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Evaluation of Technology Projects using Multi-level Criteria and TOPSIS Approach

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Abstract. The evaluation of technology projects for commercialization is intrinsically difficult but of great importance. In this paper, a project evaluation criteria and model are constructed in the following two aspects. Firstly, multi-level and multi-dimensional project evaluation criteria are formed with reference to various studies. These criteria help decision-makers to gain a comprehensive understanding of the technical level, maturity, implementability, promotion value, and industrialization foundation of the project. Secondly, since the evaluation of the project involves multiple criteria, it can be modeled as a multiple criteria decision making (MCDM) problem. A nested MCDM model for multi-level criteria is constructed using the technique for order preference by similarity to ideal solution (TOPSIS) algorithm with a hybrid of AHP and Entropy weighting methods. The results illustrate the effectiveness of the model in evaluating technology projects. The outcomes of the research enable decision-makers to comprehensively understand the projects based on multi-level criteria while making practical and rational decisions based on the evaluation model.

Keywords: Technology project, Commercialization, Entropy method, AHP, TOPSIS

1. Introduction

Nowadays, technology has become the key engine of social productivity and national economic growth. How to convert technology into productivity has received a wide range of attention from academics and business[1]. Selecting appropriate technology projects is extremely important to successful technology commercialization[2].

For research institutions, comprehensively evaluating the technology projects to determine which research to develop for commercialization is a complex process. Over fifty specific points were identified in the previous literature as necessary in technology assessment, and Heslop and Griffith (2001)[2] classified them into four major categories: the strengths of the technology itself, the market attractiveness, commercialization avenues, and management support. Meseri and Maital (2001)[3] investigated how technology transfer organizations at Israeli universities evaluate projects and found that the six most important factors that determine the ultimate success or failure of supported technology transfer projects were: market demand, market size, the existence of patents, the chance of success in the research and development stage, the level of innovation, and the maturity of the idea. Yuanchun and Chen (2017) [4] analyzed the internal and external factors that affect the efficiency of technology transfer and found that corporate participation, institutional innovation capabilities, good organizational communication, government support, market competition, and demand for new products positively impact the efficiency of technology transfer. Cedano (2021)[5] established an integrated tool for risk assessment to improve the success of technology transfer efforts from the aspect of market, competitive landscape, IP lifetime, team dynamics, technology/product adoption and value proposition.

Project evaluation always involves multiple criteria, and it is essential to utilize the multiple criteria decision making (MCDM) method to find an appropriate assessment. The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is one of the widely used MCDM methods, which was initially

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proposed by Hwang and Yoon (1995)[6]. As a finite solution multi-objective decision making and evaluation method, this method is simple to calculate and more flexible in application. During the past few years, the TOPSIS method has been successfully applied in various forms for project evaluation[7-8]. Gao and Yang (2008)[9] use the Fuzzy TOPSIS method to evaluate the information system projects. Chang [10] combines ANP and (TOPSIS) to help corporations make better decisions on new product development (NPD) project selection. Overall, TOPSIS methodology plays a crucial role in project evaluation.

The evaluation of the technology project is a multi-objective and multi-index comprehensive process. Regarding the previous literature, a comprehensive evaluation index system for technology project was established in this paper. The TOPSIS algorithm with a hybrid of AHP and Entropy weighting methods was used to prioritize the projects. It provides a tool to comprehensively evaluate the value and commercialization risks of technology projects, which will help identify the appropriate candidate project for technology transfer and commercialization.

2. Construction of Evaluation Criteria

Based on the influencing factors of the project's commercialization, the project's evaluation indicators are set from the technical level, maturity, implementability, promotion value, and industrialization foundation.

Table 1: The first-level and second-level indicators

First-level Indicators	Second-level Indicators
Techinque level	Technological advancement
	Innovation
	Independent intellectual property
Maturity	Technology maturity
	Manufacturing maturity
	Quality maturity
Implementability	Technical complexity
	Period of realization
Promotion value	Market demand
	Market competitiveness
	Expected economic benefits
	Expected social benefits
Industrialization foundation	Infrastructure
	R&D team
	Enterprise management level

2.1. Techinque level

The technical level is a core attribute of technology projects. Projects without technical advantages are easily replaced and will be eliminated. The technical level of the project usually focuses on technological advancement, innovation, and independent intellectual property. Among them, technological advancement is to compare the project's technical features with the most advanced similarity technologies at home and abroad to obtain the advanced level. Innovation level is measured by the scope and degree of technological innovation in the world. Moreover, independent intellectual property refers to the obtained intellectual property such as patents and copyrights to measure whether the core technologies and achievements are appropriately protected.

