Research on performance evaluation of scientific research staff based on entropy weight - TOPSIS method

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ABSTRACT

The aim of this study is to explore in depth the complexity of performance evaluation for university researchers and the challenges they face, especially in the current context of scientific research system reform. To ensure the fairness, rationality, and effectiveness of performance evaluation has become a common concern for universities and researchers, multiple factors need to be considered, such as total performance allocation, type and quantity of achievements, individual score, subject differences, length of service and position level, talent cultivation, new project initiation, and award level. The different combinations and weight settings of these factors will have a significant impact on the performance evaluation results. To address these issues, a mathematical model based on entropy weight method and TOPSIS comprehensive evaluation method is proposed. This model quantitatively analyzes the multidimensional indicators of researchers and comprehensively considers various factors mentioned above. Among them, the entropy weight method is used to determine the weights of each indicator, while the TOPSIS rule is used to calculate the performance scores of each researcher. The advantage of this model lies in its objectivity and impartiality, which can avoid the interference of human factors on the evaluation results. In order to verify the feasibility and effectiveness of the model, empirical research was conducted. Firstly, relevant data on research personnel from a certain university was collected, including paper publications, project applications, award status, etc. Then, the model was used to process these data and obtain the performance scores of each researcher. Finally, by comparing the results obtained from the model with the actual situation, it was found that the model has high accuracy and reliability. In addition to model validation, sensitivity analysis was also conducted on the model. By changing the parameter values in the model, the changes in the output results of the model were observed. The results indicate that the model has strong adaptability to parameter changes and can maintain stable performance in different situations. In terms of team selection and individual performance allocation, a weighted average algorithm was established to calculate with appropriate weights and obtain reasonable and fair results. The advantage of this algorithm lies in its simplicity and strong operability, which can be easily applied in practical work.

Keywords: Performance, Entropy Weighting Method, TOPSIS Comprehensive Evaluation Method, Weighted Average

1 INTRODUCTION

In the field of higher education research, performance evaluation is a key link in ensuring project quality and efficiency, and promoting the career growth of researchers. A scientific, efficient, and standardized teacher performance evaluation mechanism can accurately reflect the work effectiveness of teachers, and is a reference for teachers to improve teaching quality. Similarly, reasonable performance evaluation is conducive to encouraging and promoting researchers to engage in more innovative development, providing opportunities and rewards.

The performance evaluation plan should comprehensively consider factors such as performance fund allocation, achievement diversity, evaluation index weights, disciplinary characteristics, personnel qualifications, talent development contributions, project progress, and award impact [1]. To ensure the scientificity and practicality of the evaluation system, it is necessary to use data analysis and model construction techniques, combined with the actual scientific research of universities, to develop performance evaluation strategies that are both in line with national policies and can effectively motivate researchers[4]. The main research points include:

(1) Based on the collected data, evaluate the research achievements of 20 scientific research staff in a certain college for the year 2023, and based on these evaluation results, develop a reasonable bonus distribution plan, with a total bonus of 500000 yuan allocated.

(2) The Mathematics Department of a certain university has four research teams, each with five members, and the research results are mainly produced through team cooperation. The school's annual performance reward plan stipulates that the team ranked first can receive 35% of the total prize pool, followed by 28% for the second place, 22% for the third place, and 15% for the fourth place. The total prize pool is 1 million yuan [2]. Each team can submit a maximum of 20 achievements for review, with "horizontal funds received" considered as one achievement. According to the collected data, it is required to reasonably match the categories and quantities of results submitted by each team, and calculate the performance allocation results for each member in each team.

(3) A certain college has launched a performance evaluation plan, focusing on the horizontal transfer of funds for the project. The calculation formula for individual annual total performance is: P=(annual individual received funds/allocation of funds based on individual professional titles) x individual performance base+(annual individual achievement score/total scientific and technological achievement score) x total achievement bonus [3]. The funding amount and achievement score can be allocated to members in the same group, with a total achievement bonus of 100000 yuan. Request a suitable performance allocation plan to ensure the optimal overall performance of the target team, while balancing internal balance and fairness.

2 MATHEMATICAL MODEL

2.1 Model assumptions

The model assumes that the complexity of the actual situation is taken into account in problem solving, and in order to simplify calculations, the following related assumptions are proposed:

(1) Assuming there are no factors that do not follow objective laws of development.

