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A Pro-performance appraisal system for the university

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ABSTRACT

Due to economic pressures and declining birth rates, universities in Taiwan are seeking ways to evaluate and improve operational performance to acquire a competitive advantage to attract more students. However, current performance evaluation models have been criticized for two reasons. First, the measurement criteria currently used are not completely in accordance with the characteristics of different university types, research-intensive university, teaching-intensive university, and professional-intensive university. Second, the models assume independence of measured criteria. Nonetheless, in the real world, such measured criteria are seldom independent. To address these issues, we first reviewed the literature and interviewed Taiwanese higher education experts to integrate critical measurement criteria and develop an original performance appraisal system (OPAS). Next, we adapted a decision-making trial and evaluation laboratory (DEMATEL) method to present complex interdependent relationships and to construct a relation structure among measurement criteria for performance appraisal. A fuzzy analytic network process (FANP) was generated to address the dependence and feedback among each of the measurement criteria. Finally, we proposed a Pro-performance appraisal system (PPAS). This study offers a Pro-performance appraisal system (PPAS) to aid in future performance appraisals and improvements for all three university types.

1. Introduction

Higher education is the foundation for fostering high-tech talent, the key factor in increasing national quality, and the main way to upgrade a nation's competitive status (Fairweather, 2000; Meek, 2000). In recent years, the number of Taiwanese universities has increased to 157 in according to the Taiwanese Ministry of Education (Ministry of Education, 2006). However, the quality and operational performance among them has not increased proportionally (Taiwan Assessment and Evaluation Association, 2006). This has been a serious issue for the Taiwanese government and universities (Department of Higher Education, 2004).

Visiting and standard procedure evaluations are the two methods the Ministry of Education uses to evaluate universities. There are three types of Taiwanese universities: research-intensive universities, teaching-intensive universities, and profession-intensive universities (Li, 2007). The current measurement criteria utilized are not completely in accordance with the characteristics of these three different university types. This is the main characteristic of the current system that some universities have argued has been unfair. In this study, we argue that since the measurement criteria utilized are assumed to be independent, each criterion may significantly influence the operation performance appraisal results. However, the independence assumption is not consistent with the conditions in the real world.

For the reasons above, we propose a more professional performance appraisal mechanism with more suitable measurement criteria for the three university types. In this study, critical measurement criteria were determined by summarizing the literature and interviewing Taiwanese higher education experts. Then, a decision-making trial and evaluation laboratory (DEMATEL) method was adapted to present complex interdependent relationships and to construct a relation structure among measurement criteria for performance appraisal. A fuzzy analytic network process (FANP) was constructed to solve the problem of dependence and feedback among each measurement criterion (Liou, Tzeng, & Chang, 2007). Here, we combined a DEMATEL, and a fuzzy ANP method to form a Pro-performance appraisal system (PPAS).

2. Pro-performance appraisal system (PPAS)

Many studies offer insights on performance appraisal in higher education and some studies even develop evaluation models. However, there is inconsistency among different types of universities and the relationships between measurement criteria are not

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considered. Recent research suggests that the influential factors for operational performance for higher education vary across university types. After summarizing related literature and studies and performing in-depth interviews with higher education experts, we first developed an original performance appraisal system (OPAS). Then, we took a hybrid approach, combining DEMATEL, and Fuzzy ANP, which accounts for complex relationships using them to construct a Pro-performance appraisal system (PPAS).

3. Research methods

To precisely quantify values with a complex measurement system is difficult. Nevertheless, such systems can be categorized into subsystems to make it easier to distinguish and evaluate each subgroup (Liou et al., 2007). Here, based on the original performance appraisal system (OPAS), DEMATEL is adapted to assess the interrelations between each of the measurement criteria. Next, each criterion is weighted by conducting fuzzy ANP. Finally, we construct a Pro-performance appraisal system (PPAS) in accordance with above results.