2.2. Maturity

Generally, new technology is usually subjected to development, experimentation, refinement, and increasingly realistic testing before it can be applied. The maturity attribute is offered to measure the actual progress of the technical realization and industrialization of the project, including technology, manufacturing, and quality maturity. Technology maturity refers to how technology has been developed and verified to meet its intended use targets. It can be measured refer to the white paper from NASA [11]. Manufacturing maturity is used to determine whether a technology or process meets the production requirements. It can be measured in technology and industrial foundation, design, materials, cost and investment, process capability and control, manufacturing personnel, facilities, and manufacturing management [12]. Quality maturity follows product quality, reliability, stability, and quality management.

2.3. Implementability

The probability that the proposed project will succeed and how long it will take have been the critical factors for venture capital funds and entrepreneurs [2]. Thus, the implementability of industrialization for the project needs to be concerned, which can be measured by two indicators: technical complexity and period of realization. The technical complexity includes the complexity of the technical system, the interaction between technical components and subsystems, and the difficulty of implementing the technology; the period of realization refers to the expected time required for the industrialization and commercialization of the project.

2.4. Promotion value

Promotion value contains market demand, competitiveness, expected economic benefits, and social benefits. The market demand considers the current market demand of the product, the market growth rate, and future development prospects. Market competitiveness refers to the comparative advantage of the product with similar products in terms of characteristics, quality, cost, price, etc. The expected economic benefits include the expected industrial scale and profitability of the product. Expected social benefits can be reflected by the expected benefits of promoting industrial structure adjustment and regional economic development, improving the environment, and rationally utilizing resources.

2.5. Industrialization foundation

The industrialization foundation includes infrastructure, R&D team, and enterprise management level to measure whether it has advanced and adequate workshops, production and testing equipment, sufficient raw materials and energy, rich experience in technology research and development, a strong technical team, and the enterprise management level.

3. Comprehensive Evaluation Methodology

Technique for order performance by similarity to ideal solution (TOPSIS) is one of the multi-criteria decision making (MCDM) methods in dealing with multi-attribute problems in the real world [13]. It can help decision-makers comprehensively identify a project's situation within a complex evaluation system. Since TOPSIS does not provide weight deduction and consistency tests for determinations, several common weighting methods are used in the MCDM literature. For example, some scholars employ the Entropy-based method to identify the weight of each attribute [14-15]. However, The entropy method determines weights based on the dispersion of the data in the attribute, which does not reflect the importance of the decision maker's preference for different indicators. Besides, some lectures select the best alternatives using the analytic hierarchy process (AHP) and TOPSIS as a hybrid approach [16-17]. Since the AHP method needs decision-makers to determine the relative importance of the criteria and assign the value to each criterion, the decision makers' performances are the main factor for the derivation of weights. Experienced decision-makers and experts have a deep understanding of the impact of different indicators on the commercialization of technology projects. Therefore, the weights of the detailed indicators(the second-level indicators) are determined by AHP method firstly. However, as a subjective weighting method, the AHP method ignores the influence of data information. Since the entropy method weights the indicators more objectively from the perspective of data dispersion, the weight of the first-level indicators are determined by the hybrid AHP and Entropy methods, which can make up for the deficiencies brought by a single weighting. And the TOPSIS method was conducted to evaluate projects. The methodological details are explained in the following sub-section.

3.1. The Analytic Hierarchy Process (AHP)

The AHP[18] is a flexible and effective decision-making method for dealing with subjective and intangible criteria that have been applied in various fields, like management, governance, industry, and distribution of resources. Utilizing the AHP method to determine the weights of each indicator based on decision-makers performance, the calculating weights is given as:

- Step 1:Developing a pairwise comparison matrix

Construct a comparison matrix of the attributes using Saaty's scale (see Table 2)[19]. Assuming N attributes, the square matrix A_{nn} represents the pairwise comparison of attribute *i* with attribute *j* where a_{ij} shows the relative importance of attribute *i* over attribute *j*. In this matrix, $a_{ij} = 1$ when $i = j$ and $a_{ji} = 1/a_{ij}$.

