Evaluation of Equipment Construction Project Schemes Based on Analytic Hierarchy Process and Grey Relational Analysis

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Abstract. The evaluation of equipment construction project schemes is an important part of equipment development. On the basis of summarizing the characteristics of equipment construction project schemes evaluation, the corresponding evaluation index system and evaluation logic framework are constructed, and the evaluation mathematical model is constructed. The analytic hierarchy process (AHP) and grey relational analysis are introduced into the model analysis. The model is derived and solved, and the formula of grey correlation coefficient is improved. Finally, the effectiveness of the model is verified by an example analysis, and the optimization of the construction project scheme is realized.

Keywords: equipment construction project · scheme evaluation · analytic hierarchy process · grey correlation analysis · grey correlation coefficient

1 Introduction

Equipment construction is a very complicated project, and the starting point of its project management is to choose the appropriate construction scheme. Once the project scheme is chosen incorrectly, it will bring many negative effects to the project management, and even the project cannot be completed. The evaluation of equipment construction project schemes is not only very important for equipment procurement and subsequent planning and development, but also a powerful means to restrain the "dragging", "falling" and "rising" problems in the process of equipment construction and development. "Dragging" means to delay the progress of the project; "falling" means lowering the technical standard of the project; "rising" refers to raising the monetary cost of a project. Only after the construction project scheme passes the evaluation can the equipment enter the development and production process. If all alternatives fail to pass the evaluation, the capability task list must be modified, and equipment construction project must be regenerated. At present, many literatures have carried out a lot of studies on the front of equipment requirement demonstration, namely, equipment requirement generation mechanism and evaluation method, and achieved a lot of results [6, 9], but there is a lack of attention to the subsequent research on specific project scheme evaluation.

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The evaluation of the equipment construction project scheme has the following characteristics: First, the evaluation is multi-objective and multi-level, because the evaluation depends on the construction of evaluation index system, which is composed of many sub-systems and specific indicators. Second, it is complicated. In addition to the complexity brought by multi-target and multi-level, indicators interact with each other, which also increases the difficulty of the evaluation. Third, it is uncertain. The battlefield environment and the development of confrontation between systems change rapidly, so requirement analysis is often changing, but the information used by requirement evaluation is often static, so the assessment has a certain degree of uncertainty. Fourth, it is effective. Once the alternative scheme fails to pass the evaluation, it is inevitable that the scheme will not be considered, and once all the schemes are eliminated, the equipment construction projects need to be re-formulated.

In this paper, the evaluation index system of equipment construction project schemes based on hierarchical structure is firstly constructed, and then the evaluation logic framework is given. The analytic hierarchy process (AHP) and grey relational analysis are introduced into the scheme evaluation, and then the evaluation mathematical model is established and solved. Finally, an example is given to verify that the model is effective and feasible, which makes a beneficial attempt to the scheme evaluation and provides a new solution way.

2 The Construction of Evaluation Index System and Evaluation Framework

The basis of equipment construction project scheme evaluation is a reasonable evaluation index system. The selection of the index system follows the principles of minimalism, objectivity, completeness, testability and independence [2, 10]. This paper constructs the following evaluation index system:

Necessity C. Necessities include: (1) Satisfaction C_1, thus whether the equipment construction project scheme meets the requirements of combat tasks [1], the higher the satisfaction degree, the higher the score; (2) Urgency C_2, thus whether the equipment requirement proposed in the project is urgent, the higher the urgency, the higher the score.

Technical feasibility B_1. Technical feasibility includes: (1) Defense industrial base B_{11}, which refers to the production lines, raw materials, tools and machinery and other related industrial facilities. The stronger the industrial base, the higher the score; (2) Technical pre-research B_{12}, which refers to whether the key technologies involved in the proposed equipment have been pre-studied. The more sufficient the technical reserve is, the higher the score will be; (3) Talent reserve B_{13}, which refers to whether there is a relevant professional equipment research and development talent team. The fuller the talent team is, the higher the score is.

