A Scientific and Research Performance Evaluation model of Institutes of Higher Learning Based on Multilevel Fuzzy Comprehensive Decision Analysis

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Abstract

Scientific and research performance is an important part of the evaluation on the overall strength and the ability to achieve sustainable development of institutes of higher learning. With the purpose to deal with the multi-attribute, multilevel and fuzziness, this paper constructs a scientific and research performance evaluation system for institutes of higher learning and proposes an evaluation model based on multilevel fuzzy comprehensive decision analysis. After indicators are standardized, we can get the fuzzy nearness by fuzzy comprehensive decision analysis and Analytical Hierarchy Process for evaluating various schemes. It provides support for the analysis of teaching ability, research ability and the sustainable development of institutes of higher learning.

Keywords: Higher school; scientific and research; fuzzy decision analysis; performance evaluation; model

1 Introduction

Teaching ability and research ability are two integral part of the sustainable development of institutes of higher learning. High teaching ability has much to do with training hi-tech talents, establishing talent pool and sustainable talent seeking, which are the fundamental purposes of institutes of higher learning. High research ability reflects the ability to do scientific research, scientific exploration and technological application. Therefore, it is significant to do scientific and research performance evaluation on institutes of higher learning [1-3]. Given that it is a complicated process, many factors need to be taken into consideration. Many researchers have studied scientific and research performance evaluation and proposed relevant methods with fruitful results [4-8]. However, current evaluation methods are more of analysing sections in the process of implementation and lack the wholeness. Fuzzy information also brings about some limits. Therefore, based on previous researches, this paper intends to study scientific and research performance evaluation for institutes of higher learning by comprehensive fuzzy decision analysis [9-10] and AHP [11-12].

2 Scientific and Research Performance Evaluation System for Institutes of Higher Learning

It is a complicated process to construct scientific and research performance evaluation system. The selection of indicators should comply with the scientific principle, criticality, completeness and objectivity. The weight and data should be reasonable and accurate. The evaluation system is divided into three layers, namely, target layer, criterion layer and indicator layer, as is shown in Table 1.

TABLE 1 Scientific and scientific and research performance evaluation system for institutes of higher learning

Target layer	Criterion layer	Target layer
institutes of higher learning scientific and research performance evaluation system **U**	Teaching ability u_1	Ratio of full-time teachers to students u_{11}
		Proportion of professional teachers u_{12}
		Number of competitive classes u_{13}
		Professional knowledge degree of teaching content u_{14}
		Advanced level of teaching method u_{15}
		Software and hardware u_{16}
	Research ability u_2	The number of senior number reserve u_{21}
		The number of papers issued u_{22}
		The number of patent u_{23}
		Key laboratory above provincial level u_{24}
		The number of research project above provincial level u_{25}
		The number of award above provincial level u_{26}
	Talent training ability u_3	Graduation rate u_{31}
		Unqualified rate u_{32}
		The number of award of students above provincial level u_{33}
		Student's innovation ability u_{34}
		Student's learning ability u_{35}
	Comprehensive service u_4	Turning rate of scientific research u_{41}
		Social satisfaction on student u_{42}
		Scientific service ability u_{43}
		The number of identification of scientific and technological achievements u_{44}
	Potential for development u_5	Teaching input u_{51}
		Scientific input u_{52}
		Overall management quality u_{53}
		Social awareness u_{54}

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3 Scientific and Research Performance Evaluation System for Institutes of Higher Learning Based on Multilevel Fuzzy Comprehensive Decision Analysis

3.1 INDICATOR SET AND SCHEME SET OF MULTILEVEL SCIENTIFIC AND RESEARCH PERFORMANCE EVALUATION

The evaluation system is the set of all indicators. It has hierarchy. The criterion layer is the first-class layer of indicators:

$$U=(u_1,u_2,u_3,u_4,u_5). \tag{1}$$

Under each criterion layer, there is the second-class indicator set,

$$u_{ij}=(u_{i1},u_{i2},\cdots,u_{is}), \tag{2}$$

i is the NO. of the criterion layer u_{ij}. s is the number of indicators under the criterion layer i and there are $1\le i\le 5$, $1\le s\le 5$.

Suppose there are m institutes of higher learning for evaluation, the scheme set is:

$$C=(C_1,\cdots,C_k,\cdots,C_m) \tag{3}$$

Each evaluation scheme C_k contains the indicator set of two layers.