3.1. The decision-making trial and evaluation laboratory (DEMATEL)

It is difficult for a decision-maker to evaluate the single effect of a single factor while avoiding interference from the rest of the system because factors in a complex system may relate to each other directly or indirectly (Liou et al., 2007). In addition, an interdependent system may result in passive positioning. For example, a system with a clear hierarchical structure may give rise to linear activity with no dependence or feedback, which may cause problems that are distinct from those found in non-hierarchical systems (Tzeng, Chiang, & Li, 2007).

The Battelle Geneva Institute created DEMATEL in order to solve difficult issues using interactive man-model techniques to measure qualitative and factor-linked aspects of societal problems (Gabus & Fontela, 1972). DEMATEL has been utilized in many additional contexts, such as industrial planning, decision-making, regional environmental assessing, and even analyzing world problems (Huang, Tzeng, & Ong, 2007). In each case, DEMATEL was used to confirm criteria interdependence and restrict the relationships that affect characteristics within an essential system and its developmental trends (Liou et al., 2007).

The DEMATEL method is founded on graph theory. It allows decision-makers to analyze as well as solve visible problems. In doing so, decision-makers can separate multiple measurement criteria into cause and effect groups to identify causal relationships. In addition, directed graphs, called digraphs, are more useful than directionless graphs since they depict the directed relationships among subsystems. In other words, a digraph represents a communication network or a domination relationship between entities and their groupings (Huang et al., 2007).

The calculation steps of the DEMATEL are as follows (Liou et al., 2007; Yu & Tseng, 2006):

Step 1: Calculate the initial average matrix by scores.

Sampled experts are asked to point the direct effect based on their perception that each element i exerts on each other element j, as presented by aij, measured on a scale ranging from 0 to 4. No influence is represented by 0, while a very high influence is represented by 4. Based on groups of direct matrices from samples of experts, we can generate an average matrix $\boldsymbol{A}$ in which each element is the mean of the corresponding elements in the experts' direct matrices.

Step 2: Calculate the initial influence matrix.

After normalizing the average matrix A, the initial influence matrix D, $[d_{ij}]_{n\times n}$, is calculated so that all principal diagonal elements equal zero. In accordance with D, the initial effect that an element exerts and/or acquires from each other element is given. The map depicts a contextual relationship among the elements within a complex system. Each matrix entry can be seen as its strength of influence. As a result, we can easily translate the relationship between the causes and effects of various measurement criteria into a comprehensive structural model based on the influence degrees using DEMATEL.

Step 3: Develop the full direct/indirect influence matrix.

The indirect effects of problems decrease as the powers of D increase, e.g. $\boldsymbol{D}^2, \boldsymbol{D}^3, \ldots, \boldsymbol{D}^\infty$, which guarantees convergent solutions to the matrix inversion. Therefore, we can generate an infinite series of both direct and indirect effects. Let the (i, j) element of matrix A be presented by a_{ij}, then the direct/indirect matrix can be acquired by following Eqs. (1)–(4).

$$\boldsymbol{D} = s^*A, \quad s > 0 \tag{1}$$

or

$$[d_{ij}]_{n\times n} = s[a_{ij}]_{n\times n}, \quad s > 0, \quad i,j \in \{1,2,\ldots,n\}, \tag{2}$$

where

$$S = \mathrm{Min}\left[\frac{1}{\max_{1\le i\le n}\sum_{j=1}^{n}|a_{ij}|}, \frac{1}{\max_{1\le i\le n}\sum_{i=1}^{n}|a_{ij}|}\right] \tag{3}$$

and

$$\lim_{m\to\infty}\boldsymbol{D}^m = [0]_{n\times n} \quad \text{where } \boldsymbol{D} = [d_{ij}]_{n\times n}, \quad 0 \le d_{ij} < 1. \tag{4}$$

The total influence matrix $\boldsymbol{T}$ can be acquired by utilizing Eq. (5). Here, $\boldsymbol{I}$ is the identity matrix.

