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Project Evaluation Model Based on Group Decision-Making Vector Optimization of AHP Algorithm

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Abstract
According to some problems such as inaccuracy in the application of science and technology project evaluation of the standard AHP evaluation model. This paper proposed a science and technology project evaluation model based on group decision-making vector optimization of AHP algorithm. The evaluation index system is firstly divided into hierarchical structure, using the AHP method to determine the weight of each index, and use the fuzzy evaluation method to construct evaluation matrix, then using the group decision vector to make normalization for all attribute values of interval numbers, finally constructing the science and technology project evaluation model, using improved AHP algorithm to translate the interrelation of science and technology projects into quantitative analysis, using synthesis method of group decision-making direction vector to calculate the weight value of various indicators. The simulation experiments showed that the proposed AHP fuzzy evaluation method based on group decision-making vector optimization performed well in the application of science and technology project evaluation, its accuracy and stability are better than both of fuzzy evaluation and standard AHP evaluation methods.
Key words: AHP EVALUATION MODEL, SCIENCE AND TECHNOLOGY PROJECT EVALUATION, GROUP DECISION-MAKING VECTOR, FUZZY EVALUATION, NORMALIZATION, QUANTITATIVE ANALYSIS

1. Introduction

Science and technology project evaluation is the building up of the basis and premise of competition, incentive and supervisory mechanism in science and technology project management, a reliable basis of science and technology to ensure the task to be completed for scientific decision-making, an important support of the judgment of the performance of science and technology project implementation and achievement level, an important means to improve the level of science and technology management and safeguard [1]. Science and technology project evaluation is an important part of the management system of science and technology, is not only the starting point of the management process, and also the end-result of management process, in enhancing the management of science and technology projects, and play an important role to improve the effectiveness of science and technology resources allocation and investment benefit [2]. By means of science and technology project to conduct a comprehensive inspection, comparison, analysis, argumentation and evaluation, for both the project decision makers, managers and executives, it can make their own to find the direction of further improvement work [3]. The evaluation activity can improve the quality of science and technology management, efficiency and level, enable managers to further deepen the understanding of the objective laws of management activities.

At present many domestic and foreign experts and scholars have put forward improved evaluation model and method of science and technology project. Chen Aizu et al. classified the science and technology project into four catagories which were popularizing demonstration, application foundation, application development and soft science, and the performance evaluation can be divided into the project evaluation and assessment. Zhou Wenyong etc. divided the government investment project into five categories which were foundamental research project, applied research project, scientific and technological industrialization project, social commonweal research project, scientific conditions construction and technology and support services, and the performance evaluation could be divided into four categories which were project approval evaluation, implementation evaluation, acceptance evaluation and tracking evaluation , according to the project type and the type of the performance evaluation, seting up index respectively and adopting the method of expert opinion to determine index weight [4]. Peng Guofu set performance indicators of science and technology enterprise management to the R&D public spending of GDP propotion and patent applications; management cost index was a total of four settings according to the internal and external cost; Internal management index was were set up eight according to the industrious and honest, administrative efficiency, human resources conditions. At the same time, he also detected the bove indicators for validity and reliability to ensure the scientific nature and feasibility of indicators [5]. Brown designed a theoretical framework for scientific research evaluation of R&D laboratory. He thought that an effective system for performance evaluation of science and technology activities should have the following five characteristics: both internal and external evaluation, the evaluation of results and output rather than behavior, focus on evaluation of valuable output, a simple and objective evaluation system, distinguish between the research evaluation and development evaluation [6]. Brignall put forward a framework composed of six dimensions of results and the dominant factors. Including evaluating the results of the strategic business unit dimension, that is to measure the competitiveness and financial measures; which is used to evaluate strategic success dominant factor dimension, which is service quality measurement, flexibility, resource utilization measure and innovation measure [7]. Nixon believed that the performance evaluation of science and technology activities oriented by strategy is the most effective, according to the different emphasis on evaluation stage, the early and middle stage respectively focusing on the qualitative and quantitative strategic performance evaluation, design of indexes should be simple and reflect the views, innovation and the critical success factors of stakeholders, and also balance the principle between of financial and non-financial evaluation [8]. BowonKim and Neungshik put forward a more behavior of science and technology project evaluation method, they broke through the traditional method to evaluate science and technology project by the government, from the perspective of project implementation executing subject of science and technology, using top-down evaluation which meant performing evaluation of project personnel by the project director; using bottom-top evaluation which meant performing evaluation the of project director by project personnel to measure the project Performance. Sivathanu put forward a kind of investment in science and technology project evaluation method based on whole life cycle, the model he designed only used a formula in which covered the key factors in each stage of the project life cycle , in order to evaluate the efficiency of investment in science and technology at any time in the project life cycle [10].