3.2 WEIGHT ALLOCATION OF INDICATORS IN SCIENTIFIC AND RESEARCH PERFORMANCE EVALUATION

AHP can ensure the weight is allocated objectively, reliably and reasonably. This paper uses 1-9 ratio scale to measure the weighed allocation matrix $\boldsymbol{P}$:

$$\boldsymbol{P}=\begin{vmatrix} p_{11} & \cdots & p_{1i} & \cdots & p_{1n} \\ \vdots & \cdots & \vdots & \cdots & \vdots \\ p_{i1} & \cdots & p_{ii} & \cdots & p_{in} \\ \vdots & \cdots & \vdots & \cdots & \vdots \\ p_{n1} & \cdots & p_{ni} & \cdots & p_{nn} \end{vmatrix}_{n\times n}. \tag{4}$$

In the expression, p_{ij} is the ratio scale value of indicators. There are

$1\le p_{ij}=\dfrac{1}{p_{ji}}\le 9$, $1\le p_{ij}=\dfrac{1}{p_{ji}}\le 9$.

The weighed consistency indicator R_{CI} and the consistency rate R_{CR} are:

$$\begin{cases} R_{CI}=\dfrac{\max\limits_{1\le t\le q_\lambda}(\lambda_t(\boldsymbol{P}))-n}{n-1} \\ R_{CR}=\dfrac{R_{CI}}{R_{RI}} \end{cases}. \tag{5}$$

In the expression, $\lambda_t(\boldsymbol{P})$ refers to the characteristic value of indicator weight-allocation matrix $\boldsymbol{P}$. R_{RI} refers to random consistency indicator.

Under consistency requirement, the weight w_i of indicator i is:

$$w_i=\frac{\sum_{j=1}^{n}p_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n}p_{ij}}. \tag{6}$$

3.3 STANDARDIZATION OF SCIENTIFIC AND RESEARCH PERFORMANCE EVALUATION

It is clear that there are two types of indicators, quantitative and qualitative. They have different scales. Some are large and some are small. Therefore, they need to be subject to standardization to get unified indicators.

For quantitative indicators, we use fuzzy membership degree to describe them, as in Table 2.

TABLE 2 Value of indicators based on membership degree

Fuzzy membership degree	Explanation	
	Large indicators	*Small indicators*
1.0	Completely compliance	Not compliance
0.8	Fairly compliance	Poorly compliance
0.6	Compliance	Basically compliance
0.4	Basically compliance	Compliance
0.2	Poorly compliance	Fairly compliance
0	Not compliance	Completely compliance
0.9,0.7,0.5,0.3, 0.1	In between	In between

For quantitative indicators, suppose the i-th scheme about indicator j is $u_{ij}=[u_{ij}^L,u_{ij}^R], u_{ij}^L\le u_{ij}^R$ and if it is a large indictor, the standardized indicator v_{ij} is:

$$v_{ij}=[v_{ij}^L,v_{ij}^R]=\left[\frac{u_{ij}^L-\min\limits_{1\le i\le m}(u_{ij}^L)}{\|\Delta_{u_{ij}}\|_{max}},\frac{u_{ij}^R-\min\limits_{1\le i\le m}(u_{ij}^L)}{\|\Delta_{u_{ij}}\|_{max}}\right], \tag{7}$$

$\|\Delta_{u_{ij}}\|_{max}$ is the maximum norm in the fuzzy interval, there is: $\|\Delta_{u_{ij}}\|_{max}=\max\limits_{1\le i\le m}(u_{ij}^R)-\min\limits_{1\le i\le m}(u_{ij}^L)$. (8)

If it is a small indictor, the standardized indicator v_{ij} is:

$$v_{ij}=\left[v_{ij}^{L},v_{ij}^{R}\right]=\left[\frac{\max\limits_{1\le i\le m}\left(u_{ij}^{R}\right)-u_{ij}^{L}}{\left\|\Delta_{u_{ij}}\right\|_{max}},\frac{\max\limits_{1\le i\le m}\left(u_{ij}^{R}\right)-u_{ij}^{R}}{\left\|\Delta_{u_{ij}}\right\|_{max}}\right]. \qquad (9)$$