$$\boldsymbol{T} = \boldsymbol{D} + \boldsymbol{D}^2 + \cdots + \boldsymbol{D}^m = \boldsymbol{D}(\boldsymbol{I} - \boldsymbol{D})^{-1} \quad \text{when } m \to \infty. \tag{5}$$

If the sum of rows and the sum of columns is represented as vector r and c, respectively, in the total influence matrix $\boldsymbol{T}$, then

$$\boldsymbol{T} = [t_{ij}], \quad i,j = 1,2,\ldots,n, \tag{6}$$

$$R = [r_i]_{n\times 1} = \left(\sum_{j=1}^{n} t_{ij}\right)_{n\times 1}, \tag{7}$$

$$c = [c_j]'_{1\times n} = \left(\sum_{i=1}^{n} t_{ij}\right)_{1\times n}, \tag{8}$$

where the superscript apostrophe denotes transposition. If r_i represents the sum of the ith row components of matrix $\boldsymbol{T}$, then r_i represents the sum of both direct and indirect effects of factor i on all other criteria. In addition, if c_j represents the sum of the jth column components of matrix T, then c_j presents the sum of both direct and indirect effects that all other factors have on j. Moreover, note that $j = i$ $(r_i + c_j)$ demonstrates the degree to which factor i affects or is affected by j. Note that if $(r_i - c_j)$ is positive, then factor i affects other factors, and if it is negative, then factor i is affected by others (Liou et al., 2007; Tzeng et al., 2007).

Step 4: Set the threshold value and generate the impact relations map.

Finally, we must develop a threshold value. This value is generated by taking into account the sampled experts' opinions in order to filter minor effects presented in matrix ***T*** elements. This step is needed to isolate the relationship structure of the most relevant factors. In accordance with the matrix ***T***, each factor t_{ij} provides information about how factor i affects j. In order to decrease the complexity of the impact relations map, the decision-maker determines a threshold value for the influence degree of each factor. If the influence level of an element in matrix ***T*** is higher than the threshold value, which we denote as p, then this element is included in the final impact relations map (IRM) (Liou et al., 2007).

3.2. The fuzzy analytical network process (FANP)

3.2.1. Fuzzy set theory

Fuzzy set theory was first developed in 1965 by Zadeh when he was attempting to solve fuzzy phenomenon problems, including problems with uncertain, incomplete, unspecific, or fuzzy situations. Fuzzy set theory is more advantageous than traditional set theory when describing set concepts in human language. It allows us to address unspecific and fuzzy characteristics by using a membership function that partitions a fuzzy set into subsets of members that "incompletely belong to" or "incompletely do not belong to" a given subset.

3.2.2. Fuzzy number

We order the universe of discourse such that U is a collection of targets, where each target in the universe of discourse is called an element. A fuzzy number $\tilde{A}$ is mapped onto U such that a random $x \to U$ is appointed a real number, $\mu_{\tilde{A}}(x) \to [0, 1]$. If another element in U is greater than x, we call that element *under A*.

The universe of real numbers R is a triangular fuzzy number (TFN), $\tilde{A}$, which means that for $x \in R$, $\mu_{\tilde{A}}(x) \in [0, 1]$, and

$$\mu_{\tilde{A}}(x) = \begin{cases} (x-L)/(M-L), & L \le x \le M, \\ (U-x)/(U-M), & M \le x \le U, \\ 0 & \text{otherwise}, \end{cases}$$

Note that $\tilde{A} = (L, M, U)$, where L and U represent fuzzy probability between the lower and upper boundaries, respectively, as shown in Fig. 1. Assume two fuzzy numbers $\tilde{A}_1 = (L_1, M_1, U_1)$ and $\tilde{A}_2 = (L_2, M_2, U_2)$; then,

