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AHP Based Quantitative Evaluation Index System of Teacher's Research Performance in the University

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Abstract

With the advent of the information society and the big data era, the content of quantitative evaluation of teacher's research performance in the university constantly goes deeper, and the method of it further enriches as well. In this paper, our method references eight university ranking index systems as a source of information, and then adopts analytic hierarchy process(AHP) method to obtain a quantitative Evaluation Index System of Teacher's research Performance and to determine the weight of each index. As a result, A set of indicator system was established, including 1 first order indicator, 2 second order indicators as well as 27 third order indicators, among which, scientific research is considered as the first order indicator.

Keywords*: quantitative evaluation of teacher's research performance, index systems, AHP.*

1. Introduction

As one of the three basic functions of university, scientific research derived from Germany in the early 19th century. In Germany, according to the pure form of Humboldt, university teachers became researchers, and they used the latest research result in their own teaching. Moreover, their students ,whoever they will be in the future, doctors, teachers, civil servants or academicians, they must take part in scientific research activities. Therefore, teachers and students will work together to seek for truth. Because of its role as the prerequisite of higher education and as a basic function of university, scientific research is flourishing and unfalling for more than two centuries. In the past 30 years, it has become a huge industry, a key element that produces novel subject, as well as a crucial factor that is used to improve the influence of the university in university ranking. Meanwhile, because its expensive input, and its great benefit to the modern countries, so the supervision from investors is increasingly intensive. As a result, external evaluation about scientific research arises at the historic moment.

External evaluation about scientific research is much different from traditional qualitative evaluation given by Internal experts or colleagues , it gives quantitative evaluation mainly on the scientific research achievements and influence. For one thing, we can quantify research activities by evaluating documental growth, information aging, influence and any other metrological index. With the advent of the information society and the big data era, the content of quantitative evaluation of teacher's performance in the university constantly goes deeper, and the method of it further enriches as well. Scientometrics is an international journal for all quantitative aspects of the science,communication in science and science policy, its impact factor is 2.183. From 1979 to 2016, a total of 106 volume, 4565 articles are published in Scientometrics. As its

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branch subjects, informetrics and bibliometrics are widely applied in the quantitative evaluation of scientific research. In addition to counting and describing the scientific research activities and the research results, some complicated mathematical and Information distribution tools are also used to assess the influence of the scientific research achievements. Several publication metrics are used for the evaluation of academic productivity. *h* index, *g* index and *hg*-index relatively new statistics for this purpose. Salih Selek and Ayman Saleh Use of *h* index and *g* index had carried on a quantitative evaluation for American academic psychiatry. Their aim is to evaluate academic psychiatrists' *h* and *g* indices at different academic ranks in the United States. They found that *h* index significantly differed between academic ranks except chairperson-professor. The strongest correlation was between *h* index and *g* indexes. Of the indices evaluated, the *h*-index is best.[1] S. Alonso , F. J. Cabrerizo, E. Herrera-Viedma present a new index, called *hg*-index, to characterize the scientific output of researchers which is based on both *h*-index and *g*-index to try to keep the advantages of both measures as well as to minimize their disadvantages.[2]

The determination of index system is the premise and foundation of quantitative evaluation of scientific research. Only when we merge each metrology index into a index system, classify them, layer them, and weigh them, we can make effective evaluation to a scientific research activity, a research result or a team. Quan'e Ren and Xuemei[3] built an index system for evaluating academic papers that is constructed and verified based on the empirical analysis of papers which has gained the 6th Chinese Academy of Social Sciences Award for Outstanding Achievements. They found that some new index, such as paper discipline impact factor, discipline average cited rate per paper and discipline average downloaded rate per paper have been put forward in this paper. The empirical research results show that the ranking of papers calculated by this evaluation index system is in conformity with the awards determined by peer review in general, but still needs to be verified and improved in practice. This research tend to establish an index system that labels scientific research as the first class indicator. With reference to eight university ranking index systems, namely British "The Times Higher Education Supplement (THES for short) 2015-2016"[4], the US " US News &World Report 2016" [5] (USNWR for short), Academic Ranking Of World Universities[6] (ARWU for short) offered by world-class university research center of Shanghai Jiao Tong University, Leiden world university rankings 2015[7] and university evaluation of Management Science Research Institute, we discuss which indexes are important to scientific research , choose Relatively important indexes and reject indexes that are repetitive, useless or less usable. Then we calculate the weight of each index, as well as the influence degree of each factors , to obtain a quantitative Evaluation standard of Teacher's Performance based on analytic hierarchy process(AHP) principle.