This paper starts from the defect of the standard AHP evaluation model and puts forward an evaluation model of science and technology project based on group-decision vector optimization of AHP algorithm and its experimental simulation verifies the validity of the improvement strategy.

2. Evaluation mode based on multi-stage AHP algorithm

Analytic hierarchy process (AHP) is a kind of quantitative and qualitative analysis of multiple criteria decision-making method, it decomposes related elements of decision problems into target, criterion and plan level, and with a certain scale to male a person's subjective judgment objective and quantitative, AHP is a widely used method to determine the weight [10]. Fuzzy comprehensive evaluation is based on fuzzy mathematics, the application of the principle of fuzzy synthesis to make the unclear boundary and difficult quantitative factors quantitative, a kind of comprehensive evaluation method on the membership grade status of evaluated objects from multiple factors

In consideration of the advantages and disadvantages of the single evaluation method, this paper put forward the AHP multilevel comprehensive evaluation method with existing integrated use, to improve the reliability of evaluation results. This method is mainly embodied in dividing evaluation index system into hierarchical structural, using AHP method to determine the weight of each index and then giving hierarchical comprehensive evaluation, the evaluation result is integrated out of the total. Here is the specific step of secondary AHP comprehensive evaluation method:

(1) Factors set building

Factors set denoted by U means the set of various factors affecting evaluation result: $U=\{U_1,U_2,...,U_n\}$, in which U_i is a sub-factors factor, n is the number of evaluation factors, $U_i=\{u_{i1},u_{i2},...,u_{ij}\}$, in which j is the number of factors that U_i contains.

(2) Weight set building

To response the factor degree of importantance , a corresponding weight is assigned to each factor, A_i should require: $A_i\geq 0$; $\sum A_i=1$, Weight set is corresponding to the above factors are and also with a hierarchy, $A=\{A_1,A_2,...,A_n\}$ denotes the weight of each factor in U, $A_i=\{a_{i1},a_{i2},...,a_{ij}\}$, A_i denotes that U_i is the weight of each factor. It is the AHP method to determine the weight of each factor, using 1~9 scale method to judge quantification and construct judgment matrix, Calculating the weight of each level by solving matrix eigenvalue and finally checking the consistency of judgement matrix. When the ratio of consistency CI of judgment matrix and mean random consistency index is <0.1, then judgment matrix is considered to have satisfying consistency, or need adjustment.

(3) Evaluation set building

Evaluation set is the set made up of various kinds of total evaluation for evaluated objects. Using V to denote:

$V=\{v_1,v_2,...,v_n\}$, in which V_i represents the i th evaluation result and n is the total number.

(4) Evaluation matrix building

For i th index, degree of membership of each evaluation is the fuzzy set in V. $R_i=\{r_{i1},r_{i2},...,r_{ij}\}$, fuzzy comprehensive judgment matrix of each index is:

$$:\begin{pmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{pmatrix} \quad (1)$$

Firstly ensure the comprehensive judgment matrix of each sub-element set and then overall element set.

(5) Multistage comprehensive evaluation

Comprehensive judgment is respectively given to each factor set U_i. If R_i is single factor evaluation matrix, then getting 1st grade evaluation vector: $B_i = A_i \cdot R_i = (b_{i1}, b_{i2}, ..., b_{in})$, regard each U_i as a factor, getting 2nd grade evaluation vector.

