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Simulation Decision of Bridge Demolition Schemes Based on Multi-Factor Decision-Making Method

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Abstract. Bridge demolition project involves a variety of factors, belonging to the category of multi-factor decision-making. How to choose a reasonable demolition scheme from a variety of schemes is a problem to be considered. This paper is to use multi-factor decision-making method to optimize and select bridge demolition scheme. Taking the formulation of a certain bridge demolition scheme in China as an example, this paper demonstrates in detail the process of optimization selection and design as well as the result of the bridge demolition scheme. AHP method is used to decompose each factor of bridge demolition to form a hierarchical structure. On this basis, TOPSIS method is used to calculate the proximity between each demolition scheme and the positive ideal solution. Finally, the bridge demolition scheme is selected according to the calculation value.
Keywords: Multi-factor; decision-making; demolition scheme; simulation decision.

1. Introduction

Bridge demolition usually is a significant project relating to personnel safety, economy, traffic, local environmental protection and so on. Due to the deterioration of bridge, the reaching to expiry date of bridge design service and the re-planning of the road network, it is often necessary to demolish the existing bridge. In general, bridge demolition project involves many working procedures and complicated technology. There are a variety of demolition methods and equipment, such as hydro-demolition, blasting and mini-blasting, sawing and cutting and so on [1-2]. How to choose a rational scheme has become one of the key research contents of bridge demolition engineering. Multi-factor decision-making and evaluation are widely used in many fields, such as safety assessment, construction engineering, education, garment designing and so on [3-4]. The application of multi-factor decision analysis in the field of bridge project can comprehensively investigate a variety of factors and is conducive to making scientific decisions. AHP and TOPSIS methods are commonly used in multi-factor decision-making.

2. The Formulation of Bridge Demolition Schemes

The case in this paper comes from a practical example of bridge demolition project in a certain city of China. The demolition project is located in the relatively prosperous area of the city. At the same time, the bridge demolition needs to protect the local environment. The production of a large amount of powder should be reduced as much as possible. It should adopt advanced demolition technology to make the noise lower and vibration amplitude smaller, so as not to have a big impact on the surrounding.

The bridge to be demolished is composed of prefabricated T beams of prestressed reinforced concrete. This bridge is a viaduct on the plain with a total of 144 T beams and each T beam is 30 meters long. Each of the mid-span middle beams 32.62 cubic meters and the weight is 81.58 tons. The boundary beam of mid-span is 30.89 cubic meters per piece weighting 77.23 tons. Each piece of the middle beam of side-span is 31.9 cubic meters and the weight is 79.75 tons. Each piece of boundary beam of side-span is 30.2 cubic meters and the weight is 75.5 tons. After the antagonistic analysis of the bridge structure, three kinds of schemes of demolition are proposed.

The first scheme M1 is the way of controlled blast. The 144 beams are drilled and charged with explosives. A time-delay blasting is carried out at the specified time point. The superstructure of the bridge will be directly exploded to make it fall off or collapse, and then the blasting is continued at the bridge site.

The second scheme M2 is the way of self-propelled module transporters (SPMT). With the SPMT as the core equipment, the superstructure of the bridge is lifted up as a whole, and then transported to the dismantling site at one time. At last, the whole superstructure of the bridge is landed at the site and will be dismantled.

The third scheme M3 is the way of cutting and dismantling. The diamond wire saw is selected because of its high strength and high roughness. The diamond wire saw will be driven by the motor to cut and dismantle T beams from the mid-span position mechanically, and then the T beam is transported to a flat car with a large crane. Finally, the T beam is carried to the dismantling site and demolished.

3. Determining the Criteria and Indicators of Optimal Demolition Scheme Based on AHP Method

In order to form a scientific demolition scheme, on the basis of extensive investigation to a number of experts, their views were adopted. According to AHP method, the evaluation system of bridge demolition scheme was established. The criterion layer and the indicator layer are the most major part of the evaluation system. The hierarchy is shown in Fig.1. There are four levels in the evaluation hierarchy of bridge demolition scheme. The first level is the target layer, abbreviated as *T*, and the target is the optimal scheme of bridge demolition. The second level is the criterion layer, abbreviated as *C*.