(2) For question two, it is assumed that team members prioritize reporting significant research achievements they have obtained.

(3) Assuming that each team does not influence each other.

(4) Assuming there are no errors in university statistical data.

(5) Assuming that team members ignore the impact of research achievements other than those already displayed.

2.2 Model building

2.2.1 Model of Bonus Distribution Scheme

For the study of evaluating the 2023 scientific research achievement reward scores of 20 scientific research employees, it is necessary to divide the weights of various achievement indicators in order to calculate the scores and obtain rankings. Considering the hierarchical nature of different professional titles, the recipients of individual achievements have special characteristics. For example, the recipients of new batch of national level projects are concentrated in intermediate and senior professional titles, and no research staff with junior professional titles have been awarded [4]. Therefore, the research staff with four types of professional titles are first divided into four groups, namely the junior group, intermediate group, deputy high group, and senior high group. Next, divide the 500000 yuan performance bonus into four groups in proportions of 40%, 30%, 20%, and 10%, and then use the entropy weight TOPSIS model to calculate the ranking scores of each group. Finally, distribute the bonus based on the ranking scores.

This problem is solved using the entropy weight TOPSIS method, and its basic steps are as follows:

(1) Standardize the evaluation indicators

If there is a research objective with m evaluation objects and n evaluation indicators, it can be called the *j*th evaluation indicator under the *i*th evaluation object, $\{x_{ij}\}_{m\times n}$ is called the initial decision matrix. Then, the indicators are standardized to eliminate the differences caused by different dimensions between the indicators [5]. The standardized matrix is $Y=\{y_{ij}\}_{m\times n}$, and the calculation method is as follows:

$$y_{ij}=\frac{x_{ij}-min(x_j)}{max(x_j)-min(x_j)} \tag{1}$$

(2) Calculation of weights for evaluation indicators

Determine the proportion of the i^{th}plan in the j^{th} indicator

$$p_{ij}=\frac{x_{ij}}{\sum_{i=1}^{m}x_{ij}} \tag{2}$$

Calculate the entropy value for the *j*th indicator

$$e_j=-\frac{1}{lnm}\sum_{i=1}^{m}p_{ij}\,lnp_{ij} \tag{3}$$

Calculation of weight for the *j*th indicator

$$w_j=\frac{1-e_j}{\sum_{j=1}^{n}1-e_j},j=1,2,\dots,m \tag{4}$$

(3) Implementing weighted normalization of decision matrices

Multiply the standardized matrix $Y=\{y_{ij}\}_{m\times n}$ by the weight of the corresponding indicator of the vector to further obtain the weighted normalized decision matrix $Z=\{z_{ij}\}_{m\times n}$.

(4) Calculate the implementation of positive and negative ideal solutions for the evaluation object

After the construction of the weighted normalization matrix is completed, it is necessary to calculate the positive and negative ideal solutions of the benefit index and cost index. The maximum value in the positive indicator and the minimum value in the negative indicator form a positive ideal solution, while the minimum value in the positive indicator and the maximum value in the negative indicator form a negative ideal solution [6]. Positive ideal solutions can be represented as Z_j^+, and negative ideal solutions can be represented as, Z_j^- as shown in equations (5) and (6).

$$Z_j^+=\begin{cases}max_i z_{ij}\ ,j\ is\ Benefit\ based\ indicators\\ min_i z_{ij}\ ,j\ is\ Benefit\ based\ indicators\end{cases} \tag{5}$$

$$Z_j^- = \begin{cases} min_i z_{ij} \text{ , } j \text{ is Benefit based indicators} \\ max_i z_{ij} \text{ , } j \text{ is Benefit based indicators} \end{cases} \quad (6)$$

If indicator j is determined to be a benefit indicator, then the positive ideal solution is the maximum value. If indicator j is determined to be a cost indicator, then the negative ideal solution is the minimum value.

