of station reconstruction and expansion, etc.	qual	0.0433
	Level of emergency robustness I7	Considering the convenience of the base in mobilizing rescue equipment to recover or tow accident vehicles, as well as the deployment of the base's own facilities for firefighting, drainage, electricity, communications, etc.	qual	0.0717
User resilience D3 0.3098	Vehicle operation and maintenance effectiveness I8	Estimating the level of supply and demand for vehicle operation and maintenance at the base under the premise of determining the vehicle type and grouping The ratio of the scale of vehicles designed for operation and maintenance of the base to the scale of vehicles required for operation and maintenance of the planned routes	quant	0.0871
	Smoothness of process organization I9	Service quality of user functions of the vehicle base Considering the reasonableness of the general layout of the station yard, including the layout type of the main line facilities affecting the operation of the train section, such as the washing line, whether the section location of the test line and shunting line is conducive to the test and shunting operation, whether the parking garage, train inspection garage, inspection garage, and the non-drop wheel turning garage are arranged according to the similar functional clusters, and whether the number of parallel operation approaches to the throat area of the station yard, the length of the throat area, and the intersection of the trains entering and exiting the section and the shunting operation are the same as those of the train section. Crossing of shunting operations and other factors	qual	0.1308

	Convenience of production I10	Considering the accessibility of roads in the section, whether the layout of auxiliary production rooms, office and living rooms, and other living facilities is convenient for management, whether it is conducive to the production work of the employees, and whether it reduces the walking distance of the employees	qual	0.0471
	Level of application of new technologies I11	Level of innovation in base process design and tooling equipment based on the development of vehicle operation and overhaul processes	qual	0.0448
Social resilience D4 0.2592	Land use efficiency I12	Evaluating the level of utilization of base land resources Ratio of station footprint to the size of vehicles designed for operation, maintenance, and spare parts	quant	0.1009
	Degree of urban functions disturbance I13	Considering the distribution of factories and private houses in the site of the base, and the impact on existing roads, water supply and drainage, heating, power supply, gas, communication pipelines, and other municipal facilities	qual	0.0724
	Degree of ecological disturbance I14	Evaluation of the impact of vehicle bases on the water, air, sanitation and soil environments	qual	0.0859

3 Evaluation Model

3.1 Indicator Weights

This paper adopts the 5/5-9/1 scale method to assign weights to the indicators [15], and its steps are as follows:

(1) Constructing a judgment matrix

A judgment matrix is constructed using the 5/5-9/1 scale method, with element aij meaning the importance of element Ai relative to Aj under the dominance of the overall goal.

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1m} \\ a_{21} & a_{22} & \cdots & a_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nm} \end{bmatrix} \tag{1}$$

(2) Matrix consistency test and correction

The method of judgment matrix consistency test is to calculate the matrix consistency ratio CR with the following formula:

$$CR = CI / RI \tag{2}$$

where RI is a constant value, determined by the matrix order, and CI is the matrix consistency index, calculated as:

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{3}$$

Where $\lambda_{\max}$ is the maximum eigenvalue of the judgment matrix.

Then the judgment matrix CR is analyzed. When CR < 0.1, the matrix satisfies the consistency condition and the indicator weights can be further calculated. Otherwise, the calculation of the perturbation variable $\Delta\sigma_{ij}$ is used and the correction starts from the element with the maximum value of the variable.

(3) Calculation of individual composite weights

The feature vector method is relatively simple to compute, so we use it to compute single-level weights. The obtained vector $W = (w_1, w_2, \cdots, w_n)^T$, is the weight ordering of the indicators at that level with respect to the indicators at the upper level. Then, by calculating the product of the weight vectors, the weight vectors of the nk elements of the kth layer with respect to the total target are obtained as:

$$(w_1^{(k)}, w_2^{(k)}, \cdots, w_{nk}^{(k)})^T = (p_1^{(k)}, p_1^{(k)}, \cdots, p_{k-1}^{(k)}) w^{(k-1)} \tag{4}$$

where $p_i^{(k)} = (w_{1i}^{(k)}, w_{2i}^{(k)}, \cdots, w_{nki}^{(k)})^T$ is a single-level weight vector for element ui.

(4) General consistency test

According to Equation (5), the k-level matrix total consistency test was performed.

$$CR^k = \frac{CI^k}{RI^k} \tag{5}$$

If $CR^k < 0.1$, then the evaluation model can be considered to meet the consistency requirement at the k-level level, otherwise, the matrix needs to be adjusted accordingly.

(5) Cluster Decision Weight Calculation

We use the sum of weight vectors method and the weighted geometric mean method to compute the combined weights and obtain the new ranking vectors:

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

That is the ranking of the importance of the indicators for the cluster decision.

3.2 Indicator Assignment and Standardization

The indicator system consists of two categories: quantitative indicators and qualitative indicators. For quantitative indicators, the results obtained through a series of statistical calculations can intuitively show the level of the indicator, and are standardized using the linear scale transformation method. For the qualitative indicators, the method of expert evaluation grade affiliation (A, B, C, D, E) is used to determine the level of the indicator, and the corresponding evaluation standard scale (1, 0.8, 0.6, 0.4, 0) is assigned.