AHP is formally proposed by Saaty, an operational research expert from America in the mid 1970s. It is a systematic and hierarchical decision analysis method combining qualitative evaluation and quantitative one. This method is often used to deal with multi-objective, multi-factor, multi-level and unstructured complicated decision problems, and is widely used in Production Engineering, Information Systems and Applications[8]], Environmental Science & Engineering[9], Geology[10], Production etc.

2. Establishment of Index System

2.1 Hierarchy Structure Model

According to Times higher education world university rankings, the content of scientific research includes three terms, namely research reputation, research income and research production. Scientific research is the overall goal of the decision analysis, so it is

placed on the top of the structure without any other element at the same level. And three terms it includes are put in the middle of the structure, while at the bottom branch, there is a collection of factors which influence the middle layer elements. It is necessary to choose relative factors that will influence last level elements largely and to reject factors that are repetitive, useless or less usable. The amount of foundational elements should be in the rank of 1 to 9 .With reference to relevant information, we finally establish the hierarchical structure of the model, it is shown in figure 1.

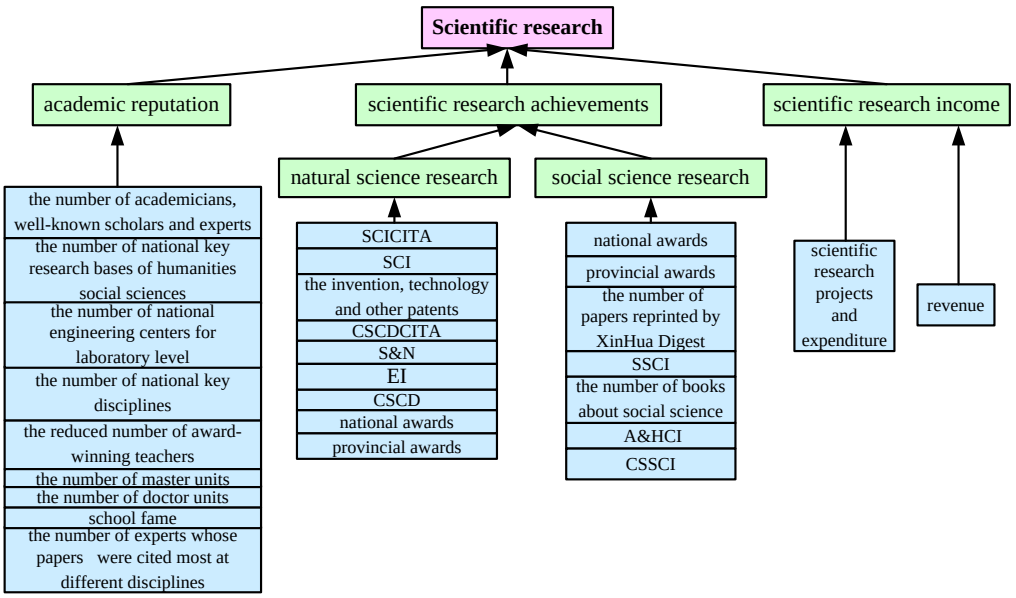

Figure 1. Level Structure of Scientific Research

2.2 Construct judgment matrix

If m factors exist relative importance to last element, according to the specific scale and rule, , compare the ith (i=1,2,3,…,m) factor with the jh (j=1,2,3,…,m) factor, their relative importance can be denoted by a_{ij} .So, we can get an m × m matrix $A=(a_{ij})_{m*m}$, namely Judgment Matrix, which is used to determine the priority weights of the factors about some criteria.