$$A_{nn} = \begin{bmatrix} a_{11}, a_{12}, ..., a_{1n} \\ a_{21}, a_{22}, ..., a_{2n} \\ .... \\ .... \\ a_{n1}, a_{n2}, ..., a_{nn} \end{bmatrix} \quad (1)$$

Table 2: Scale of relative importance

Ranking	**Scale of Importance for Pairwise Comparisons**
1	Equal Importance
3	Moderate Importance
5	More Importance
7	Strong Importance
9	Extreme Importance
2,4,6,8	Intermediate value of the above judgements

- Step 2:Calculate the criteria weights

Normalize the columns of the pairwise comparison matrix $A`_{nn}$. Then, the weights equal the geometric mean of the elements (Eigenvectors) in each row. Where $a_{ij}^{'} = a_{ij} / \sum_{i}^{n} a_{ij}$.

$$A_{nn}^{'} = \begin{bmatrix} a_{11} / \sum_{i=1}^{n} a_{i1}, a_{12} / \sum_{i=1}^{n} a_{i2}, ..., a_{1n} / \sum_{i=1}^{n} a_{in} \\ a_{21} / \sum_{i=1}^{n} a_{i1}, a_{22} / \sum_{i=1}^{n} a_{i2}, ..., a_{2n} / \sum_{i=1}^{n} a_{in} \\ ...,...,...,... \\ ...,...,...,... \\ a_{n1} / \sum_{i=1}^{n} a_{i1}, a_{n2} / \sum_{i=1}^{n} a_{i2}, ..., a_{nn} / \sum_{i=1}^{n} a_{in} \end{bmatrix} \quad (2)$$

$$\begin{aligned} W_i &= [(\prod_{n}^{j=1} a_{1j}^{'})^{1/n}, (\prod_{n}^{j=1} a_{2j}^{'})^{1/n}, ..., (\prod_{n}^{j=1} a_{nj}^{'})^{1/n}]^T \\ &= [w_1, w_2, ..., w_n]^T \end{aligned} \quad (3)$$

- Step 3: Judging the consistency of pairwise comparison matrix

According to the explanation of Saaty[19], if the comparison matrix is consistent, The weight vector is the normalized eigenvector when taking the largest lambda (λ). The largest lambda is calculated by Equation (4).

$$\begin{aligned} AW &= \lambda W \\ \lambda_{max} &= \sum_{i}^{n} (\sum_{i}^{n} a_{ij}) w_i \end{aligned} \quad (4)$$

Then, to examine the consistency for pairwise comparisons in AHP by calculating the consistency ratio (CR) (Equation (6)), which measures the probability that the pairwise comparison matrix[20] and the RI is the random index. The CI is the consistency index, which measures in Equation (5).

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (5)$$

$$CR = \frac{CI}{RI} \quad (6)$$

If the CR is less than 0.10, it means an acceptable level of consistency of the comparisons matrix. If CR is greater than 0.10, the comparisons matrix is inconsistent. The Random Index (RI) is given in. Table 3.

Table 3: Random index

Num of attributes	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
R.I	0	0	0.52	0.89	1.11	1.25	1.35	1.4	1.45

The research data were derived from the evaluation of projects by experts. All participants are administrative staff and academics who have expertise in the various evaluation indicators of the project and can complete the AHP table briefly.

3.2. TOPSIS Method

The TOPSIS method is a systemic and comprehensive multi-criteria decision-making framework. The core concept of this method is to estimate the relative closeness of each alternative to the optimal solution based on the distance of each criterion to the positive and negative ideal solution[21]. The procedure of TOPSIS is given as:

- Step 1:Construct decision matrix

$$D = \begin{array}{c c} & X_1, X_2 .....X_n \\ \begin{array}{c} Y_1 \\ Y_2 \\ \vdots \\ Y_n \end{array} & \begin{bmatrix} x_{11}, x_{12}, ..., x_{1n} \\ x_{21}, x_{22}, ..., x_{2n} \\ ...... \\ x_{n1}, x_{n2}, ..., x_{nn} \end{bmatrix} \end{array} \tag{7}$$

In the decision matrix D, Y_i represents the alternative i, i = 1,…,n. X_i denotes the attribute or criterion j , j = 1,…,n. x_{ij} indicates the performance rating of alternative Y_i concerning attribute X_i.