(1) $\tilde{A}_1 \oplus \tilde{A}_2 = (L_1, M_1, U_1) \oplus (L_2, M_2, U_2) = (L_1 + L_2, M_1 + M_2, U_1 + U_2)$
(2) $\tilde{A}_1 \otimes \tilde{A}_2 = (L_1, M_1, U_1) \otimes (L_2, M_2, U_2) = (L_1 L_2, M_1 M_2, U_1 U_2)$, $L_i > 0$, $M_i > 0$, $U_i > 0$
(3) $\tilde{A}_1 - \tilde{A}_2 = (L_1, M_1, U_1) - (L_2, M_2, U_2) = (L_1 - L_2, M_1 - M_2, U_1 - U_2)$
(4) $\tilde{A}_1 \div \tilde{A}_2 = (L_1, M_1, U_1) \div (L_2, M_2, U_2) = (L_1/U_2, M_1/M_2, U_1/L_2)$, $L_i > 0$, $M_i > 0$, $U_i > 0$
$\tilde{A}_1^{-1} = (L_1, M_1, U_1)^{-1} = (1/U_1, 1/M_1, 1/L_1)$, $L_i > 0$, $M_i > 0$, $U_i > 0$

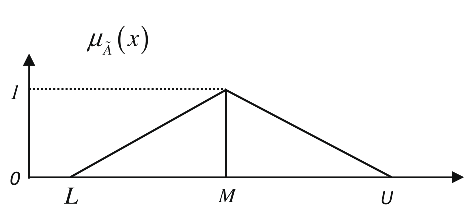


Fig. 1. Triangular fuzzy number.

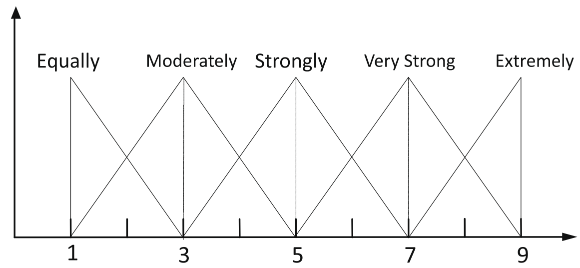


Fig. 2. A fuzzy membership function for linguistic variable attributes.

Table 1
Definition and membership function of fuzzy number.

Fuzzy number	Linguistic variable	Triangular fuzzy number
$\tilde{9}$	Extremely important/preferred	(7, 9, 9)
$\tilde{7}$	Very strongly important/ preferred	(5, 7, 9)
$\tilde{5}$	Strongly important/preferred	(3, 5, 7)
$\tilde{3}$	Moderately important/preferred	(1, 3, 5)
$\tilde{1}$	Equally important/preferred	(1, 1, 3)

3.2.3. Fuzzy linguistic variable

The fuzzy linguistic variable reflects different aspects of human language. Its value represents the range from natural to artificial language. When the values or meanings of a linguistic factor are being reflected, the resulting variable must also reflect appropriate modes of change for that linguistic factor. Moreover, variables describing a human word or sentence can be divided into numerous linguistic criteria, such as equally important, moderately important, strongly important, very strongly important, and extremely important, as shown in Fig. 2. Definitions and descriptions are shown in Table 1. For the purposes of this study, the 5-point scale (equally important, moderately important, strongly important, very strongly important and extremely important) is used.

3.2.4. Analytic network process (ANP)

The purpose of the ANP approach is to solve problems involving interdependence and feedback between criteria or alternative solutions. ANP is the general form of the analytic hierarchy process (AHP), which has been used in multi-criteria decision-making (MCDM) in order to consider non-hierarchical structures. MCDM has been applied to numerous disciplines (Huang, Tzeng, & Ong, 2005).