Rate of progress B_2. It has two meanings, including both research and development schedule, and production schedule. Rate of progress includes: (1) Accessibility B_{21}, which refers to the length of the completion cycle of equipment development and mass production. The shorter the cycle, the higher the score; (2) Schedule risk B_{22}, refers to

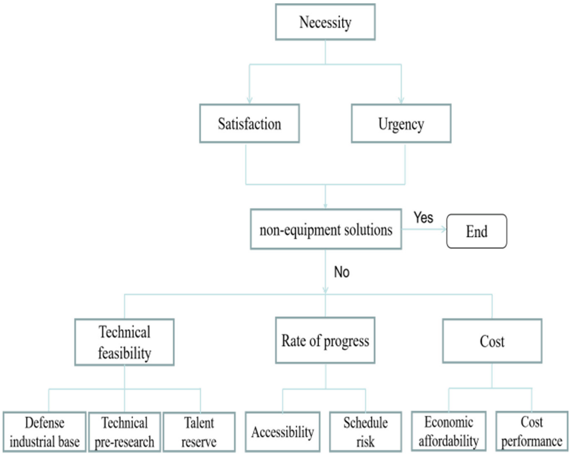

Fig. 1. Evaluation framework of equipment construction project scheme.

whether equipment research and development and mass production can be completed as scheduled and the risk degree of delay. The lower the risk, the higher the score.

Cost B_3. Cost includes: (1) Economic affordability B_{31}, which refers to the amount of money needed for research and development. The less money, the higher the score; (2) Cost performance B_{32}, which refers to the relationship between performance and implementation cost. The higher the cost performance, the higher the score..

The evaluation index system constructed above can be summarized as necessity, technical feasibility, time rationality and economy, including four major items and nine minor items. Based on the above indicator system, the evaluation framework of equipment construction project scheme is constructed as shown in Fig. 1.

Equipment construction project scheme assessment framework indicates its logical relationship, namely first need assessment, including whether to meet the demand of combat mission and urgency, secondly considering the non-equipment solutions can meet the demand of the proposed equipment, such as strengthening personnel training and further development of the existing equipment function. If a non-equipment solution can be used to meet the demand, assessment ends; if not, technical feasibility, rate of progress, and cost assessments are carried out. Therefore, logically speaking, necessity is not on the same level as technical feasibility, schedule and cost. Necessity is the priority. In many equipment construction projects, due to the necessity of consideration is not sufficient, leading to the construction of projects in a hurry, and eventually many projects repeated construction, both a waste of money, and a waste of time. Therefore, the necessity needs to be discussed first. Many literatures equate the priority of necessity with technical feasibility, rate of progress, and cost, which is very inappropriate. The first thing to be considered in the equipment construction project is the necessity. If there is no need to build a certain equipment, even if the technology is mature, the progress is fast, and the cost is small, it is completely meaningless to build it.

3 Construction and Solution of Mathematical Evaluation Model

3.1 Construction of Mathematical Evaluation Model

According to the scheme evaluation framework given above, this paper uses analytic Hierarchy Process (AHP) and grey relational analysis to jointly build the evaluation mathematical model. Among them, the analytic hierarchy process is used to determine the weight of indicators at different levels [7]. AHP is a decision analysis method that combines qualitative and quantitative methods to solve multi-objective complex problems. This method can effectively combine statistical data, expert opinions and subjective judgment of analysts, and then divide various factors in a complex system into a multi-level structural model [11]. By seeking the main relationship between various factors in the system, the grey correlation model finds out the important factors that affect the target value, so as to master the main characteristics of things, and then quantitatively describe and compare the development and change situation of the system [8]. Its basic idea is to determine the correlation coefficient and correlation degree between reference sequence (parent sequence) and several comparative sequence (subsequence) according to the four principles of normalization, symmetry, integrity and proximity based on the mathematical basis of space theory [3].

Construct the following mathematical model to judge the merits and demerits of the scheme:

$$\boldsymbol{A} = \boldsymbol{B} \cdot \sum_{l=1}^{2} P_l \alpha_l \tag{1}$$

In the above formula, both $\boldsymbol{A}$ and $\boldsymbol{B}$ are matrices. α_1 and α_2 respectively represent the evaluation of experts on whether the construction project meets the requirements C_1 and urgency C_2 of the combat task. P_1 and P_2 respectively represent the weights of the above two indicators. Therefore, $\sum_{l=1}^{2} P_l \alpha_l$ represents the comprehensive evaluation of experts on the necessity. $\boldsymbol{B}$ is the comprehensive evaluation of technical feasibility, schedule and cost, which is a $1 \times n$ matrix. So $\boldsymbol{A}$ is also a $1 \times n$ matrix. Therefore, Eq. (1) can be interpreted as the product of necessity, technical feasibility, progress and cost comprehensive evaluation. On the one hand, the above formula conforms to the evaluation framework proposed above, that is, necessity is the first consideration of evaluation, avoiding the disadvantage that many literatures regard necessity and other indicators as parallel indicators and thus simplify data processing. On the other hand, it can avoid the situation that necessity index and other indicators compete for weight, leading to the compression of the influence of other indicators.