- Step 2:Normalization

Convert the decision matrix D into the normalized matrix $R = (r_{ij})$, using the normalization formula as:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{n} (x_{ij})^2}} \tag{8}$$

- Step 3:Determine the positive and negative ideal solution

$$\begin{aligned} S^+ &= \{r_1^+, ..., r_n^+\} = \{(max_i r_{ij}^k \mid j \in J), (min_i r_{ij}^k \mid j \in J')\} \\ S^- &= \{r_1^-, ..., r_n^-\} = \{(min_i r_{ij}^k \mid j \in J), (max_i r_{ij}^k \mid j \in J')\} \end{aligned} \tag{9}$$

Where J and J' are associated with the benefit criteria and cost criteria respectively.

- Step 4:Calculate the separation measures

The positive ideal separation is:

$$d_i^+ = \sqrt{\sum_{j=1}^{n} w_j (r_{ij} - r_j^+)^2} \tag{10}$$

The negative ideal separation is:

$$d_i^- = \sqrt{\sum_{j=1}^{n} w_j (r_{ij} - r_j^-)^2} \tag{11}$$

Where w_j is the weight of the attribute calculated by AHP.

- Step 5:Calculate the relative closeness

The Relative Closeness (RC) to the positive ideal solution is calculated by Equation (12).

$$RC_i^* = \frac{d_i^-}{d_i^+ + d_i^-}, i = 1, 2, ..., n \tag{12}$$

Where the relative closeness index value ranges between 0 and 1. The larger index value means the better performance of the alternative (project) and vice versa.

The multi-level criteria were used to evaluate the performance of a project. The higher the rating is given to the criteria, the better the project performance.

3.3. Multi-level Evaluation Model

The project evaluation framework utilizes a multi-level criterion for comprehensive evaluation. Thus, We constructed a multi-level evaluation model nested in the TOPSIS approach. This model consists of two main parts. The first part focuses on the weighting of project evaluation criteria. Since the evaluation system contains two-level indicators, the first-level and second-level criteria were scored by the relative importance based on expert knowledge. Then, the Analytic Hierarchy Process (AHP) was used to weight the criteria. Besides, the Entropy method[15] for weighting second-level criteria is still available. In the second part, The TOPSIS is used to comprehensively evaluate the multi-dimensional second-level attributes under each first-level criteria, where the weight of each criterion is assigned in part one. Thus, we can obtain a composite evaluation score for each first-level attribute for each alternative. Then, we further utilize the TOPSIS method to obtain an overall project performance rank based on the weights and scores of each first-level criteria, where weights can be calculated using the AHP and Entropy approach. Finally, the evaluation model determines the overall performance of each project. The scale of the TOPSIS rating is 0 to 1. The higher the TOPSIS rating, the better the performance of the projects. Fig. 1 shows the simple workflow.

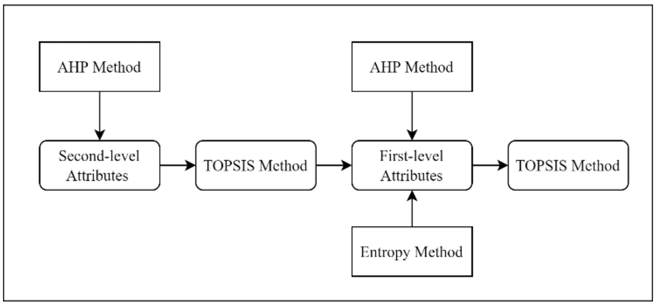

Fig. 1: Multi-level Evaluation Model

4. Results and discussions

Table 4 shows the weights of the first-level indicators measured by the AHP and Entropy method. Indicator A4, ‘Promotion value,’ was the essential attribute under both weighting methods. In project evaluation, promotion value evaluates the long-term development trend. Only the projects with long-term development advantages will attract the most attention from investors and decision-makers. While A1, ‘Technical level’ is the second essential attribute. The A3, ‘Implementability’ is the fourth important indicator under the two weighting methods. However, A2 ‘Maturity’ and A5 ‘Industrialization foundation’ display different weighting ranks in the AHP and Entropy method. This difference mainly stems from the diversity of the two weighting approaches. The AHP method focuses more on evaluating relative importance among criteria. However, in information theory, the Entropy method can be considered a criterion for the degree of uncertainty represented by a discrete probability distribution. Overall, this study has used different weighting methods within the first-level criteria and has obtained roughly similar weight ranks. Therefore, it is acceptable to use both sets of weights.