The beginning stage of an ANP uses pair-wise comparisons of the measured criteria to form a super matrix. The relative importance-values of pair-wise comparisons can be categorized from 1

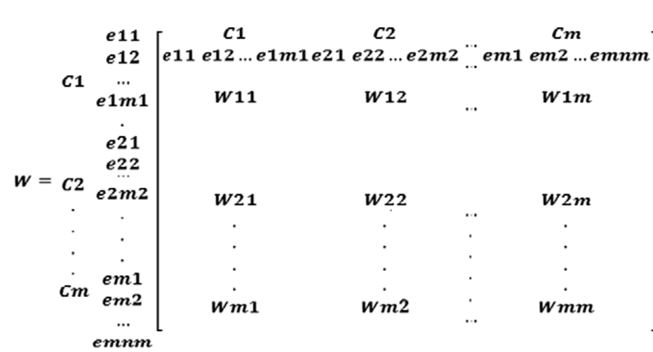
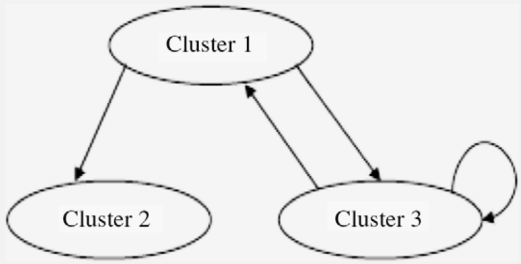
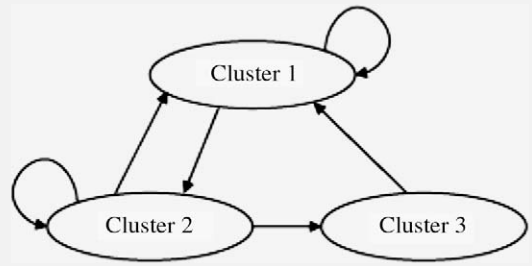


Fig. 3. The general form of the super matrix (Liou et al., 2007; Yu and Tseng, 2006).

Table 2
Two simple cases.

Number	Case 1	Case 2
Structure type		
Matrix forming	$W = \begin{array}{c} C_1 \\ C_2 \\ C_3 \end{array} \overset{\begin{array}{ccc} C_1 & C_2 & C_3 \end{array}}{\begin{bmatrix} 0 & 0 & W_{13} \\ W_{21} & 0 & 0 \\ W_{31} & 0 & W_{33} \end{bmatrix}}$	$W = \begin{array}{c} C_1 \\ C_2 \\ C_3 \end{array} \overset{\begin{array}{ccc} C_1 & C_2 & C_3 \end{array}}{\begin{bmatrix} W_{11} & W_{12} & W_{13} \\ W_{21} & W_{22} & 0 \\ 0 & W_{32} & 0 \end{bmatrix}}$

to 9 in order to represent pairs of equal importance (1) to extreme inequality in importance (9) (Saaty, 1980). Fig. 3 shows the general form of the super matrix where c_m represents the mth cluster, e_{mn} represents the nth element in the mth cluster, and $\boldsymbol{w}_{ij}$ is the principal eigenvector measuring the influence of the jth cluster elements on the ith cluster elements. In addition, if the jth cluster has no influence on the ith cluster, then $\boldsymbol{w}_{ij} = 0$ (Yu & Tseng, 2006).

The form of the super matrix depends on the variety of its structure. In order to demonstrate how the structure is affected by the super matrix, Huang et al. (2005), Yu and Tseng (2006), and Liou et al. (2007) offer two simple cases that both involve three clusters to illustrate how to form a super matrix in accordance with different structures (see Table 2). Case 1 is much simpler than case 2, and based on each structure, the super matrices are given under each.

Next, the weighted super matrix is generated by transforming all column sums to unity (Huang et al., 2005; Yu & Tseng, 2006). Then, we use the weighted super matrix to generate a limiting super matrix by using Eq. (9) to calculate global weights (Huang et al., 2005).

$$\lim_{k \to \infty} \boldsymbol{w}^k \tag{9}$$

Table 4
The average initial direct-relation 10∗10 matrix $\boldsymbol{A}$.