The main work to construct a judgment matrix is to design ideal scale and rule which can pair compare and judge relative importance between two factors. Therefore, the degree of relative importance can be defined by numbers. This article uses 1-9 scaling method, its meaning of scale at all levels is shown in table 1.

Table 1 1-9 Scaling method · meaning of scale at all levels

scale	define	meaning
1	Equally important	For some criteria, one factor is as important as the other one
3	Slightly important	For some criteria, one factor is a little more important than the other one
5	Obviously important	For some criteria, one factor is obviously more important than the other one

7	Very important	For some criteria, one factor is much more important than the other one
9	Extremely important	For some criteria, one factor is extremely important compared to the other one
2,4,6,8	The median value between adjacent scales	Denotes scales when two adjacent scales strike an average
the reciprocal of scales above	converse comparison	If factor i VS factor j, the scale is a_{ij}, then factor j VS factor i will result in sacle $a_{ji}=1/a_{ij}$

According to 1-9 scaling method, construct judgment matrix $A=(a_{ij})_{m*m}$,as shown in table 2.

Table 2. Judgment Matrix A

C_r	A_1	…	A_J	…	A_m
A_1	a_{11}	…	a_{1j}	…	a_{1m}
⋮	⋮	…	⋮	…	⋮
A_J	a_{j1}	…	a_{jj}	…	a_{jm}
⋮	⋮	…	⋮	…	⋮
A_m	a_{m1}	…	a_{mj}	…	a_{mm}

The table above can also be directly described by matrix. The j and m of a_{jm} respectively denote the ith factor and the jth factor. If $a_{jm}=3$, it means in the rule of C_r,the jth factor is slightly more important than the ith one. The meaning of other scales is similar to $a_{jm}=3$.

Accordingly, we need to respectively construct judgment matrices for scientific research, academic reputation, scientific research achievements, and scientific research income which include natural science research and social science research, specific as follows:

scientific research: $A_1=\begin{bmatrix} 1 & 4 & 4 \\ 1/4 & 1 & 1 \\ 1/4 & 1 & 1 \end{bmatrix}$

academic reputation: $A_2 = \begin{bmatrix} 1 & 3 & 3 & 4 & 4 & 5 & 3 & 4 & 4 \\ 1/3 & 1 & 1 & 3 & 2 & 4 & 1/2 & 3 & 2 \\ 1/3 & 1 & 1 & 3 & 2 & 4 & 1/2 & 3 & 2 \\ 1/4 & 1/3 & 1/3 & 1 & 1 & 3 & 1/3 & 2 & 1 \\ 1/4 & 1/2 & 1/2 & 1 & 1 & 3 & 1/3 & 2 & 1 \\ 1/5 & 1/4 & 1/4 & 1/3 & 1/3 & 1 & 1/4 & 1/2 & 1/2 \\ 1/3 & 2 & 2 & 3 & 3 & 4 & 1 & 3 & 3 \\ 1/4 & 1/3 & 1/3 & 1/2 & 1/2 & 2 & 1/3 & 1 & 1/2 \\ 1/4 & 1/2 & 1/4 & 1 & 1 & 2 & 1/3 & 2 & 1 \end{bmatrix}$

scientific research achievements: $A_3 = \begin{bmatrix} 1 & 5 \\ 1/5 & 1 \end{bmatrix}$

natural science research:

$A_{31} = \begin{bmatrix} 1 & 1/3 & 1/3 & 2 & 2 & 1/3 & 1/2 & 1 & 1/2 \\ 3 & 1 & 1 & 4 & 4 & 1 & 2 & 3 & 2 \\ 3 & 1 & 1 & 5 & 3 & 1 & 2 & 3 & 2 \\ 1/2 & 1/4 & 1/5 & 1 & 1/2 & 1/4 & 1/3 & 1/2 & 1/3 \\ 1/2 & 1/4 & 1/3 & 2 & 1 & 1/3 & 1/2 & 1/2 & 1/2 \\ 3 & 1 & 1 & 4 & 3 & 1 & 2 & 3 & 2 \\ 2 & 1/2 & 1/2 & 3 & 2 & 1/2 & 1 & 2 & 1 \\ 1 & 1/3 & 1/3 & 2 & 2 & 1/3 & 1/2 & 1 & 1/4 \\ 2 & 1/2 & 1/2 & 3 & 2 & 1/2 & 1 & 4 & 1 \end{bmatrix}$

