Identification of Key Factors in Construction Progress of Undercrossing Existing Railway Lines under Frame Bridges

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Abstract. Firstly, based on the model of "Driving force-State-Response" (DSR), take the construction parameters as the driving force indicators, the construction progress as the state indicators, and the construction progress enhancement measures as the response indicators, and construct the construction progress system of the frame bridge crossing the existing railroad line; secondly, take the driving force indicators and response indicators as the object of analysis, and combine the C-OWA operator method and CRITIC method to construct the complex network model. Secondly, taking the driving force indicators and response indicators as the analysis object, combining the C-OWA operator method and CRITIC method to construct a complex network model, determining the importance of the driving force and response elements' own nodes, the intensity of the influence between the nodes and the comprehensive importance of the nodes in turn, and determining the key influencing factors of the construction progress of the frame bridge crossing the existing railroad line project; finally, taking the empirical analysis of the construction progress of a frame bridge crossing the established railroad line project, and analyzing the results of the study. Finally, a frame bridge under the existing railway line project is used to carry out empirical analysis, and according to the results of the study, the key influencing factors are the selection of overhead reinforcement methods, jacking distance and optimal deployment of mechanical equipment.

Keywords: crossing the existing railway line under the framework bridge; construction progress; complex network model

1 Introduction

By the end of 2022, China's railroad mileage of 155,000 kilometers, railroad network density of 161.1 km / 10,000 square kilometers, highway mileage of 5,354,800 kilometers, highway density of 55.78 kilometers / 100 square kilometers , frame bridges under the existing railroad line project will continue to increase.

Many scholars have carried out related research on the frame bridge underneath the existing railroad line project.VEGA et al [1] investigated the dynamic response of the roof slab of the concrete channel under the railroad when the train is running; KOMIYA [2] investigated the effect of pipe shed method of jacking construction on the surface settlement; OSAMA et al [3] studied the interaction between the soil body and the frame bridge by using the centrifugal test of the physical model; BABAK et al [4] investigated the risks related to the BJ method of the trenchless undercutting construction; Dong Chuanqin [5] et al. proposed a continuous steel

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bogie beam reinforcement system consisting of longitudinal girders, steel sleeper girders, and transverse lifting girders, which is suitable for large-span frame bridges jacked down to penetrate the existing railroad line project.

Since the frame bridge under the existing railroad line project involves multi-disciplines and multi-departments, and the construction progress management is difficult, this paper relies on the actual project to identify the key influencing factors of the construction progress of the frame bridge under the existing railroad line.

2 Construction progress indicator system of frame bridge under the existing railway line

2.1 Construction progress indicator system based on dsr theory

DSR theory [6] consists of three dimensions: driving force (D), state (S) and response (R), based on which the construction progress evaluation index system is constructed. Driving force indicators refer to the Technical Specification for Highway and Municipal Engineering Underpassing High-speed Railway (TB 10182-2017) [7] and related literature, and 24 construction parameters are extracted as the driving force indicators; completion rate and completion time are taken as the state indicators; the response indicators are based on the actual project and refer to related literature, and 7 response indicators are extracted. The details are shown in Fig. 1.

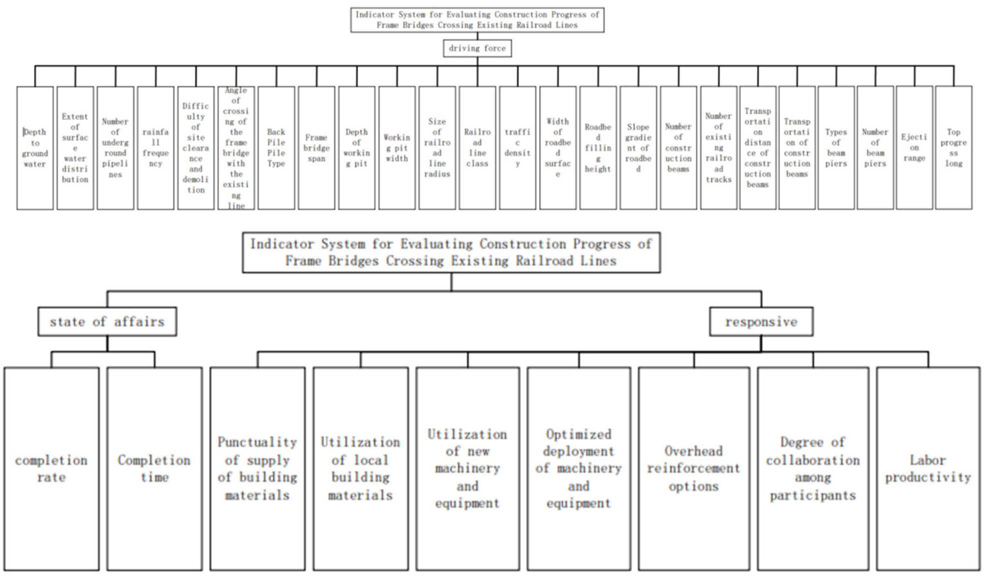

Fig.1 Evaluation index system for construction progress of framework bridge crossing existing railway lines