$B = A \cdot R = (b_1, b_2, ..., b_n)$, if U_i contains majority of factors, U_i will be redevised and there will be higher grade evaluation model.

3. Science and technology project evaluation model based on group decision-making vector optimization of AHP algorithm

3.1 AHP algorithm based on fuzzy optimization

AHP fuzzy synthetic optimization model contains two parts: analytic hierarchy process and fuzzy synthetic evaluation. Using AHP fuzzy synthetic evaluation to determine the weight of evaluation factor, and generally according to the following steps:

(1) Approximate calculation of weight vector

Root method to calculate weight vector is to adopt geometric average of each line vector in judgment matrix, and the uniformization is done. Calculating steps are as follows:

Calculating the product of factors in each line of judgment matrix

$$M_i = \prod_{j=1}^{n} a_{ij}, i = 1, 2, 3, \cdots, n \quad (2)$$

Calculating the n root of M_i

$$\bar{M}_i = \sqrt[n]{M_i}, i = 1, 2, 3, \cdots, n \quad (3)$$

Standardizing M_i

$$M_i = \frac{\left(\prod_{j=1}^{n} a_{ij}\right)^{\frac{1}{n}}}{\sum_{k=1}^{n}\left(\prod_{j=1}^{n} a_{ij}\right)^{\frac{1}{n}}}, \ i = 1, 2, 3, \cdots, n \quad (4)$$

(2) calculation of the maximum characteristic root

For consistency check, it needs to calculate the maximum characteristic root $\lambda_{\max}$ of judgment matrix. This paper adopts the following formula to calculate the maximum characteristic root $\lambda_{\max}$.

$$\lambda_{\max} = \sum_{i=1}^{N} \frac{(Aw_i)i}{nw_i}, i = 1, 2, 3, \cdots, n \quad (5)$$

(3) Respective uniformization is done for W vector and achieve the weight vector of each compared factor in single criterion.

(4) consistency check

The basic steps of consistency check are as followings: using above formula to calculate the maximum value of judgment matrix, and then calculating the consistency index CI and consistency ratio CR of judgment matrix, checking the consistency

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad (6)$$

The higher the degree of consistency of judgment matrix, the smaller the value of CI. When $CI = 0$, judgment matrix reaches complete consistency. But in the process of establishing judging matrix, the influence of judgmental inconsistent by thought is just one reason for the consistency of judgment matrix, using proportional scale as a result to compare two factors was also the reason of deviating from the consistency of judgment matrix. Only according to the CI value to set an acceptable inconsistent standard is clearly inappropriate. In order to get a critical value of consistency check for applicable judgment matrix with different order number, you must eliminate the influence of the matrix order.

3.2 Group decision-making vector optimization of AHP algorithm

Firstly conducting problem description, for hybrid multiple attribute group decision-making problems, let $M = \{1, 2, ..., m\}$, $N = \{1, 2, ..., n\}$, $L = \{1, 2, ..., l\}$, suppose $X = \{x_1, x_2, ..., x_m\}$ as scheme set, $D = \{d_1, d_2, ..., d_l\}$ as decision set and $U = \{u_1, u_2, ..., u_n\}$ as attribute set adopted by decision maker, $w = (w_1, w_2, ..., w_n)^T$ is the known unified weight vector of attributes given by group of experts, in which $w_j \geq 0$, $j \in N$, $\sum_{j=1}^{n} w_j = 1$; $\omega = (\omega_1, \omega_2, ..., \omega_l)^T$ is the known weight vector of decision maker, in which $\omega_k \geq 0$, $k \in L$, $\sum_{k=1}^{l} \omega_k = 1$. N_1, N_2, N_3 are respective the indicative subscript set of accurate value of attributes, interval number and fuzzy language, and $N_1 \cup N_2 \cup N_3 = N$. Decision maker d_k measures scheme x_i according to attributes u_j, getting attributes value x_{ij}^k and the decision matrix $D^k = (x_{ij}^k)_{m \times n}$ of decision maker d_k, it will get l decision matrix in this way and the matrix includes accurate value of attributes, interval number and fuzzy language expression.