social science research: $A_{32} = \begin{bmatrix} 1 & 2 & 1/4 & 1/3 & 1/2 & 1/2 & 1/3 \\ 1/2 & 1 & 1/5 & 1/4 & 1/3 & 1/3 & 1/4 \\ 4 & 5 & 1 & 2 & 4 & 3 & 3 \\ 3 & 4 & 1/2 & 1 & 3 & 2 & 2 \\ 2 & 3 & 1/4 & 1/3 & 1 & 1/2 & 1/2 \\ 2 & 3 & 1/3 & 1/2 & 2 & 1 & 2 \\ 3 & 4 & 1/3 & 1/2 & 2 & 1/2 & 1 \end{bmatrix}$

scientific research income: $A_4 = \begin{bmatrix} 1 & 3 \\ 1/3 & 1 \end{bmatrix}$

2.3 Degree of Relative Importance

Determine the largest eigenvalue λ_{max} and its corresponding eigenvector W of each judgment matrix, $A_i W = \lambda_{max} W$.

(1) Determine the eigenvector W of each judgment matrix W, W($W_1, W_2, \cdots, W_m$)denotes the degree of relative importance, namely weighting coefficient of m factors.

There are two method to work out weighting coefficient, sum-product method and root method. This paper adopts the former, so we only discuss sum-product method in this paper. It comprise the following steps:

①Normalize each column of the judgment matrix to get a new judgment matrix :

$$\bar{a}_{ij} = a_{ij} \Big/ \sum_{k=1}^{m} b_{kj} \quad (i, j = 1,2,\cdots,m)$$

②Sum up each row of the new judgment matrix: $\bar{W}_i = \sum_{j=1}^{m} \bar{b}_{ij} (i = 1,2,\cdots,m)$

③Normalize vector $\bar{W} = \left[\bar{W}_1, \bar{W}_2, \cdots, \bar{W}_m \right]^T$: $W_i = \bar{W}_i \Big/ \sum_{i=1}^{m} \bar{W}_i \quad (i = 1,2,\cdots,m)$,

then $W = \left[W_1, W_2, \cdots, W_m \right]^T$ is the feature vector we seek. And accordingly, single hierarchical arrangement matrix can be certain.

(2)The formula of the largest eigenvalue can be written as $\lambda_{max} = \sum_{i=1}^{m} \frac{(AW)_i}{mW_i}$, where (AW_i) denotes the ith component of vector AW.

Given the formulas above, it is easy to get the following data, as shown in table 3, and feature vector W and single hierarchical arrangement matrix P of each index can be obtained.

Table 3. Data Table

Index	scientific research	academic reputation	scientific research achievements	natural science research	social science research	scientific research income
Weight	1.0000	0.6667	0.1667	0.1389	0.0278	0.1667
largest eigenvalue λ_{max}	3.0000	9.2984	2.0000	9.1927	7.2538	2.0000

feature vector matrix:

$$W = (0.6667, 0.1667, 0.1667)^T$$

single hierarchical arrangement matrices:

Academic Reputation:

$$P_1 = \left(0.2866,0.1277,0.1277,0.0651,0.0712,0.0317,0.1761,0.0457,0.0681\right)^T$$

Scientific Research Achievements:

$$P_2 = \left(0.8333,0.1667\right)^T$$

Natural Science Research:

$$P_3 = \left(0.0654,0.1911,0.1898,0.0360,0.0503,0.1851,0.1066,0.0606,0.1151\right)^T$$