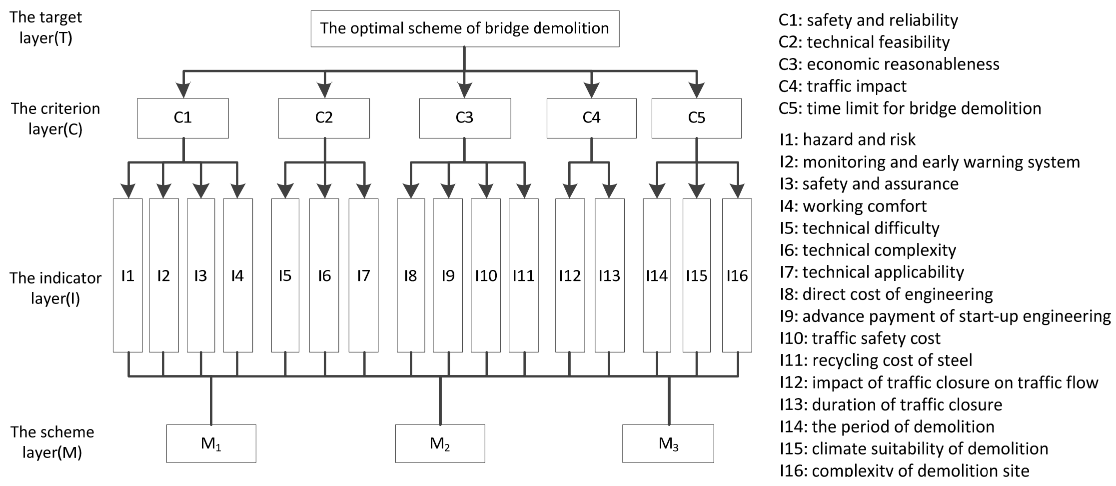

Figure 1. The evaluation hierarchy of optimal bridge demolition scheme.

The steps of weight calculation are as follows: firstly, the importance of each indicator in the criterion layer is compared in pairs; secondly, the judgment matrix is constructed according to the result of pairwise comparison; finally, the compatibility of the constructed judgment matrix is tested and the weights of each criterion in the matrix are calculated. Saaty proposed a fuzzy demarcation that compares the importance of two factors and comes up with a specific value as shown in Table 1[5].

Table 1. The scales of the importance of between A_i and A_j.

Importance degree	$f\left(\frac{A_i}{A_j}\right)$	$f\left(\frac{A_j}{A_i}\right)$
A_i and A_j are equally important	1	1/1
A_i is more important than A_j slightly	3	1/3
A_i is more important than A_j obviously	5	1/5
A_i is more important than A_j strongly	7	1/7
A_i is more important than A_j absolutely	9	1/9

A total of twelve bridge engineering experts participated in the scoring of the criteria so as to make the weights of the criteria more reasonable. According to the fuzzy scale method in Table 1, all the criteria in the criterion layer were firstly compared in pairs and the result of the comparison formed the judgment matrix *A*. The judgment matrix *A* that the criterion layer corresponding to the target layer in demolition scheme was constructed by using $f\left(\frac{A_i}{A_j}\right)$ and $f\left(\frac{A_j}{A_i}\right)$ as follows.

$$A = \begin{bmatrix} 1 & \frac{1}{2} & \frac{1}{2} & \frac{1}{2} & \frac{1}{3} \\ 2 & 1 & \frac{1}{2} & \frac{1}{2} & \frac{1}{3} \\ 1 & 2 & 1 & 1 & \frac{1}{2} \\ 2 & 2 & 2 & 1 & \frac{1}{2} \\ 3 & 3 & 2 & 2 & 1 \end{bmatrix}$$

Due to the interference of the subjective experience of decision-makers and the influence of multi-level factors, the judgment matrix inevitably had some errors. It was necessary to calculate the compatibility of the judgment matrix in order to avoid the deviation of the calculated results from the objective reality caused by the excessive errors. The calculation formula for the compatibility of judgment matrix was $CR = \frac{CI}{RI}$, and the value of *CI* was calculated using the formula $CI = \frac{\lambda_{max}-n}{n-1}$. *RI* was the mean random consistency index, and the value of *RI* could be taken according to Table 2 shown as follows.

Table 2. Mean random consistency index of 1-order to 9-order.

The matrix order *n*	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

If *CR* was less than 0.1, the judgment matrix could be considered to be compatible. On the other hand, if *CR* was bigger than 0.1, the judgment matrix should be re-constructed until the value of *CR* was less than 0.1. After calculation, the maximum eigenvalue λ_{max} of the judgment matrix *A* had been obtained and could be used as the weight vector *W*. The eigenvector was normalized by using the formula $\omega_i = \frac{\omega_i}{\sum_{j=1}^{n}\omega_j}(i = 1,2,\dots,n)$, and the weight vector $W = (\omega_1, \omega_2, \dots, \omega_n)^T$ was obtained finally. The weight vectors of the criterion layer *C* towards the target layer *T* and the indicator layer *I* towards the criterion layer *C* were tabulated as shown in Table 3.