(5) Determine Euclidean distance

Calculate the Euclidean distance from positive and negative ideal solutions for each evaluation object, as shown in equations (7) and (8):

$$D_i^+ = \sqrt{\sum_{j=1}^{n}(z_{ij} - Z_j^+)^2} \quad (7)$$

$$D_i^- = \sqrt{\sum_{j=1}^{n}(z_{ij} - Z_j^-)^2} \quad (8)$$

(6) Calculate relative closeness

Calculate the relative closeness of the optimal and worst solutions for each evaluation object, as shown in equation (9):

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-} \quad (9)$$

Sort the evaluation objects in order based on the calculated relative progress indicator C_i. If the value of C_i is larger, it indicates that the evaluation object is closest to the optimal solution and farthest from the worst solution, indicating a relatively good evaluation object. Conversely, if the value C_i is smaller, it indicates that the evaluation object is farthest from the optimal solution and closest to the worst solution, indicating a relatively poor evaluation object.

2.2.2 Model of Performance Allocation

The allocation of performance rewards is based on the total score of the team, with the first ranked team receiving 35% of the total prize pool, the second ranked team receiving 28%, the third ranked team receiving 22%, and the fourth ranked team receiving 15%. The total prize pool is 1 million yuan. Each team can submit a maximum of 20 achievements for review, with "horizontal funds received" considered as one achievement [7]. In order to reasonably match the categories and quantities of submitted results, and calculate the performance allocation results for each member in each team, our team has set the following scoring rules:

(1) Team research achievement upload: Each member must upload four research achievements, and each member can only upload up to two research achievements of the same category.

(2) Team Overall Performance Evaluation: Each team consists of five individuals who upload a total of 20 scientific research achievements, which are then weighted and averaged to obtain the team's score and determine the team's ranking. According to the model assumption, team members default to uploading the research results with the highest proportion and weight. Personal performance evaluation: Weighted average processing is performed based on the scientific research projects uploaded by each member, and then divided by the total score of the team to determine individual performance.

(3) Each member of the team must report four research achievements, partly because the questions limit the number of team uploads, and team members with too many research achievements can only selectively select representative works. On the other hand, team members have different abilities and positions, and their research results are not uniform. It is relatively fair for each person to upload their own research results.

(4) In response to the restriction that only two works of the same type can be uploaded, we believe that some people have achieved a lot of results in one type of research while others have

less. In order to encourage researchers to learn more and broaden their horizons, we have adopted this method.

For the determination of the weight of scientific research achievements, our team determines the weight of each achievement type based on the influence, difficulty, and expert evaluation and historical data of scientific research achievements, as shown in Table 1.

Table 1: Weighted Table of Sixteen Scientific Research Achievements

Item	Description	Weight
1	Invention patent	0.25
2	National level scientific research awards	0.2
3	Provincial and ministerial level scientific research awards	0.15
4	Newly approved national level projects	0.1
5	Newly approved provincial and ministerial level projects	0.08
6	Publication of works	0.07
7	National standards/specifications	0.06
8	Provincial or industry standards/plans	0.05
9	SCI	0.04
10	EI	0.03
11	Chinese Core	0.02
12	Other intellectual property rights	0.01
13	Number of current graduate students	0.01
14	Horizontal transfer of funds/10000 yuan	0.01
15	Talent Plan	0.01
16	Academic part-time jobs	0.01

Weighted average is a statistical method used to calculate the weighted average by assigning different weights to different data points to reflect their relative importance. In the field of education, especially in the evaluation of research teams in universities, the flexibility and adaptability of WAM are crucial. It allows researchers to allocate weights based on different evaluation dimensions, ensuring that the evaluation results comprehensively reflect the team's overall strength and contribution. The calculation process of WAM is simple and intuitive, providing standardized data integration and comparison methods to support scientific and objective decision-making.

Formula expression: Weighted average=(Σ(data point value x data point weight))/$\sum$ (data point weight)

The formula for calculating the total team score is as follows:

(1) Team total score=(Σ (scientific research achievements x weight of each scientific research achievement));

(2) The formula for calculating individual performance scores and allocation amounts is as follows;

(3) Personal performance score=(Σ (research project x weight of each research achievement));

(4) Individual performance allocation amount=Individual performance score/Total team performance score.