3 Identification of key factors affecting the construction progress of a frame bridge under an existing railroad line

3.1 Identification of key influential factors based on complex network modeling

3.1.1 "Driver-state-response" Complex network modeling

Based on DSR theory, the construction progress of the frame bridge crossing the existing railroad line is constructed as "driving force - state - response" network model [8], as shown in Fig. 2, which is divided into driving force layer, state layer and response layer according to the different attributes of the nodes. In this model, the driving force plays a dominant role, the response factor plays the role of feedback optimization, and the state factor is the dependent variable under the joint action of pressure exertion and response regulation, so the driving force factor and the response factor are used as the key elements of the construction progress identification object. Each element is abstracted as a network node, the node importance represents the importance of the element's own attributes, the link between the elements as a node edge, edge weight for the intensity of the influence between the nodes, through the node importance and the intensity of the influence between the nodes to determine the node comprehensive importance, the node comprehensive importance of the large that is, the frame bridge under the existing railroad construction progress of the key elements.

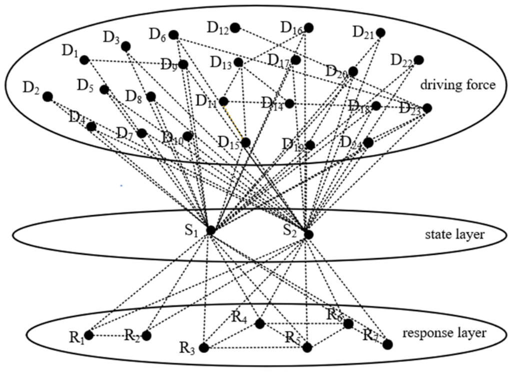

Fig.2 Double layered complex network of "Railway Roadbed Engineering - Carbon Emissions"

3.1.2 Network model nodes own importance

In this paper, C-OWA (Ordered Weighted Averaging) operator is used to calculate the node's own importance. The specific steps are as follows:

1) Select m experts, according to the importance of the construction progress indicators k_j scoring, can be obtained decision-making data set $A = (k_{1j}, k_{2j}, \dots, k_{mj})$, the data in the set A from the largest to the smallest reordering, to get the decision-making data sets $B = (y_{0j}, y_{2j}, \dots, y_{(m-1)j})$.

2) Determine the data position weights μ_i in set B, calculated as:

$$\mu_i = \frac{C_{m-1}^i}{\sum_{k=0}^{m-1} C_{m-1}^k} = \frac{C_{m-1}^i}{2^{m-1}} \tag{1}$$

where: C_{m-1}^i is the number of combinations of i selected from m-1 data, i∈[0，m-1] and satisfies $\sum_{i=0}^{m-1} \mu_i = 1$.

3) Determine the construction indicator k_j absolute weight λ_j, calculated as:

$$\lambda_j = \sum_{i=0}^{m-1} \mu_i y_{ij} \tag{2}$$

Where: j = 1, 2, ..., n, where n is the number of indicators.

4) Calculate the progress evaluation index k_j node own attribute importance I_{jz} with the formula:

$$I_{jz} = \frac{\lambda_j}{\sum_{j=1}^{n} \lambda_j} \tag{3}$$

3.1.3 Strength of influence between network model nodes

In this paper, the CRITIC algorithm is applied to determine the intensity of inter-nodal influence, and the specific calculation steps are:

1) Initial data standardization

The normalized formula for the positive indicator is:

$$y_{ij} = \frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}} \tag{4}$$

The negative indicator normalization formula is:

$$y_{ij} = \frac{\max x_{ij} - x_{ij}}{\max x_{ij} - \min x_{ij}} \tag{5}$$

2) Calculate the standard deviation of each construction progress indicator using the formula:

$$\delta_j = \sqrt{\frac{1}{m} \sum_{i=1}^{m} (y_{ij} - \overline{y}_j^{\,2})} \tag{6}$$

Where: δj is the indicator aj standard deviation, j= 1, 2,⋯, n; i = 1, 2,⋯, m; n is the number of indicators; m is the number of samples; y_{j2} is the mean of the jth indicator

3) Calculate the correlation coefficient between each construction progress indicator γij , calculated as:

$$\gamma_{ij} = \frac{\sum_{i=1}^{n}(y_i - \bar{y}_i)(y_j - \bar{y}_j)}{\sqrt{\sum_{i=1}^{n}(y_i - \bar{y}_j^{\,2})\sum_{j=1}^{n}(y_j - \bar{y}_j^{\,2})}} \tag{7}$$

4) Calculate the intensity of impact Ijy between each construction progress indicator with the formula:

$$Y_j = \delta_j \sum_{i=1}^{n}(1 - \gamma_{ij}) \tag{8}$$

$$I_{jy} = \frac{Y_j}{\sum_{j=1}^{n} Y_j} \tag{9}$$

3.1.4 Integrated importance of network model nodes

The multiplicative synthesis method [9] was selected to combine the node's own importance and the intensity of the influence between nodes in order to determine the node's integrated importance I_j, the greater the integrated importance represents the greater the importance of the element, which is calculated by the formula:

$$I_j = \frac{I_{jz} I_{jy}}{\sum_{j=1}^{m} I_{jz} I_{jy}} \tag{10}$$

4 Case study

4.1 Project overview

A frame bridge under the existing railroad line project is located at K166+626.7 crossing, the overpass adopts a new 12+12m two-hole separated reinforced concrete frame bridge, with a structural clear height of 7.3m. Since the start of the project in August 2023, it has completed the construction tasks such as deep foundation pit excavation, protection pile pouring, and rotary spraying pile driving, etc., and the project will be fully completed at the end of May 2024.