Table 3. The weights of optimal scheme of bridge demolition.

Criteria	***C1***			***C2***			***C3***			***C4***			***C5***			
weight	0.094			0.125			0.183			0.237			0.360			
Indicator	*I1*	*I2*	*I3*	*I4*	*I5*	*I6*	*I7*	*I8*	*I9*	*I10*	*I11*	*I12*	*I13*	*I14*	*I15*	*I16*
weight	0.19	0.33	0.33	0.14	0.29	0.16	0.53	0.44	0.28	0.16	0.10	0.66	0.33	0.49	0.19	0.31

9	0	0	1	7	4	9	8	3	4	6	7	3	4	6	1

4. The Model of Optimal Decision-making Based on AHP and TOPSIS

Assuming that the set of bridge demolition scheme is $M = \{M_1, M_2, \dots, M_m\}$ and the set of evaluation indicators is $N = \{X_1, X_2, \dots, X_n\}$. After a number of engineering experts scored the evaluation indicators of the each alternative bridge demolition scheme, the initial decision matrix $P = \left(X_{ij}\right)_{m\times n}$ is formed.

Each evaluation indicator of the initial decision matrix has different dimension. In order to eliminate the inhomogeneity and incommensurability caused by the initial decision matrix, the initial decision matrix needs to be standardized. Formula (1) is the normalized formula.

$$b_{ij} = \frac{X_{ij}-\min(X_j)}{max(X_j)-\min(X_j)} \tag{1}$$

The initial decision matrix is standardized to form the standardized decision matrix$B = \left(b_{ij}\right)_{m\times n}$. Each column of B is multiplied by the weights ω_n of the evaluation indicators determined by AHP method to obtain the weighted standardized decision matrix Q as show below.

$$Q = \left(q_{ij}\right)_{m\times n} = \begin{bmatrix} \omega_1 b_{11} & \omega_2 b_{12} & \cdots & \omega_n b_{1n} \\ \omega_1 b_{21} & \omega_2 b_{22} & \cdots & \omega_n b_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \omega_1 b_{m1} & \omega_2 b_{m2} & \cdots & \omega_n b_{mn} \end{bmatrix} \tag{2}$$

The ideal solution of the demolition scheme can be obtained by selecting the positive and negative ideal solutions of each evaluation indicator in the weighted standardized matrix Q. The ideal solution is given by the following formula (3). Q^+ is the positive ideal solution, and Q^- is the negative ideal solution. J_1 is the set of benefit indicators, and J_2 is the set of cost indicators.

$$\begin{cases} Q^+ = \left\{\left(\max q_{ij} \mid j \in J_1\right), \left(\min q_{ij} \mid j \in J_2\right)\right\} \\ Q^- = \left\{\left(\min q_{ij} \mid j \in J_1\right), \left(\max q_{ij} \mid j \in J_2\right)\right\} \end{cases} \tag{3}$$

The degree of similarity to the ideal solution reflects the pros and cons of alternative schemes. The closer the similarity is to 1, the better the scheme will be at the current criterion level. The distance between the alternative demolition scheme and the ideal solution is calculated using the following formula (4).

The distances between the alternative solution and the positive ideal solution and the negative ideal solution are presented by D_i^+ and D_i^-, respectively. q_i^+ is the corresponding indicators in Q^+, and q_i^- is the corresponding indicators in Q^-.

$$\begin{cases} D_i^+ = \sqrt{\sum_{j=1}^{n}\left(q_{ij} - q_i^+\right)^2} \\ D_i^- = \sqrt{\sum_{j=1}^{n}\left(q_{ij} - q_i^-\right)^2} \end{cases} \tag{4}$$

The similarity between the alternative scheme and positive ideal solution can be expressed by the following formula (5). The value of E_i^+ ranges from 0 to 1.When the alternative scheme tends to the positive ideal solution, E_i^+ tends to 1, and when the alternative scheme tends to the negative ideal solution, E_i^+ tends to 0.

$$E_i^+ = \frac{D_i^-}{D_i^+ + D_i^-} \tag{5}$$

The similarity matrix E of each bridge demolition scheme to the positive ideal solution is multiplied by the weight vector W of the criteria layer corresponding to the target layer, and the result vector F of the comprehensive optimal alternative bridge demolition scheme is obtained. The result vector F takes into account all the criteria layer factors and reflects the preferred order of bridge demolition schemes. The higher the value of F, the closer it is to the ideal scheme, which is the best demolition scheme that the

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decision maker should choose.