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
D1	0	3.17	1.02	0.24	0.11	0.43	0.11	0.30	2.14	0.10
D2	0.23	0	1.17	0.01	0.13	0.32	0.01	0.00	2.45	0.15
D3	3.33	3.21	0	1.12	1.86	3.37	0.23	0.14	1.07	0.40
D4	3.16	2.42	1.12	0	0.31	3.23	1.06	1.12	3.27	0.41
D5	0.13	0.08	0.03	1.03	0	2.18	1.22	1.19	3.36	0.27
D6	0.03	2.09	0.01	1.19	1.01	0	1.11	1.16	3.17	1.05
D7	2.21	0.12	2.33	3.05	3.42	3.18	0	1.10	3.16	3.31
D8	1.00	0.06	1.96	1.13	3.24	3.19	2.87	0	3.55	1.11
D9	1.23	0.23	0.05	1.06	2.04	1.31	0.38	0.21	0	0.20
D10	2.12	0.10	0.03	1.10	2.27	1.45	2.01	3.42	1.28	0

Table 3
An original 10-dimensional performance appraisal system (OPAS).

System	Measurement dimensions	Measurement criteria
The original performance appraisal system (OPAS)	Learning performance (D1)	The enrollment rate of new students (C1)
		The graduation rate of current students (C2)
	Life development (D2)	The job acquiring rate of students (C3)
		The relations degree of students' major and jobs (C4)
		Rate of continuing education (C5)
	Learning behavior (D3)	Student innovative/creative ability (C6)
		The rate of borrowing books (C7)
		The rate of club participation (C8)
	Quality of teaching (D4)	The rate of course performance appraisal (C9)
		The rate of practical training course opening (C10)
		The rate of optional course opening (C11)
	Research performance (D5)	Number of plans given by NSC (C12)
		The job promotion rate of faculty (C13)
		Number of articles published in international journals (C14)
	Professional skill performance (D6)	Number of thesis winning of students (C15)
		Number of patents (C16)
	Organizational development (D7)	The performance of occupational refresher courses (C17)
		The supplemental budget of faculty research (C18)
		The budget of scholarships (C19)
	External interactions (D8)	The budget of industry-university relations (C20)
		The budget of international relations (C21)
		Number of international conferences (C22)
	School prestige (D9)	The satisfaction degree of students and faculty (C23)
		Employee turnover (C24)
		Score given by Ministry of Education (C25)
	Budget handling performance (D10)	The unit cost of each student (C26)
		The rate of tuition and schooling in school income (C27)
		The rate of government supplement in school overall income (C28)

Table 5
Total influence ***T***.

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
D1	0.029	0.169	0.064	0.032	0.038	0.058	0.020	0.027	0.201	0.017
D2	0.033	0.020	0.059	0.017	0.031	0.043	0.011	0.010	0.203	0.015
D3	0.195	0.214	0.035	0.095	0.139	0.223	0.049	0.045	0.180	0.047
D4	0.202	0.184	0.092	0.059	0.097	0.236	0.094	0.092	0.286	0.058
D5	0.053	0.043	0.029	0.094	0.068	0.171	0.094	0.088	0.246	0.045
D6	0.052	0.128	0.033	0.100	0.114	0.080	0.090	0.089	0.243	0.078
D7	0.210	0.109	0.200	0.228	0.278	0.306	0.088	0.137	0.355	0.203
D8	0.093	0.077	0.133	0.141	0.260	0.283	0.200	0.069	0.336	0.110
D9	0.082	0.033	0.017	0.075	0.213	0.106	0.042	0.034	0.072	0.027
D10	0.158	0.063	0.053	0.121	0.201	0.186	0.156	0.205	0.220	0.052

Table 6
The sum of influences on measurement dimensions.