4.2 Construction schedule key factor identification

4.2.1 Data collection

Obtaining basic data by collecting and organizing basic information,part of the qualitative indicators by the project expert evaluation scoring to obtain, scoring standards:(8, 10] are categorized as excellent, (6, 8] are categorized as better, (4, 6] are categorized as good, (2, 4] are categorized as poor, and (0, 2] are categorized as poor.In addition, five experts of the frame bridge crossing the existing railroad line were invited to score the intensity of the impacts of the intra- and inter-layer elements, with a total score of 10 and a score accurate to 0.1, and to divide the score interval as follows: (8, 10] for strong impacts, (6, 8] for stronger impacts, (4, 6] for medium impacts, (2, 4] for weaker impacts, and (0, 2] for weaker impacts.

4.2.2 Model calculation

1) Determine the importance of the elements themselves

Using formula (1)~equation (3) to calculate the importance of the driver layer and response layer elements themselves, the calculation results are shown in Table 1

Table 1. The importance of the feature node itself.

factor	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8
βi	2.269	2.173	2.811	2.852	2.275	3.124	3.354	4.544
factor	D_9	D_{10}	D_{11}	D_{12}	D_{13}	D_{14}	D_{15}	D_{16}
βi	3.876	2.680	2.243	2.876	2.269	3.867	4.194	2.132
factor	D_{17}	D_{18}	D_{19}	D_{20}	D_{21}	D_{22}	D_{23}	D_{24}
βi	2.198	2.269	2.344	3.281	3.151	3.600	4.999	3.103
factor	R_1	R_2	R_3	R_4	R_5	R_6	R_7	
βi	2.876	3.222	3.976	5.494	6.107	3.112	2.734	

2) Calculation of the intensity of impacts between elements

According to Eq. (4)~Eq. (9), the influence intensity of elements between the "driving force-state" layer and the "response-state" layer, and within the driving force layer and the response layer are calculated respectively, and the specific calculation results are shown in Table 2.

Table 2. The strength of the influence between feature nodes.

connective tissue	Nodes affect strength	connective tissue	Nodes affect strength	connective tissue	Nodes affect strength	connective tissue	Nodes affect strength
D_1-S	0.00979	D_{13}-S	0.01010	R_1-S	0.01584	D_{12}-D_{23}	0.01748
D_2-S	0.01858	D_{14}-S	0.02381	R_2-S	0.01808	D_{13}-D_{14}	0.02746
D_3-S	0.01070	D_{15}-S	0.00513	R_3-S	0.01420	D_{13}-D_{15}	0.01057
D_4-S	0.01580	D_{16}-S	0.02920	R_4-S	0.01265	D_{13}-D_{16}	0.01769
D_5-S	0.02026	D_{17}-S	0.03340	R_5-S	0.02607	D_{19}-D_{20}	0.02016
D_6-S	0.01431	D_{18}-S	0.01052	R_6-S	0.02191	D_{23}-D_{24}	0.01366
D_7-S	0.03154	D_{19}-S	0.01443	R_7-S	0.03967	R_1-R_2	0.01607
D_8-S	0.01331	D_{20}-S	0.01862	D_1-D_9	0.01912	R_3-R_4	0.01867
D_9-S	0.01464	D_{21}-S	0.03052	D_6-D_{23}	0.03493	R_3-R_5	0.04653
D_{10}-S	0.01828	D_{22}-S	0.01327	D_{11}-D_{13}	0.01013	R_4-R_6	0.04189
D_{11}-S	0.02188	D_{23}-S	0.02504	D_{11}-D_{15}	0.06122	R_5-R_6	0.03911
D_{12}-S	0.01623	D_{24}-S	0.01730	D_{11}-D_{23}	0.01013	R_6-R_7	0.01010

3) Combined importance of element nodes

Using formula (10) to calculate the node comprehensive importance S_i (i=1， 2， …， n), and the node comprehensive importance ranking, the frame bridge under the existing railroad line construction progress key elements are: overhead reinforcement method selection, jacking distance and mechanical equipment optimization deployment.

5 Conclusions

1) Based on the DSR model, the construction progress indicator system of the frame bridge under the existing railroad line is constructed by taking the construction parameters as the pressure indicators, the construction progress as the state indicators, and the construction progress improvement measures as the response indicators.

2) Taking the driving force index and response index as the object of analysis, the complex network model is constructed to identify the key elements of the construction progress of the frame bridge under the existing railroad line as the selection of overhead reinforcement method, jacking distance and the optimal deployment of mechanical equipment.

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