3.4 FUZZY CLEARNESS OF INDICATORS IN SCIENTIFIC AND RESEARCH PERFORMANCE EVALUATION

After standardization, indicators are unified. Suppose there are *m* institutes of higher learning for scientific and research performance evaluation. The i-th scheme about indicator *j* is $v_{ij}=\left[v_{ij}^{L},v_{ij}^{R}\right]$, and fits $0\le v_{ij}^{L}\le v_{ij}^{R}\le 1$, then the maximum fuzzy indicator field $v_{\Delta j}$ of indicator *j* is:

$$v_{\Delta j}=\left[v_{\Delta j}^{L},v_{\Delta j}^{R}\right]=\left[\max_{1\le i\le m}\left(v_{ij}^{L}\right),\max_{1\le i\le m}\left(v_{ij}^{R}\right)\right]. \qquad (10)$$

Similarly, the minimum fuzzy indicator field $v_{\Delta j}$ of indicator *j* is:

$$v_{\nabla j}=\left[v_{\nabla j}^{L},v_{\nabla j}^{R}\right]=\left[\min_{1\le i\le m}\left(v_{ij}^{L}\right),\min_{1\le i\le m}\left(v_{ij}^{R}\right)\right]. \qquad (11)$$

The fuzzy clearness τ_{ij}^{Δ} between the i-th scheme and the j-th maximum fuzzy indicator field $v_{\Delta j}$ about indicator j is:

$$\tau_{ij}^{\Delta}=\sqrt[p]{\frac{\left|\max\limits_{1\le i\le m}\left(v_{ij}^{L}\right)-v_{ij}^{L}\right|^{T}+\left|\max\limits_{1\le i\le m}\left(v_{ij}^{R}\right)-v_{ij}^{R}\right|^{T}}{2}}. \qquad (12)$$

The weighed fuzzy clearness ρ_{i}^{Δ} between the i-th scheme and the j-th maximum fuzzy indicator field $v_{\Delta j}$ about indicator j is:

$$\rho_{i}^{\Delta}=\sum_{j=1}^{n}\left(w_{j}*\tau_{ij}^{\Delta}\right). \qquad (13)$$

Similarly, the fuzzy clearness τ_{ij}^{Δ} between the i-th scheme and the j-th minimum fuzzy indicator field $v_{\Delta j}$ about indicator j is:

$$\tau_{ij}^{\nabla}=\sqrt[p]{\frac{\left|\min\limits_{1\le i\le m}\left(v_{ij}^{R}\right)-v_{ij}^{L}\right|^{T}+\left|\min\limits_{1\le i\le m}\left(v_{ij}^{L}\right)-v_{ij}^{R}\right|^{T}}{2}}. \qquad (14)$$

The weighed fuzzy clearness τ_{ij}^{∇} between the i-th scheme and the j-th maximum fuzzy indicator field $v_{\Delta j}$ about indicator *j* is:

$$\rho_{i}^{\nabla}=\sum_{j=1}^{n}\left(w_{j}*\tau_{ij}^{\nabla}\right). \qquad (15)$$

The comprehensive fuzzy nearness for the i-th scheme is expressed as:

$$\rho_{i}=1/\left(1+\left(\left|\frac{\rho_{i}^{\Delta}}{\rho_{i}^{\nabla}}\right|\right)^{2}\right). \qquad (16)$$

3.5 MULTILEVEL FUZZY COMPREHENSIVE EVALUATION

Based on the optimization principle of fuzzy clearness, if there is:

$$\rho_{max}=max\left(\rho_{1},\cdots,\rho_{i},\cdots,\rho_{m}\right)=\rho_{k}, \qquad (17)$$

where *k* is the optimal scheme in scientific and research performance evaluation, indicating that k-th scheme has the best teaching ability and research ability among institutes of higher learning.

The specific steps of evaluation are as follows:

Step 1: Select evaluation indicators according to relevant principles and construct the evaluation system.

Step 2: Standardize different qualitative indicators as Table 2, and subject quantitative indicators to expression (7) to (9);

Step 3: Select the first-class indicator set and the second-class indicator set based on (1) to (3) and acquire the scheme set of scientific and research performance evaluation of institutes of higher learning;

Step 4: Allocate weight to indicators according to expression (4) to (6);

Step 5: Standardize indicators according to (10) to (11);

Step 6: Acquire the evaluation scheme and the fuzzy nearness of the minimum fuzzy indicator field about different indicators;

Step 7: Acquire weighed fuzzy nearness according to (13) to (15) and get the comprehensive fuzzy nearness through (16);

Step 8: Get the optimal scheme based on comprehensive fuzzy nearness.

4 Case Studies and Test

This paper takes scientific and research performance evaluation of key institutes of higher learning in a province as an example. Based on the indicator system, we can get the value of a quantity of indicators, as shown in Table 3.