3.3 Calculation of Comprehensive Evaluation Value

After determining the values and weights of the evaluation indexes, it is necessary to calculate the comprehensive evaluation value of the program to carry out quantitative evaluation of the program. In the comprehensive evaluation of the program, the generalized utility function has been widely used because of its simple calculation and clear thinking, which is also used in this paper to calculate the comprehensive evaluation value of the program to be evaluated:

$$U(P_i) = \sum_{j=1}^{14} T_{ij} W_j \tag{7}$$

Where,

$U(P_i)$ is the combined evaluated value of program i;

T_{ij} is standardized value of the jth indicator for scenario i;

W_j is the weight value of the jth indicator.

We selected the evaluation data of 5 project leaders from different design units. In addition, we consulted 1 construction expert, 2 operation experts, 2 scientific research experts, and carried out data processing according to the method of equal rights for each expert 's opinion. Finally, the weight results of the criterion layer and the index layer are calculated, as shown in Table 1.

4 Case Analysis

Using the evaluation methodology proposed in this paper, the cases of vehicle base design solutions described in the literature [15] were evaluated and analyzed. The S vehicle base connects to station D in the center of the line. The entry and exit section lines are connected to station D with two lines. The general layout of Option 1 adopts the side-by-side and end-to-end arrangement, with 20 parking lanes for 40 vehicles. The total site area is 25.87 hectares. As shown in Figure 1. Option 2 increases the parking scale of the vehicle section to reduce the idle distance of the receiving operation and improve the flexibility of the dispatching operation, and the general plan of the vehicle section adopts the inverted layout. There are 25 parking column check lines, which can park 50 vehicles. The total land area is 27.23 hectares. As shown in Figure 2.

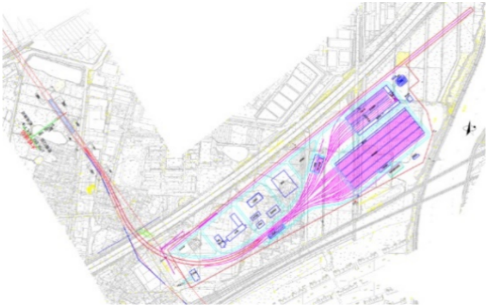

Fig. 1. Design drawings for vehicle base station option 1

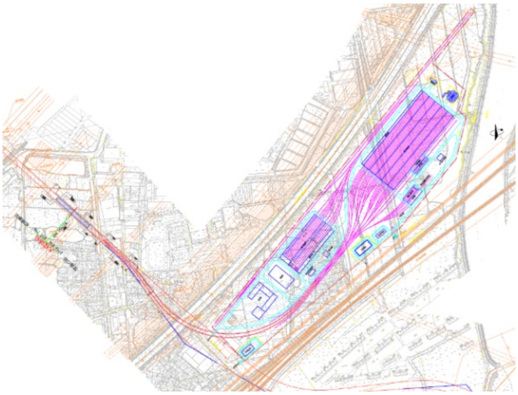

Fig. 2. Design drawings for vehicle base station option 2

We used the evaluation model proposed in this paper to evaluate and compare these 2 design options, and the results are shown in Table 2.

Table 2. Vehicle base design program resilience rating values

Evaluation indicators	Score of option 1	Score of option 2
I1	0.1024	0.086016
I2	0.0477	0.042453
I3	0.0875	0.076125
I4	0.026026	0.0286
I5	0.0498	0.0498
I6	0.02598	0.03464
I7	0.05736	0.0717
I8	0.071422	0.0871
I9	0.10464	0.09156
I10	0.0471	0.03768
I11	0.0448	0.0448
I12	0.087783	0.1009
I13	0.05792	0.0724
I14	0.05154	0.05154
Total	0.861971	0.875314

Since U(P2) > U(P1), based on this evaluation method, under the existing data conditions and based on the resilience theory, the vehicle base design option 2 is generally better than option 1. Specifically analyzing the criterion layer indicators, the asset resilience and user resilience scores of Option 1 are higher than those of Option 2, and due to the small construction scale of Option 1, its whole life cycle cost is lower than that of Option 2, and the station layout facilitates the daily operation of the vehicles and the production and life of the employees. However, considering the need for a certain amount of construction redundancy in the resilience value orientation, Scenario 2 is significantly better than Scenario 1 in terms of spatial reservation and its own anti-disturbance, and its disturbance of urban functions is less.

5 Conclusions

(1) In engineering practice, the evaluation of the evaluation index is more important than the overall decision-making lack of quantitative comparison, qualitative evaluation is difficult to control the comprehensive level of the program. This paper proposes a comprehensive evaluation of the resilience of the method is characterized by the actual engineering decision-making process is abstracted into a mathematical model and mode, the existing information, data for calculation, with a systematic point of view to comprehensively measure the comparison, can effectively improve the decision-making evaluation criteria are diverse, decision-making human interference with a lot of factors, reflecting the characteristics of the systematic decision-making.

(2) There are still some limitations in this study. For example, the evaluation indicators selected lack consideration for civil construction conditions and engineering structure aspects. In addition, the evaluation of qualitative indicators relies on the experience of decision makers, which is still very subjective. These are areas that need to be explored in depth in the future.

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