Measurement dimensions	$r_i + c_i$	$r_i - c_i$
D1	1.709	−0.503
D2	1.417	−0.661
D3	1.894	0.549
D4	2.362	0.441
D5	2.281	−0.419
D6	2.700	−0.688
D7	2.912	1.232
D8	2.494	0.901
D9	2.838	−1.615
D10	2.067	0.763

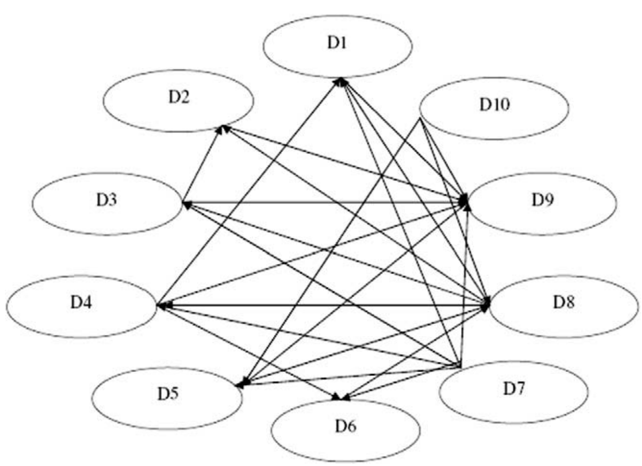


Fig. 4. The impact relations map of this study.

In this step, if the super matrix shows signs of cyclicity, then more than one limiting super matrix must exist. In this case, the Cesaro sum must be calculated to obtain the priority order of the multiple super matrices (Yu & Tseng, 2006). The Cesaro sum is calculated using Eq. (10) (Huang et al., 2005; Yu & Tseng, 2006)

$$\lim_{k-\infty}\left(\frac{1}{N}\right)\sum_{k=1}^{N}\boldsymbol{w}^{k} \tag{10}$$

Eq. (10) calculates the average effect of a limiting super matrix. Otherwise, the super matrix would be raised to a large power to generate the priority weights (Liou et al., 2007; Yu & Tseng, 2006).

4. Empirical study of Pro-performance appraisal system (PPAS)

Due to economic pressures and declining birth rates, Taiwanese universities are seeking ways to improve operational performance to acquire a competitive advantage and attract more students. In the previous section, we explained that performance appraisal criteria vary greatly from one university to another. In addition, criteria can affect each other. There are three university types in Taiwan, the research-intensive universities, the teaching-intensive universities, and the professional-intensive university, and the performance improvement and evaluation focuses are different for each university type. To overcome the challenges outlined and to meet the requirements above, we take the interrelationship between criteria and the types of universities into account while developing a Pro-performance appraisal system (PPAS).

4.1. Forming an original performance appraisal system (OPAS)

Due to the different measurement criteria involved, constructing a Pro-performance appraisal system (PPAS) for universities is complicated. The Pro-performance appraisal system (PPAS) must allow for interdependence and be in accord with real practice. In this study, we first categorized related measurement criteria from existing studies (Cameron, 1978; Lysons, Hatherly, & Mitchell, 1998). For a detailed summary of the measurement criteria, refer to Mei and Lee (2006). Twenty-five higher education experts were also consulted: ten from research-intensive universities, seven from professional-intensive universities, and eight from teaching-intensive universities. The works of the National Science Council (NSC) were consulted to form an original ten-dimensional performance appraisal system (OPAS) (Learning performance (D1), Life development (D2), Learning behavior (D3), Quality of teaching (D4), Research performance (D5), Professional skill performance (D6), Organizational development (D7), External interactions (D8), School prestige (D9), and Budget handling performance (D10)). Each category includes 2–3 measurement criteria (Table 3). A questionnaire was adapted and given to 66 experts from the three university types. Of the 66 questionnaires, 41 were used for this study: sixteen from the research-intensive universities (16/

Table 7
The example of the local weight of criteria 23–25 under the effect of criteria 3.