When the attributes value is denoted by fuzzy language, attributes value expressed by fuzzy language will be transformed into corresponding interval number. The transformed each decision matrix is $A^k = (a_{ij}^k)_{m \times n}$, the formed attributes value of original

N_1 and N_2 in each evaluation matrix keep invariant. in this way the attributes value of each decision matrix in hybrid multiple attribute group decision-making problems will only contain two types of accurate value of attributes and interval number.

Supposing J_1 and J_2 respectively the subscript set of efficiency and cost. To eliminate the influence of different physical dimensions to decision results, it needs to normalize the decision matrix. When attributes value is interval number, suppose $a_{ij}^k = [a_{ij}^{k-}, a_{ij}^{k+}]$ $, i \in M$, $j \in N_2$, in which a_{ij}^{k-} and a_{ij}^{k+} respective the left and right endpoint of the interval number.

As hybrid multiple attribute group decision-making problems of each interval attribute values given by the decision makers are not identical, attribute value around the border of each are also different, therefore this article choose the maximum right interval value under a particular attribute of all the decision makers as maximum value, and select the left minimum interval value as minimum value. To take the difference between two values as the standard, under this property all the interval numbers are underwent standardized treatment. In this paper this normalization method is called group range regularization method. Supposing interval attribute number of interval value normalization decision matrix B^k as $b_{ij}^k = [b_{ij}^{k-}, b_{ij}^{k+}]$, in which:

$$b_{ij}^{k-} = \begin{cases} \dfrac{a_{ij}^{k-} - \min\limits_k \min\limits_i a_{ij}^{k-}}{\max\limits_k \max\limits_i a_{ij}^{k+} - \min\limits_k \min\limits_i a_{ij}^{k-}}, j \in J_1 \\ \dfrac{\max\limits_k \max\limits_i a_{ij}^{k+} - a_{ij}^{k+}}{\max\limits_k \max\limits_i a_{ij}^{k+} - \min\limits_k \min\limits_i a_{ij}^{k-}}, j \in J_2 \end{cases} \quad (7)$$

$$b_{ij}^{k+} = \begin{cases} \dfrac{a_{ij}^{k+} - \min\limits_k \min\limits_i a_{ij}^{k-}}{\max\limits_k \max\limits_i a_{ij}^{k+} - \min\limits_k \min\limits_i a_{ij}^{k-}}, j \in J_1 \\ \dfrac{\max\limits_k \max\limits_i a_{ij}^{k+} - a_{ij}^{k-}}{\max\limits_k \max\limits_i a_{ij}^{k+} - \min\limits_k \min\limits_i a_{ij}^{k-}}, j \in J_2 \end{cases} \quad (8)$$

When attributes value is accurate number, if it is objective attribute values, attribute values in the expert evaluation matrix are same, so standardization is also relatively simple, normalization method of group range standardization is as follows:

$$b_{ij}'^k = \begin{cases} \dfrac{a_{ij}^k - \min\limits_i a_{ij}}{\max\limits_i a_{ij} - \min\limits_i a_{ij}}, j \in J_1 \\ \dfrac{\max\limits_i a_{ij} - a_{ij}^k}{\max\limits_i a_{ij} - \min\limits_i a_{ij}}, j \in J_2 \end{cases} \quad (9)$$

If the certainty appraisal of the experts gives the precise attribute values, each experts' data is not necessarily the same, normalization method of group range standardization is as follows:

$$b_{ij}'^k = \begin{cases} \dfrac{a_{ij}^k - \min\limits_k \min\limits_i a_{ij}^k}{\max\limits_k \max\limits_i a_{ij}^k - \min\limits_i a_{ij}^k}, j \in J_1 \\ \dfrac{\max\limits_k \max\limits_i a_{ij}^k - a_{ij}^k}{\max\limits_k \max\limits_i a_{ij}^k - \min\limits_k \min\limits_i a_{ij}^k}, j \in J_2 \end{cases} \quad (10)$$