Social Science Research:

$$P_4 = \left(0.0629,0.0410,0.3274,0.2134,0.0861,0.1412,0.1279\right)^T$$

Scientific Research Income:

$$P_5 = \left(0.7500,0.2500\right)^T$$

2.4 Consistency Check

the coincident indicator of judgment matrix can be represented as:

$$CI = \frac{\lambda_{\max} - \mathrm{m}}{\mathrm{m} - 1}$$

where m is the order number of judgment matrix, $\lambda_{\max}$ is the largest eigenvalue of judgment matrix. The bigger the CI, the greater the deviation consistency, on the contrary, the smaller the CI ,the smaller deviation consistency. In general, if $CI \le 0.01$, then it shows the judgment matrix is with consistency. In addition, the greater the order number m of judgment matrix, the greater the deviation consistency resulted from subjective factors, hence the greater the deviation consistency. While when $\mathrm{m} \le 2$, CI=0,we say the judgment matrix is with completely consistency.

Therefore, it is necessary to import random consistency index RI . Index RI changes for the order number of judgment matrix, the concrete numerical value is shown in table 4. Table 4 lists the 1-15 order index value RI of judgment matrix. These RIs are mean values of coincident indicators which are calculated repeatedly more than 500 times by constructing judgment matrices.

Table 4. Random Consistency Index

Order	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49	1.52	1.54	1.56	1.58	1.59

we can define the consistence ratio as the ratio of the consistency index CI in to the random consistency index CR of the same order:

$$CR = \frac{CI}{RI}$$

Judge the consistence by consistence ratio. the smaller the CR is, the better the consistency of judgment matrix CR will be. In general, if $CR \le 0.1$,then it shows the judgment matrix accords with the standard consistency, hence the result of hierarchy single sorting can be accepted. While if $CR > 0.1$, it means the judgment matrix need to be corrected until it can pass the validation process.

Through the above formula, calculate consistence ratio of each index, as shown in table 5

Table 5. Consistence Ratio of Each Index

index	scientific research	academic reputation	Scientific research achievements	natural science research	social science research	scientific research income
CR	0.0000	0.0255	0.0000	0.0165	0.0311	0.0000

From the table, it is clear that every index is satisfying, and all judgment matrices can pass the validation.

2.5 Overall Importance Analysis

On the basis of analyzing the relation between each index and synthetical goal, the overall comprehensive importance (namely overall weight of the system) can be obtained top to down starting from the superior, then we can order all levels.

overall level ranking need to be proceeded from up to down. For the highest lever, its next level's single hierarchical ranking is the same with overall ranking.

If the last layer's total hierarchy sorting has been done, elements A1, A2, …, Am respectively get their weight value a1, a2, …, am. And for current layer elements B1, B2, …, Bn, which correspond to Aj, its single hierarchical ranking is $\left(b_1^j,\ b_2^j,\cdots,\ b_n^j\right)^T$. When Aj is independent of Bi, then $b_j^i=0$. Hence, overall ranking of B level is shown in table 6.

Table 6. Overall Level Ranking

Level B / Level A	A_1	A_2	…	A_m	overall ranking of level B
	a_1	a_2	…	a_m	
B_1	b_1^1	b_1^2	…	b_1^m	$\sum_{j=1}^{m} ajb_1^j$
B_2	b_2^1	b_2^2	…	b_2^m	$\sum_{j=1}^{m} ajb_2^j$
⋮	⋮	⋮		⋮	⋮
B_n	b_n^1	b_n^2	…	b_n^m	$\sum_{j=1}^{m} ajb_n^j$

Apparently, $\sum_{i=1}^{n}\sum_{j=1}^{m} a_j b_i^j = 1$, because the overall level ranking is a normalized matrix.