2.2.3 Optimization Model of Bonus Distribution

It is necessary to determine the individual's annual total performance based on the formula

given in the question, and use this to calculate the team's total performance for the three teams. The title also clearly states that we need to ensure that the total performance of the target team in Annex 3 is the highest. In summary, we can first calculate the personal annual performance calculation formula (calculate the annual personal income/allocation of funds by personal professional title) x personal performance base data based on the given individual annual performance calculation formula. From this, we can first determine the gap between the target team and the other two teams, and use it as a standard to set the proportion. Therefore, the weight of each research indicator and the score of each member can be calculated using TOPSIS based on entropy weight method to set the relevant proportion. Calculate (annual individual achievement score/total scientific and technological achievement score) x total achievement bonus to achieve the optimal annual total performance of the target team.

For the 7 scientific research indicators given in Annex 3, the more scientific research data provided during the performance evaluation process, the more performance can be given. Therefore, each team can judge that the quantity given for each indicator is as large as possible, which is considered extremely large. For data processing, only standardization is required, without the need for forward processing.

For this question, after data analysis and understanding, it is recommended to use the Topsis method based on entropy weight method. TOPSIS method is a commonly used intra group comprehensive evaluation method that can fully utilize the information of raw data, and its results can accurately reflect the differences between evaluation schemes. The basic process is based on the normalized raw data matrix, using the cosine method to find the optimal and worst quality solutions among the limited options, and then calculating the distance between each evaluation object and the optimal and worst solutions separately. So as to obtain the relative closeness of each evaluation object to the optimal solution, which serves as the basis for the superiority or inferiority of the solution.

The calculated information entropy and weight values are shown in Table 2:

Table 2: Weights and Information Entropy of Scientific Research Indicators

Scientific research indicators	SCI	EI	Core papers	General papers	Invention patents	Other patent	C
Weight	0.10469	0.15334	0.14549	0.16302	0.15334	0.12247	0.15765
Information entropy	0.493	0.258	0.295	0.209	0.258	0.407	0.237

The weights of scientific research indicators are shown in Figure 1. The importance of each indicator can be clearly and intuitively compared. The entropy weight method gives lower weights for SCI and other patents, while the weight differences for other scientific research indicators are relatively small.

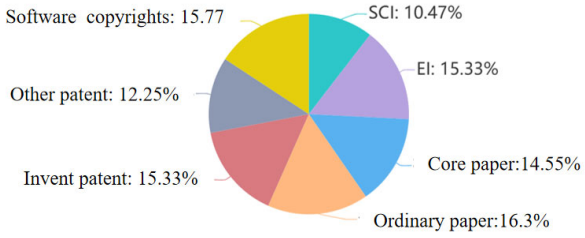

Fig.1: Research indicator weight pie chart

3 MODEL ANALYSIS

3.1 Solution of bonus distribution scheme

Using the entropy weight method, calculate the weights of each achievement in the four groups. The types and weights of achievements in each group are different, and use this weight to calculate the ranking of scores for each research position employee. The ranking results of the primary group scores are shown in Table 3.

Number Positive Ideal Solution Distance (D+) Negative Ideal Solution Distance (D--) Comprehensive Score Index Sorting

Table 3: Ranking of Primary Group Scores

Item	Positive Ideal Solution Distance (D+)	Negative Ideal Solution Distance (D -)	Comprehensive Score Index	Sorting
20	0.46905686	0.75680113	0.61736444	1
16	0.77434641	0.51278835	0.39839523	2
4	0.83611786	0.48033788	0.36487203	3
12	0.84923745	0.42147451	0.33168375	4
8	0.86534171	0.28637223	0.24864875	5

The junior group bonus accounts for 10% of the total bonus, which is 50000 yuan. According to the proportion of comprehensive scores to the total group scores, the bonuses received by the junior group's various research positions are calculated as shown in Table 4.

Table 4: Bonus for employees in various scientific research positions in the junior group

Item	20	16	4	12	8
Received bonus (yuan)	15816	10204	9184	8418	6378

The ranking results of intermediate group scores are shown in Table 5.

Table 5: Ranking of Intermediate Group Scores

Item	Positive Ideal Solution Distance (D+)	Negative Ideal Solution Distance (D -)	Comprehensive Score Index	Sorting
15	0.72801706	0.67289617	0.4803268	1
3	0.68632509	0.60586395	0.46886634	2
11	0.7876438	0.60121804	0.43288542	3
7	0.81457145	0.56419789	0.40920397	4
19	0.80005869	0.52051465	0.39415808	5

The intermediate group bonus accounts for 20% of the total bonus, which is 100000 yuan. According to the proportion of comprehensive scores to the total group scores, the bonuses received by the intermediate group's various research positions are calculated as shown in Table 6.