3.2 Establishment and Solution of Grey Relational Model

The grey relational degree method is used to solve matrix $\boldsymbol{B}$. $\boldsymbol{B}$ represents the comprehensive evaluation of technical feasibility, schedule and cost, which includes seven specific indicators including national defense industrial foundation, technical pre-research, talent reserve, schedule accessibility, schedule risk, economic affordability and cost-effectiveness ratio. It should be pointed out that since the solution of $\boldsymbol{B}$ is derived here, the scheme indicators described below do not include the two necessary indicators. Assuming a total of n equipment construction project schemes, m ($m = 7$) evaluation indicators of the i-th project scheme constitute a series:

$$X_{ik} = \{X_{i1}, X_{i2}, .., X_{im}\}, i = 1, 2, ..., n; k = 1, 2, ..., m \tag{2}$$

Then the original index matrix formed by n schemes is:

$$X = \begin{bmatrix} X_{11} & X_{12} \ldots X_{1m} \\ X_{21} & X_{22} \ldots X_{2m} \\ \ldots & \ldots \ \ldots \ \ldots \\ X_{n1} & X_{n2} \ \ldots \ X_{nm} \end{bmatrix} \tag{3}$$

After determining the original matrix, the optimal indicator set is constructed:

$$X_0 = \{X_{01}, X_{02}, ..., X_{0m}\} \tag{4}$$

In formula (4), $X_{0\mathrm{j}}$ ($j = 1,2\ldots M$) is the optimal value of the j-th index in all schemes. If a certain index is bigger, it is better to take the maximum value of this index in various schemes; otherwise, it takes the minimum value. As the research object of this paper is the scoring value of each index, the optimal index set is the maximum scoring value of each index for this paper. The significance of the optimal index set X_0 is to select the optimal index from all the schemes to form the optimal scheme, take this as the quasi-basis, and take the grey correlation degree as the measure to judge the relationship between the schemes and the ideal optimal scheme, so as to obtain the order of merits and disadvantages of each scheme [4]. In view of different dimensions and orders of magnitude, the values between indicators often cannot be directly compared. Therefore, Formula (5) should be adopted to normalize the values of indicators:

$$\lambda_{ik} = \frac{X_{ik} - X_{imin}}{X_{imax} - X_{imin}} \tag{5}$$

In the above formula, λ_{ik} refers to the normalized value of the k-th index in the i-th scheme, X_{imin} refers to the minimum value of the k-th index in all schemes, and $X_{i\max}$ refers to the maximum value of the k-th index in all schemes. Therefore, the normalization matrix can be obtained as:

$$\lambda = \begin{bmatrix} \lambda_{01} \ \lambda_{02} & \ldots \ \lambda_{0m} \\ \lambda_{11} & \lambda_{12} & \ldots & \lambda_{1m} \\ \ldots & \ldots & \ldots & \ldots \\ \lambda_{n1} & \lambda_{n2} & \ldots & \lambda_{nm} \end{bmatrix} \tag{6}$$

The normalized optimal index set is taken as the sequence to be compared:

$$\{\lambda_{0k}\} = \{\lambda_{01}, \lambda_{02}, ..., \lambda_{0m}\} \tag{7}$$

According to Eq. (5), since the optimal index set X_0 has either a maximum value or a minimum value, according to Eq. (5), there are only two possibilities for the element in $\{\lambda_{0k}\}$, 1 or 0. Since the index value to be dealt with in this paper is the score value, the higher the score value, the better, it can be inferred that all elements in $\{\lambda_{0k}\}$ are 1. After the normalization matrix is worked out, the correlation coefficient $\zeta_i(k)$ between the k-th index and the k-th optimal index in the i-th scheme can be obtained by the following formula:

$$\zeta_i(k) = \frac{min_i min_k|\lambda_{0k} - \lambda_{ik}| + \rho max_i max_k|\lambda_{0k} - \lambda_{ik}|}{|\lambda_{0k} - \lambda_{ik}| + \rho max_i max_k|\lambda_{0k} - \lambda_{ik}|} \tag{8}$$