From the above content, we can conclude scientific research is arranged at the highest level, elements at its next level, academic reputation, scientific research achievements as well as scientific research income , their weigh to the goal is 0.6667,0.1667 and 0.1667 respectively. And their corresponding single hierarchical ranking is shown as following:

$$P_1 = \left(0.2866,0.1277,0.1277,0.0651,0.0712,0.0317,0.1761,0.0457,0.0681\right)^T$$

$$P_2 = \left(0.8333,0.1667\right)^T$$

$$P_5 = \left(0.7500,0.2500\right)^T$$

Where scientific research achievements are parted into natural science research and social science research, their single hierarchical ranking is:

$$P_3 = \left(0.0654,0.1973,0.1897,0.0360,0.0633,0.0503,0.1850,0.1065,0.1065\right)^T$$

$$P_4 = \left(0.0629,0.0410,0.1279,0.3274,0.2134,0.0861,0.1412\right)^T$$

Reference to formulas shown in table, weigh of the bottom elements in this system can be certain, as shown in table 7.

3. Results

After a series of analysis and calculation, we worked out a new index system, detail information about the system is shown in table 7.

Table 7. Quantitative Evaluation Index System of Teacher's Performance in the University

First class	Second class	Third class		weight
scientific research 100%	academic reputation 66.67%	the number of academicians, well-known scholars and experts		0.1910
		the reduced number of award-winning teachers		0.0852
		the number of experts whose papers were cited most at different disciplines		0.0852
		the number of national key disciplines		0.0434
		the number of national key research bases of humanities social sciences		0.0475
		the number of doctor units		0.0454
		school fame		0.1174
		the number of national engineering centers for laboratory level		0.0305
		the number of master units		0.0212
	scientific research achievements 16.67%	natural science research 13.89%	SCICITA	0.0263
			CSCDCITA	0.0274
			provincial awards	0.0084
			SCI	0.0148
			the invention, technology and other patents	0.0257
			EI	0.0091
			national awards	0.0160
			CSCD	0.0070
			S&N	0.0050
		social sciences	CSSCI	0.0091

		research 2.77%	the number of books about social science	0.0059
			national awards	0.0039
			provincial awards	0.0036
			the number of papers reprinted by XinHua Digest	0.0024
			SSCI	0.0017
			A&HCI	0.0011
	scientific research income 16.67%	scientific research projects and expenditure		0.1250
		revenue		0.0417

In this paper, we adopt analytic hierarchy process(AHP) method and analyze a lot of relevant data to obtain a Quantitative Evaluation Index System of Teacher's Performance and to determine the weight of each index. Finally, a set of indicator system was established, including 1 first class indicator, 2 second class indicators as well as 27 third class indicators, among which, scientific research is considered as the first class indicator.

Our result shows, among three indexes at level two, academic reputation is dominant in the proportion of 66.67%. Academic reputation is mainly examined by 9 items at three level, namely the number of academicians, well-known scholars and experts, the reduced number of award-winning teachers, school fame, number of experts whose papers were cited most at different disciplines, the number of national key disciplines, the number of national key research bases of humanities social sciences, the number of doctor units and the number of national engineering centers for laboratory level. Among which, the number of academicians, well-known scholars and experts share the most 0.1910, close to 1/3 of academic reputation. Weight of school fame is 0.1174, in second place. The number of award-winning teachers and experts whose papers were cited most at different disciplines respectively accounted for 0.0852. And the weight of other 5 items is about 0.4.

In addition to academic reputation, among items at level 2, scientific research achievements and scientific research income respectively weigh 0.1667. For the item of scientific research achievements, natural science research contributes 0.1389, which is six times social sciences research does. It is obvious that natural science research contributes more to scientific research performance. The item of natural science research includes 9 subitems: the number of papers included by SCI, EI, CSCD and S&N; national and provincial award; patents; the number of papers which were cited and included by SCI and CSCD(SCICITA, CSCDCITA). Among which, weight of SCICITA, CSCDCITA, the invention, technology and other patents is bigger. The item of social sciences research includes the following indexes: the number of papers included by SSCI, CSSCI, A&HCI; the number of papers reprinted by XinHua Digest; the number of books about social science. Scientific research income mainly includes scientific research projects and revenue, the former weigh bigger.

The quantitative evaluation index system we research is suit for evaluating teacher's performance in the university. And it helps universities and research teams to reasonably choose scientific research direction and goal, and to establish effective research policy. Furthermore, there is much reference value especially for universities which is looking forward to good grades among university rankings as well as high social influence.

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