Table 6: Bonus for employees in various scientific research positions in the intermediate group

Item	15	3	11	7	19
Received bonus (yuan)	22018	21560	19725	18807	17890

The ranking results of the sub high group scores are shown in Table 7.

Table 7: Ranking Table of Scores for Deputy High Team

Item	Positive Ideal Solution Distance (D+)	Negative Ideal Solution Distance (D -)	Comprehensive Score Index	Sorting
10	0.54297059	0.78234824	0.59030946	1
14	0.79748166	0.55296157	0.40946673	2
18	0.82454186	0.53404398	0.39308814	3
2	0.79789889	0.50746514	0.38875373	4
6	0.9342647	0.27560027	0.22779424	5

The bonus for the vice high team accounts for 30% of the total bonus, which is 150000 yuan. According to the proportion of comprehensive scores to the total group scores, the bonus received by the staff in each research position of the vice high group is calculated as shown in Table 8.

Table 8: Bonus for employees in various research positions of the deputy senior team

Item	10	14	18	2	6
Received bonus (yuan)	44555	30446	28960	28960	17079

The ranking results of the positive high group scores are shown in Table 9.

Table 9: Ranking of Scores for Positive and High Groups

Item	Positive Ideal Solution Distance (D+)	Negative Ideal Solution Distance (D -)	Comprehensive Score Index	Sorting
1	0.52571494	0.75610206	0.5898674	1
5	0.67548627	0.59666708	0.46902135	2
9	0.75877922	0.61163775	0.44631507	3
13	0.73630504	0.54572202	0.42567122	4
17	0.78715607	0.51000353	0.39316945	5

The bonus for the senior group accounts for 40% of the total bonus, which is 200000 yuan. According to the proportion of comprehensive scores to the total group scores, the bonus received by the staff in each research position of the vice high group is calculated as shown in Table 10.

Table 10: Bonus for employees in various scientific research positions of the senior group

Item	1	5	9	13	17
Received bonus (yuan)	50644	40343	38627	36910	33476

3.2 Solution of performance allocation

After calculation, we have obtained the scores and rankings of the four teams, as shown in Table 11.

Table 11: Team Achievement Table

Ranking	Team Code	Total Score
1	A	2.22
2	B	2.19
3	C	2.1
4	D	1.94

The team performance score is shown in Fig.2, which shows that Team A ranks first, Team B ranks second, Team C ranks third, and Team D ranks fourth. The score difference among the

first three teams is not significant, all above 2 points, with a significant difference between the third and fourth places.

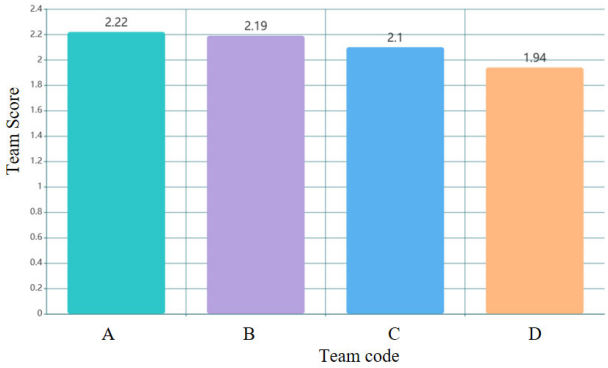

Fig.2: Team Achievement Chart

3.3 Analysis of optimization model for bonus distribution

The final performance calculation begins. Firstly, according to the first half of the calculation formula given in the question (calculating annual personal incoming funds/allocating funds based on individual professional titles) * individual performance base, it can be seen that the score of the target team is 6, the score of the second team is 12.75, and the score of the third team is 4.55. It can be seen that the main competitor of the target team is the second team. From Attachment 3, it is not difficult to see that the research achievements presented by the third team are relatively small compared to the first two teams. In the subsequent performance calculation process, the main comparison is between the target team and the first team.

In order to achieve the goal of achieving optimal team performance as required in the question, first select the individual achievement score evaluation indicator in the second part of the performance formula (annual individual achievement score/total scientific and technological achievement score) * total achievement bonus amount.