5. Calculating the Similarity to an Ideal Solution

Delphi method was used to grade the evaluation indicators and each evaluation indicator of the three bridge demolition schemes were scored by twelve engineering experts. The five-scale, that is {1,3,5,7,9}, was used. Then the initial decision matrix *P* was constructed by taking the value nearest to the mean value and the initial decision matrix was shown in the "Schemes" column of Table 4.

According to formula (1) and (2), the evaluation indicators under each criterion layer were standardized and normalized to form a weighted normalization matrix. It should be noted that the indicators under each criterion layer could be classified as benefit-type indicator and cost-type indicator, denoted as *X* and *Y* respectively. It was easy to obtain the positive ideal solution and negative ideal solution for each criterion layer of three schemes according to from formula (3) to (5). Finally, the degree of similarity between each criterion layer and positive ideal solution in the three schemes was calculated. The final calculation result was shown in the Table 4.

Table 4. The similarity of the criteria to the positive ideal solution of the three demolition schemes.

The criteria	The indicators	Type	Schemes			The weighted standardization schemes			The ideal solution		The optimal similarity		
			M1	*M2*	*M3*	*M1*	*M2*	*M3*	Positive	Negative	*M1*	*M2*	*M3*
C1	*I1*	*X*	7	3	5	0.199	0.000	0.100	0.000	0.199	0.710	0.309	0.321
	I2	*Y*	7	5	5	0.330	0.000	0.000	0.330	0.000			
	I3	*Y*	9	5	7	0.330	0.000	0.165	0.330	0.000			
	I4	*Y*	7	5	3	0.141	0.070	0.000	0.141	0.000			
C2	*I5*	*X*	3	7	5	0.000	0.297	0.148	0.000	0.297	0.325	0.634	0.220
	I6	*Y*	3	7	5	0.000	0.164	0.082	0.164	0.000			
	I7	*Y*	5	7	5	0.000	0.539	0.000	0.539	0.000			
C3	*I8*	*X*	3	5	7	0.000	0.224	0.448	0.000	0.448	0.566	0.554	0.415
	4I9	*X*	7	5	3	0.283	0.141	0.000	0.000	0.283			
	I10	*X*	7	5	5	0.164	0.000	0.000	0.000	0.164			
	I11	*Y*	3	7	3	0.000	0.106	0.000	0.106	0.000			
C4	*I12*	*X*	7	3	5	0.667	0.000	0.333	0.000	0.667	0.333	1.000	0.414
	I13	*X*	3	3	5	0.000	0.000	0.333	0.000	0.333			
C5	*I14*	*X*	3	5	7	0.000	0.247	0.494	0.000	0.494	0.631	0.558	0.369
	I15	*Y*	7	5	5	0.196	0.000	0.000	0.196	0.000			

I16	*X*	9	5	5	0.311	0.000	0.000	0.000	0.311

6. Results

The weight of the criterion layer corresponding to the target layer was obtained using the AHP method, that is, the weight $W = [0.094,\ 0.125,\ 0.183,\ 0.237,\ 0.360]$. The matrix E was constructed as follows by using the optimal similarity of the alternative schemes to the positive ideal solution in Table 4.

$$E = \begin{bmatrix} 0.710 & 0.309 & 0.321 \\ 0.325 & 0.634 & 0.220 \\ 0.566 & 0.554 & 0.415 \\ 0.333 & 1.000 & 0.414 \\ 0.631 & 0.558 & 0.369 \end{bmatrix}$$

It was easy to calculate the result vector of comprehensive optimization F by using the formula $F = W \times E$ and the value of F was equal to (0.517,0.648,0.365). In general, the comprehensive optimization of three bridge demolition schemes was 51.7%, 64.8%, and 36.5% respectively. The order of priority of schemes was *M2*, *M1* and *M3*. Therefore, the scheme *M2* was adopted in the actual project of bridge demolition.

7. Conclusions

In this paper, multi-factor decision method is used to optimize the selection and evaluation of the bridge demolition scheme. The multi-factor decision method based on AHP and TOPSIS method can avoid the deviation of subjective judgment method to the greatest extent and evaluate the bridge demolition scheme scientifically. The practice of the bridge demolition shows that the optimal model is reasonable and feasible, and the bridge was dismantled safely, economically and efficiently.

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