TABLE 3 Value of a quantity of indicators of scientific and research performance evaluation

Criterion layer	Weight	Indicators	weight	Value of a quantity of indicators		
				Institute A	Institute B	Institute C
Teaching ability u_1	0.286	Ratio of full-time teachers to students u_{11}	0.25	12	12	16
		Proportion of professional teachers u_{12}	0.12	0.42	0.51	0.46
		Number of competitive classes u_{13}	0.15	53	62	46
		Professional knowledge degree of teaching content u_{14}	0.10	0.80-0.85	0.80-0.85	0.85-0.90
		Advanced level of teaching method u_{15}	0.18	0.80-0.85	0.85-0.90	0.80-0.85
		Software and hardware u_{16}	0.20	0.90-0.95	0.85-0.90	0.85-0.90
Research ability u_2	0.247	The number of senior number reserve u_{21}	0.16	135	182	167
		The number of papers issued u_{22}	0.13	2028	1986	2476
		The number of patent u_{23}	0.10	362	419	275
		Key laboratory above provincial level u_{24}	0.23	18	26	18
		The number of research project above provincial level u_{25}	0.15	235	271	184
		The number of award above provincial level u_{26}	0.23	13	10	8
Talent training ability u_3	0.163	Graduation rate u_{31}	0.20	0.925	0.937	0.956
		Unqualified rate u_{32}	0.23	0.03	0.05	0.02
		The number of award of students above provincial level u_{33}	0.25	22	19	15
		Student's innovation ability u_{34}	0.16	0.80-0.85	0.85-0.90	0.80-0.85
		Student's learning ability u_{35}	0.16	0.85-0.90	0.80-0.85	0.80-0.85
Comprehensive service u_4	0.208	Turning rate of scientific research u_{41}	0.30	0.26	0.38	0.32
		Social satisfaction on student u_{42}	0.30	0.85-0.90	0.85-0.90	0.80-0.85
		Scientific service ability u_{43}	0.20	0.80-0.85	0.85-0.90	0.85-0.90
		The number of identification of scientific and technological achievements u_{44}	0.20	127	201	162
Potential for development u_5	0.096	Teaching input u_{51}	0.30	0.80-0.85	0.85-0.90	0.85-0.90
		Scientific input u_{52}	0.30	0.85-0.90	0.85-0.90	0.80-0.85
		Overall management quality u_{53}	0.20	0.85-0.90	0.85-0.90	0.80-0.85
		Social awareness u_{54}	0.20	0.75-0.80	0.75-0.80	0.80-0.85

Given different weight of indicators, we can get the weighed fuzzy nearness ρ_i^{Δ} and ρ_i^{∇}, as is shown in Table 4.

TABLE 4 Fuzzy nearness of indicators in scientific and research performance evaluation of institutes of higher learning

Criterion layer	Institute A		Institute B		Institute C	
	ρ_i^{Δ}	ρ_i^{Δ}	ρ_i^{Δ}	ρ_i^{Δ}	ρ_i^{Δ}	ρ_i^{Δ}
Teaching ability u_1	0.019	0.026	0.007	0.038	0.041	0.004
Research ability u_2	0.042	0.035	0.003	0.057	0.063	0.013
Talent training ability u_3	0.034	0.015	0.009	0.009	0.017	0.002
Comprehensive service u_4	0.039	0.004	0	0.041	0.023	0.019
Potential for development u_5	0.004	0.003	0.002	0.004	0.004	0.004

Through comprehensive fuzzy nearness model, we can get the comprehensive fuzzy nearness sequence of three institutes of higher learning, namely,

$$\rho=\left(\rho_A,\rho_B,\rho_C\right)=\left(0.266,0.833,0.077\right)\cdot$$

Institute B has the optimal scientific and research level followed by A and then C. Therefore, Institute B is the priority of development.

4 Conclusions

This paper constructs a scientific and research performance evaluation system for institutes of higher learning and proposes an evaluation model based on multilevel fuzzy comprehensive decision analysis. After indicators are standardized, we can get the fuzzy nearness by fuzzy comprehensive decision analysis and Analytical Hierarchy Process for evaluating various schemes to find out the optimal scheme. This model is clear and easy to calculate for computer aid design and intelligence design. Case study has proved that the model and the algorithm are effective. The evaluation method proposed by this paper provides a solution to analyze scientific and research performance evaluation of institutes of higher learning as well as a support to computer program.

Acknowledgments

This research was supported by Education Office Foundation of Guangxi with project No. 201202ZD010. It is the Automatic monitoring system of optical mark method based on PON.

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