According to the analysis in Fig.1, a proportion can be set for each research project. The annual individual achievement score can be calculated using the number of research projects owned by each person multiplied by the corresponding research performance ratio, and the accumulated score will be recorded as the individual's final score. Then, the scores of all scientific and technological achievements are calculated based on the total scores obtained by all team members, and finally substituted into the formula to calculate the final score for evaluation. The proportions that can be set based on the pie chart are shown in Table 12.

Table 12: Calculation proportion of performance research indicators set

Scientific research indicators	SCI	EI	Core papers	General papers	Invention patents	other patent	software copyrights
Calculate proportion	5%	20%	15%	25%	25%	5%	5%

According to Table 12, the second part of the calculation results obtained by this type of calculation method are all 10 points. In order to achieve the best performance evaluation of the target team, only the data in the lower part of the calculation formula can be limited.

By analyzing Attachment 3, it can be concluded that the personnel in each team are not consistent. Compared to Team 1, the target team consists of one junior member, while Team 1

does not. In this way, restrictions can be set on this item, with a limit ratio of q for calculating scores, which means that team members with different professional titles need to be calculated proportionally when calculating annual personal achievement scores. The proportion given here is shown in Table 13.

Table 13: Calculation Ratio for Vocational High Schools

Title	Senior	Vice Senior	Intermediate	Junior
Limit ratio for calculating scores q	10%	10%	60%	20%

Based on this, it can be concluded that the final performance calculation formula under the prescribed performance evaluation scheme is:

$$P = \frac{Annual\ personal\ funds\ received}{Allocation\ of\ funds\ according\ to\ individual\ titles} \times Individual\ performance\ base \times q + \frac{Annual\ individual\ outcome\ score}{Score\ of\ all\ scientific\ and\ technological\ achievements} \times Total\ bonus \quad (10)$$

Based on the above equation, the scores obtained using the prescribed performance calculation plan are as follows: (1) Target team score: 1.35; (2) Other team 1 score: 1.2375; (3) Other team 2 scored 0.87. At this point, the plan that can achieve the best performance evaluation for the target team has been obtained.

4 CONCLUSION

The TOPSIS method based on entropy weight method can first calculate the entropy value of each indicator using entropy weight method to determine the weight. Some conclusions could be obtained as follows.

(1) Based on the idea of information entropy, it can objectively reflect the differences and importance of different indicators, and the calculation results are relatively accurate;

(2) The Analysis result could not be influenced by subjective factors, in this question, the main focus is to determine one of the central issues of performance evaluation indicators, which requires the use of objectivity to ensure rationality and impartiality, which could be able to the interrelationships between multiple factors and take into account the correlation and interaction between different indicators;

(3) For the weighted average method used in problem two, the performance allocation result for each member is calculated, and the advantage of weighted average is that it can process data more reasonably, improve the accuracy and reliability of analysis results, and have strong flexibility and adaptability, suitable for various different application scenarios.

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REFERENCES

[1] Lu, M. H. (2024). Research on teacher performance appraisal based on fuzzy comprehensive evaluation model. Heilongjiang Science, 15(01), 59-61

[2] Hu, H. Y. (2024). Exploration of budget performance management practice in scientific research institutions. Accounting Learning, 2024(02), 71-73.

[3] Jiang, X. Y. (2023). Research on performance evaluation of research funds in universities under the background of "double first class" [Doctoral dissertation, Changzhou University].
[4] Meng, Y. G., & Cai, Y. (2024). Research on countermeasures for strengthening and improving the overall expenditure performance evaluation index system of scientific research institutions. Finance & Accounting for Transport, 2024(03), 42-46.
[5] Wang, F. (2016). The application of arithmetic mean and weighted mean in score evaluation. Teacher, 2016(16), 95.
[6] Chen, D., Chen, W., & Wen, Y. L. (2023). A study on the performance evaluation of industry education integration in Hubei vocational colleges by combining entropy method and CRITIC method for weighting. Journal of Guangxi Vocational and Technical College, 16(05), 89-98.
[7] Xu, Y. (2023). Analysis of financial performance of listed companies in the air transport industry based on entropy weight-TOPSIS model. Logistics Sci-Tech, 46(16), 110-113.