In the above formula, ρ is the resolution, generally $\rho = 0.5$ [5]. According to the specific situation of this paper, Eq. (8) is discussed and improved. Started with $min_i min_k|\lambda_{0k} - \lambda_{ik}|$, and what this part of the formula means is that no matter what the values of k and i are in their domains, $|\lambda_{0k} - \lambda_{ik}|$ should be minimized. As mentioned above, all elements in $\{\lambda_{0k}\}$ are 1, and according to Eq. (5), λ_{ik} is less than or equal to 1. Therefore, the smallest case for $|\lambda_{0k} - \lambda_{ik}|$ is if λ_{ik} is 1, the absolute value is 0, so $min_i min_k|\lambda_{0k} - \lambda_{ik}|$ is 0. Similarly, the maximum case for $|\lambda_{0k} - \lambda_{ik}|$ is if λ_{ik} is 0, and the number in the absolute value is 1, so $max_i max_k|\lambda_{0k} - \lambda_{ik}|$ is 1. Therefore, according to the specific situation of this paper, Eq. (8) can be simplified as:

$$\zeta_i(k) = \frac{\rho}{|\lambda_{0k} - \lambda_{ik}| + \rho} \tag{9}$$

Therefore, the correlation matrix can be obtained according to Eq. (9):

$$E = \begin{bmatrix} \zeta_1(1) & \zeta_1(2) & \ldots & \zeta_1(m) \\ \zeta_2(1) & \zeta_2(2) & \ldots & \zeta_2(m) \\ \ldots & \ldots & \ldots & \ldots \\ \zeta_n(1) & \zeta_n(2) & \ldots & \zeta_n(m) \end{bmatrix} \tag{10}$$

Evaluation model is established:

$$\boldsymbol{B} = \boldsymbol{P} \times \boldsymbol{E}^{\mathrm{T}} \tag{11}$$

In the above formula, $\boldsymbol{B} = [b_1, b_2 \ldots, b_{\mathrm{n}}]$ is the comprehensive evaluation matrix of the technical feasibility, progress and cost of n schemes, where b_i represents the evaluation result of the i-th scheme. $\boldsymbol{P} = [P_1, P_2, \ldots P_{\mathrm{m}}]$ is the weight distribution matrix of m (m = 7) evaluation indicators, and the weight distribution is determined by AHP, which satisfies:

$$\sum_{k=1}^{m} P_k = 1 \tag{12}$$

The comprehensive evaluation result of the i-th scheme, namely, the correlation degree b_i, can be obtained by the following formula:

$$b_i = P \cdot \begin{bmatrix} \zeta_i(1) \\ \zeta_i(2) \\ \ldots \\ \zeta_i(m) \end{bmatrix} = \sum_{k=1}^{m} P_k \zeta_i(k) \tag{13}$$

If the correlation degree b_i is the largest, it indicates that $\{\lambda_{ik}\}$ is closest to $\{\lambda_{0k}\}$. At this point, the matrix $\boldsymbol{B}$ is solved, and then put it into formula (1) to solve $\boldsymbol{A}$, according to which the order of pros and cons of each scheme can be derived, and the optimal scheme can be selected.

4 Instance Analysis

4.1 Solution of Model

At present, there are five alternatives for a certain anti-tank equipment construction project, and 12 experts are invited to score it. The given standard of scoring is divided into five categories: poor, average, medium, good and excellent. The scores corresponding to each level of comments are shown in Table 1.

The scores of the experts are all integer points, and after the scoring, if the difference between the highest score and the lowest score is more than 10 points, that is, it has crossed an order of magnitude, the highest score and the lowest score will be removed, and the average score of the remaining 10 experts will be used as the score of this index. If the difference between the highest score and the lowest score is no more than 10 points, the average score of 12 experts will be used as the score of this index. Table 2 shows the scores of all indicators of the five schemes after statistical summary.

Table 1. Correspondence between comments and marks.

Standard	Score
Excellent	[90,100)
Good	[80,90)
Medium	[70,80)
Average	[60,70)
Poor	[0,60)

Table 2. A summary of experts' scores for the five equipment schemes.

	Necessity C		Technical feasibility B_1			Rate of progress B_2		Cost B_3	
	C_1	C_2	B_{11}	B_{12}	B_{13}	B_{21}	B_{22}	B_{31}	B_{32}
1	94	90	88	88	82	82	75	80	86
2	92	93	86	85	83	82	79	85	84
3	90	91	92	86	87	80	74	84	86
4	94	89	90	84	89	86	72	81	89
5	93	92	87	90	85	84	79	82	90

Table 3. Weight of each index.