Table 4: The weights for first-level indicators

First-level	Indicators	AHP-weight	Rank	Entropy-weight	Rank
A1	Technical level	0.328	2	0.213	2
A2	Maturity	0.062	5	0.203	3
A3	Implementability	0.100	4	0.200	4

A4	Promotion value	0.368	1	0.221	1
A5	Industrialisation foundation	0.142	3	0.164	5

As mentioned above, the second-level criteria are weighted by the AHP method. Table 5 displays the weights distribution of each indicator. The sum of second-level indicators' weights is equal to 1 within thousandths of error. Using the TOPSIS method of weighting the Second-level indicators, each project can obtain an integrated score for the first-level indexes.

Table 5: The weights for second-level indicators

Second-level	**Indicators**	**Weight**	**Rank**
A1B1	Technological advancement	0.277	2
A1B2	Innovation	0.129	3
A1B3	Independent intellectual property	0.595	1
The Sum of Second-level Weights of A1: 1.001			
A2B1	Technology maturity	0.539	1
A2B2	Manufacturing maturity	0.297	2
A2B3	Quality maturity	0.164	3
The Sum of Second-level Weights of A2: 1.000			
A3B1	Technical complexity	0.200	2
A3B2	Period of realization	0.800	1
The Sum of Second-level Weights of A3: 1.000			
A4B1	Market demand	0.251	2
A4B2	Market competitiveness	0.157	3
A4B3	Expected economic benefits	0.472	1
A4B4	Expected social benefits	0.119	4
The Sum of Second-level Weights of A4: 0.999			
A5B1	Infrastructure	0.255	2
A5B2	R&D Team	0.597	1
A5B3	Enterprise management level	0.148	3
The Sum of Second-level Weights of A5: 1.000			

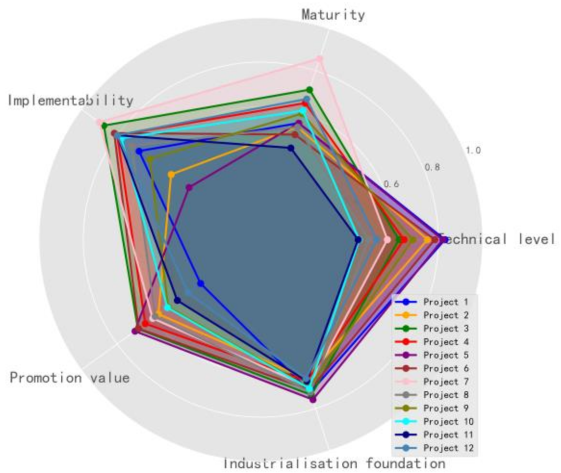

Fig. 2: Radar Chart of First Level Indicators Scores

In Table VI, shows the normalized aggregate scores for all projects' first-level indicators. The score for each first-level indicator is calculated using the AHP weighted TOPSIS method for the second-level criteria.

This Radar Chart shows that Project 7 has the highest scores on the 'Maturity' and 'Implementability' fields. Project 5 received remarkably higher scores on 'Technical level,' 'Promotion value' and 'Industrialization foundation' than the other two indicators, which exhibits a significant bias in its overall performance. However, project 3 displays a balanced performance on all indicators. In addition, we found that on the indicator of 'Industrialization foundation,' all projects were scored very close to each other, which means that the 'Industrialization foundation' may not affect the results significantly when evaluating projects in aggregate. Overall, the differences in project evaluation mainly stem from the dispersion of each project on each indicator.

In Table 6, the d+ and d- are positive and negative ideal separation; Overall-RC is the result of calculating the aggregated scores for all first-level criteria using the TOPSIS method. Panels A and B show AHP and Entropy weighting results, respectively. The results show that Project 3 and 7 are ranked top among all. Neither of these projects is the most technically advanced, but their performance is not inferior in any five aspects. Hence the highest overall score indicated that these projects had better commercialization conditions. As shown in Fig 2, Project 1 had the highest technical level among all projects. However, the low promotion value reflects the more significant market risks the project faces, which means it is unsuitable for industrialization. Besides, though Project 10 performed well in terms of maturity, implementability, and industrialization foundation, there was a risk of being replaced due to its low technical level and weak market competitiveness. It is worth mentioning that Project 5 had a significant technical difficulty and a long realization period. There might be a risk of technical failure. However, due to its high technical level and promotion value, it still had a commercial value.