Using formula (7), (8), (9), (10) to transform decision matrixes A^k of each decision makers into normalization decision matrix $B^k = (b_{ij}^k)_{m\times n}$, in which

$$b_{ij}^k = \begin{cases} [b_{ij}^{k-}, b_{ij}^{k+}], j \in N_2 \\ b_{ij}'^k, j \in N_1 \end{cases} \quad (11)$$

Under the condition of knowing weight ω of decision makers, adopting the simple weighted average operator to gather the information of decision makers, getting the following comprehensive decision matrix $B = (b_{ij})_{m\times n}$, in which

$$b_{ij} = \sum_{k=1}^{l} \omega_k b_{ij}^k \quad (12)$$

The calculation of interval numbers is according to rule of interval numbers calculation, $b_{ij} = [b_{ij}^-, b_{ij}^+]$ when b_{ij} is the interval number. In this way group decision-making problems will be transformed into single decision-making problems.

4. Project evaluation model based on optimized AHP algorithm

The evaluation index system table and the index of the instructions proposed preliminarily are sent to each domain experts in the form of a letter, to hire experts in a specified way, and set index series of importance and quantity per level. Generally important degree can be divided into five, five values are respectively taken 1, 2, 3, 4, 5 and the smaller ,the more important.

Suppose that there are M indexes in a certain level of proposed index system and let P domain experts review. Do statistical analysis on the concentration and dispersion degree of each index.

Define concentration degree of th the domain experts' opinion:

$$\tilde{E}_i = \frac{1}{P} \sum_{j=1}^{N} E_j n_{ij} \quad (13)$$

Dispersion degree of the domain experts' opinion can be calculated with standard deviation σ_i :

$$\sigma_i = \sqrt{\frac{1}{P} \sum_{j=1}^{N} n_{ij} (E_J - \tilde{E}_i)^2} \quad (14)$$

In the formula: N is the serious of importance degree of stated index and generally divided into five grade; E_J is the importance degree value of j th grade; n_{ij} is the number of domain experts about the importance degree between the i th index and the j

th grade. Considering the practical characteristic of science and technology project, judgment according to $\tilde{E}_i \le 3$, $\sigma_i < 0.5$, index meeting the condition enters into synthetic evaluation index system of science and technology project.

Then making use of improved AHP algorithm to transfer those complex and fuzzy interrelation of science and technology project into quantitative analysis graphics to get leaf layer index. Using group decision-making direction vector synthesis method to calculate the weight value of various indicators.

Decision-making system G consist of $S_1, S_2, ..., S_m$ has m mutual equal status of the experts, evaluating n objects $B_1, B_2, ..., B_n$ and giving their relative importance. Set evaluating score of S_i to j th evaluated target B_j as $x_{ij} \in (0,1]$, then the decision vector of S_i is :

$$x_i = (x_{i1}, x_{i2}, ..., x_{in})^T \in E^n \tag{15}$$

The larger the value of x_{ij}, the more optimal of the value of target B_j.Decision vector i of S_i not only has numerical magnitude but also direction. The value $\|x_i\|$ of x_i reflects the overall impression of the i th expert to $B_1, B_2, ..., B_n$, under the condition of the same direction, scoring of different expert may be different, some experts may be the whole on the high side, some experts may be lower overall, but is proportional to the corresponding component. In group decision, what we care is the relative importance of n evaluation objects $B_1, B_2, ..., B_n$, but the information of this kind of relative importance is expressed by the direction of decision vector, and independent on the magnitude, therefore it should eliminate the magnitude of vector before formulating gathering principle.

Considering that experts' evaluation of importance on n objects $B_1, B_2, ..., B_n$ is only related to the direction of decision vector, but independent on the magnitude of vector, making

$$a_1 = \frac{x_1}{\|x_1\|}, a_1 = \frac{x_2}{\|x_2\|}, ..., a_m = \frac{x_m}{\|x_m\|} \tag{16}$$

That means $a_1, a_2, ..., a_m$ are the corresponding unit vector of $x_1, x_2, ..., x_m$ respectively.