Primary indicators	Weight allocation	Secondary indicators	Weight allocation
Necessity C	1	C_1	0.45
		C_2	0.55
Technical feasibility B_1	0.4	B_{11}	0.25
		B_{12}	0.25
		B_{13}	0.5
Rate of progress B_2	0.3	B_{21}	0.5
		B_{22}	0.5
Cost B_3	0.3	B_{31}	0.6
		B_{32}	0.4

According to the relevant theories of AHP, the weight of each indicator is determined as shown in Table 3.

According to Formula (4), the optimal index set is:

$$X_0 = \{92, 90, 89, 86, 79, 85, 90\} \tag{14}$$

According to Eqs. (5) and (13), the normalized matrix can be obtained as:

$$\lambda = \begin{bmatrix} 0.3333 & 0.6667 & 0.0000 & 0.3333 & 0.4286 & 0.0000 & 0.3333 \\ 0.0000 & 0.1667 & 0.1429 & 0.3333 & 1.0000 & 1.0000 & 0.0000 \\ 1.0000 & 0.3333 & 0.7143 & 0.0000 & 0.2857 & 0.8000 & 0.3333 \\ 0.6667 & 0.0000 & 1.0000 & 1.0000 & 0.0000 & 0.2000 & 0.8333 \\ 0.1677 & 1.0000 & 0.4286 & 0.6667 & 1.0000 & 0.4000 & 1.0000 \end{bmatrix} \tag{15}$$

According to Eqs. (9) and (15), the correlation matrix can be obtained as follows:

$$E = \begin{bmatrix} 0.4286 & 0.6000 & 0.3333 & 0.4286 & 0.4667 & 0.3333 & 0.4286 \\ 0.3333 & 0.3750 & 0.3684 & 0.4286 & 1.0000 & 1.0000 & 0.3333 \\ 1.0000 & 0.4286 & 0.6364 & 0.3333 & 0.4118 & 0.7143 & 0.4286 \\ 0.6000 & 0.3333 & 1.0000 & 1.0000 & 0.3333 & 0.3846 & 0.7500 \\ 0.3750 & 1.0000 & 0.4667 & 0.6000 & 1.0000 & 0.4545 & 1.0000 \end{bmatrix} \tag{16}$$

According to AHP and Table 3, $\boldsymbol{P}$ can be obtained as follows:

$$\boldsymbol{P} = [0.10.10.20.150.150.180.12] \tag{17}$$

According to Eqs. (13), (16) and (17), $\boldsymbol{B}$ can be obtained as:

$$\boldsymbol{B} = [0.4150.5790.5620.6530.673] \tag{18}$$

According to Formula (1),

$$\boldsymbol{A} = [38.1253.5750.8859.5462.19] \tag{19}$$

4.2 Result and Discussion

According to Formula (19), scheme 5 > Scheme 4 > Scheme 2 > Scheme 3 > Scheme 1. Therefore, under the current index system, comprehensive judgment scheme 5 is the optimal scheme. Next, the equipment construction project will be implemented according to scheme 5. According to Table 2, it can be found that the score of each item in scheme 5 is not the highest, but according to the algorithm proposed in the paper, scheme 5 gives the best consideration to all indicators, so its score is also the highest.

5 Conclusions

For many years, the problems of "dragging", "falling" and "rising" have been perplexing equipment construction projects. The root of these problems lies in the inability to effectively select the equipment construction engineering scheme. As the starting point of equipment construction project management, once the scheme is selected incorrectly, it will bring many disadvantages to the project, such as increased cost, decreased technical indicators, delayed progress, etc. On the basis of summarizing the characteristics of equipment construction project evaluation, this paper firstly constructs the evaluation index system, including necessity, technical feasibility, time rationality and economy. In the evaluation index system, the difference between this paper and other literatures lies in giving priority to the necessity of engineering schemes, rather than treating the necessity with other indexes equally. According to the evaluation index system, the evaluation framework is constructed and the logical relationship of program evaluation is pointed out. On this basis, the evaluation mathematical model is established, and the analytic hierarchy process and grey correlation analysis are used to deduce and solve the model, and the solution formula of grey correlation coefficient is improved. Finally, the model is proved to be scientific and practical by an example.

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