Table 6 also listed the results of the weighted mean. It can be seen that there are differences in the ranking of projects. Compared with the weighted method, the nested TOPSIS approach is more focus on the variation of individual indicators, can detect the distance between the evaluation object and the optimal solution as well as the worst solution, and is more conducive to avoiding the risk of project selection. In addition, the uses of TOPSIS approach for multi-level criteria to obtain consistent results under different weighting methods, demonstrates that the model is stable and effective in evaluating project performance and can further assist decision-makers in making comprehensive decisions.

Table 6: Results of TOPSIS technique with different weights

Panel A The AHP Weights						
	TOPSIS mean				***Weighted mean***	
	d⁺	***d⁻***	***Overall-RC***	***Rank***	***Normalized score***	***Rank***
Project 1	0.259	0.239	0.480	8	0.269	8
Project 2	0.203	0.224	0.525	6	0.287	6
Project 3	0.143	0.275	**0.658**	**2**	0.314	3
Project 4	0.158	0.264	0.626	4	0.299	4
Project 5	0.174	0.302	0.635	3	0.323	2
Project 6	0.177	0.278	0.611	5	0.328	1
Project 7	0.152	0.293	**0.659**	**1**	0.295	5
Project 8	0.246	0.186	0.430	9	0.264	9
Project 9	0.187	0.201	0.517	7	0.275	7
Project 10	0.258	0.166	0.392	10	0.249	10
Project 11	0.318	0.132	**0.293**	**12**	0.231	12
Project 12	0.264	0.148	**0.359**	**11**	0.238	11
Panel B The Entropy Weight						
	TOPSIS mean				***Weighted mean***	
	d⁺	***d⁻***	***Overall-RC***	***Rank***	***Normalized score***	***Rank***
Project 1	0.181	0.256	0.585	10	0.272	7
Project 2	0.167	0.249	0.598	7	0.268	9

Project 3	0.121	0.294	**0.708**	**1**	0.320	1
Project 4	0.136	0.277	0.671	4	0.298	4
Project 5	0.153	0.274	0.641	5	0.289	5
Project 6	0.136	0.285	0.677	3	0.308	3
Project 7	0.130	0.297	**0.696**	**2**	0.319	2
Project 8	0.170	0.246	0.591	8	0.266	10
Project 9	0.161	0.252	0.610	6	0.275	6
Project 10	0.174	0.247	0.586	9	0.268	8
Project 11	0.199	0.226	**0.532**	**12**	0.240	12
Project 12	0.178	0.247	**0.580**	**11**	0.262	11

5. Results and discussions

The evaluation of technology projects is a multi-objective and multi-criteria decision-making process. In this paper, multi-dimensional criteria is constructed including 5 first-level and 15 second-level criteria, considering the technical level, maturity, implementability, promotion value, and industrialization foundation of the project comprehensively, which provides a reference for identifying suitable projects for commercialization. Furthermore, a multi-layer nested TOPSIS model with a hybrid AHP and entropy weighting method is constructed, which is used to comprehensively evaluate projects with multi-dimensional criteria and assist decision-makers in making decisions. Compared to traditional subjective decision-making, this technology project evaluation criteria and models are a new approach that combines subjective analysis and objective quantification. The findings also show that the use of the model is valid for evaluation purposes. There are apparent variations in ‘technical level’ and ‘promotion value’ between projects, which have the most significant impact on project evaluation. In addition, although the ‘Implementability’ and ‘maturity’ indicators have low weights, the scores of different projects vary widely, providing a reference for identifying specific project risks. This finding will help experts and decision-makers analyze similarities and differences between projects in greater depth while optimizing and improving comprehensive project assessments.

Due to the lack of additional data for the project evaluation, the experiment was conducted using only in-sample data. Thus, we still think a large number of examples should be recommended for tests in future studies. Besides, we further consider optimizing the comprehensive evaluation criteria and models regarding more theories and methods.

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