In group decision-making, we believe that the group can the way to achieve consistent best decision-making is to maximize the influence result of experts on the final decision. Due to

$$\begin{aligned} \|\gamma_i\|_2 &= \|a_i\| \cos\theta_i \\ &= \|a_i\| \frac{a_i a}{\|a_i\|\|a\|} \end{aligned} \tag{17}$$

Therefore, calculating the maximum of $\sum_{i=2}^{m} \|\gamma_i\|_2$

$$\sum_{i=1}^{m} a_i a \sum_{i=1}^{\|a\|=1} \|\gamma_i\|_2 = \max^{\|a\|=1} \sum_{i=1}^{m} a_i a \tag{18}$$

By the definition of inner product

$$\sum_{i=1}^{m} a_i a = \left\|\sum_{i=1}^{m} a_i\right\| \|a\| \cos\theta \tag{19}$$

As a result, getting maximum value when the angle between vector $\sum_{i=1}^{m} a_i$ and a is the minimum. At this time,

$$\sum_{i=1}^{m} a_i a = \left\|\sum_{i=1}^{m} a_i\right\| \tag{20}$$

Both sides of formula (20) with premultiplication, after simplification

$$a = \frac{\sum_{i=1}^{m} a_i}{\left\|\sum_{i=1}^{m} a_i\right\|} \tag{21}$$

The result of above decision-making is the composite vector in $x_1, x_2, ..., x_m$ direction.

5. Simulation of algorithm performance

In order to verify the effectiveness of the algorithm this paper proposed, the simulation experiment is conducted. Adopting the proposed evaluation model of science and technology project based on group decision vector optimization of AHP fuzzy evaluation method, respectively for project basis, research approach, research foundation, funding opinions, opinions and evaluation opinion, etc., and then set up evaluation matrix of science and technology project , evaluation questionnaire in a certain of 100 science and technology projects, the resulting evaluation is shown in the table below:

Table 1. Fuzzy evaluation results of scientific and technological projects

Target layer	Evaluation results	
Project Evaluation	Excellent	10%
	Good	24%
	General	58%
	Poor	8%

From Table 1, the percent of "excellent" in these 100 projects is 10%, "good" 24%, "common" 58% and "bad" 8%. Afterwards, comparing these results with those of experts, the error rate is as follows. From the instantial simulation result, the proposed AHP fuzzy evaluation method based on group decision vector optimization performed well in the application of science and technology project evaluation, fuzzy evaluation method and its accuracy is higher than standard AHP evaluation method, and more stable.

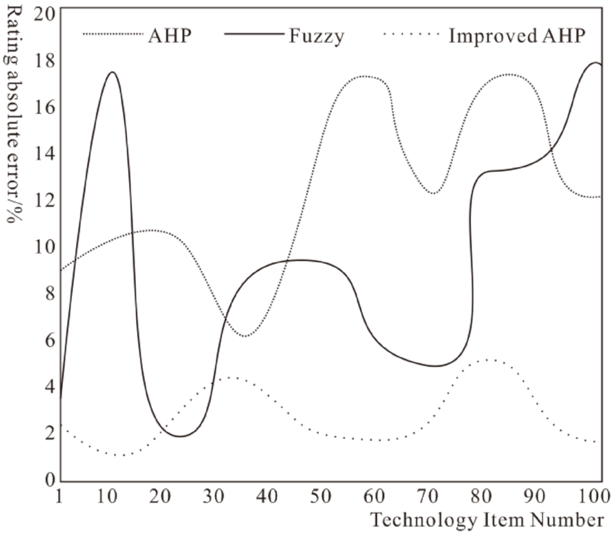

Figure 1. Comparative analysis with the results of expert

6. Conclusions

It has important theoretical and practical significance to build a scientific, reasonable and strong operable evaluation system for science and technology plan projects, so as to realize the value recognition and recognized degrees of project research, promoting the conversion of the project research results to the market and the popularization of application, achieving the potential economic and social benefits, meeting the needs of national economic and social development. Starting from the defect of the standard AHP evaluation model, this paper proposed a science and technology project evaluation model based on group decision-making vector optimization of AHP algorithm, compared with the standard algorithm and the fuzzy evaluation method, the experimental simulation results show that the proposed algorithm has better matching effect in the application of science and technology project evaluation.

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