Measurement criteria	C23			C24			C25			Local weight
C23	1.000	1.000	3.000	0.126	0.149	0.218	0.155	0.212	0.435	0.075
C24	4.583	6.708	7.937	1.000	1.000	3.000	5.433	7.504	8.631	0.742
C25	2.297	4.711	6.433	0.116	0.133	0.184	1.000	1.000	3.000	0.182

Table 8
The un-weighted matrix.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23	C24	C25	C26	C27	C28
C1	0	0	0	0	0	0	0	0	0.09	0.11	0.08	0	0	0	0	0	0.03	0.07	0.05	0	0	0	0	0	0	0	0	0
C2	0	0	0	0	0	0	0	0	0.03	0.02	0.02	0	0	0	0	0	0.02	0.006	0.03	0	0	0	0	0	0	0	0	0
C3	0	0	0	0	0	0.06	0.08	0.11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C4	0	0	0	0	0	0.04	0.03	0.06	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C5	0	0	0	0	0	0.03	0.07	0.04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0.04	0.06	0	0	0	0	0	0	0	0	0
C7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.02	0.04	0.03	0	0	0	0	0	0	0	0	0
C8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0.01	0.02	0	0	0	0	0	0	0	0	0
C9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.07	0.09	0.07	0	0	0	0	0	0	0	0	0
C10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.06	0.07	0.08	0	0	0	0	0	0	0	0	0
C11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03	0.03	0.04	0	0	0	0	0	0	0	0	0
C12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.11	0.11	0.1	0.17	0.2	0.16	0.24	0.31	0.27	0.21	0.16	0.15
C13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.09	0.14	0.08	0.15	0.11	0.13	0.18	0.22	0.24	0.11	0.14	0.13
C14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.13	0.12	0.19	0.18	0.23	0.24	0.58	0.47	0.49	0.24	0.19	0.16
C15	0	0	0	0	0	0.20	0.28	0.31	0.26	0.22	0.27	0	0	0	0	0	0.07	0.05	0.06	0.08	0.07	0.07	0	0	0	0	0	0
C16	0	0	0	0	0	0.67	0.54	0.48	0.41	0.36	0.36	0	0	0	0	0	0.10	0.11	0.09	0.13	0.08	0.16	0	0	0	0	0	0
C17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.06	0.07	0.06	0	0	0	0	0	0
C18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.09	0.09	0.08	0	0	0	0	0	0
C19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.04	0.06	0.03	0	0	0	0	0	0
C20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.09	0.12	0.13
C21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.13	0.11
C22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.15	0.11	0.13
C23	0.05	0.16	0.07	0.08	0.21	0	0	0	0.02	0.04	0.02	0.17	0.16	0.16	0.19	0.17	0.01	0.004	0.005	0.01	0.02	0.01	0	0	0	0.01	0.01	0.03
C24	0.68	0.61	0.57	0.74	0.55	0	0	0	0.13	0.17	0.14	0.62	0.48	0.51	0.43	0.59	0.06	0.03	0.04	0.03	0.02	0.02	0	0	0	0.03	0.06	0.07
C25	0.27	0.23	0.36	0.18	0.24	0	0	0	0.06	0.08	0.11	0.21	0.36	0.33	0.38	0.24	0.04	0.06	0.05	0.06	0.05	0.04	0	0	0	0.06	0.08	0.09
C26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0.007	0.001	0	0	0	0	0	0	0	0	0
C27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03	0.01	0.001	0	0	0	0	0	0	0	0	0
C28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.02	0.003	0.003	0	0	0	0	0	0	0	0	0

Table 9
The weighted matrix.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23	C24	C25	C26	C27	C28
C1	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024
C2	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007
C3	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021
C4	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011
C5	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012
C6	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004
C7	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003
C8	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
C9	0.0077	0.0077	0.0077	0.0077	0.0077	0.0077	0.0077	0.0077	0.0077	0.0077	0.0077	0.0077	0.0077	0.0077	0.0077	0.0077	0.0077	0.0077	0.0077	0.0077	0.0077	0.0077	0.0077	0.0077	0.0077	0.0077	0.0077	0.0077
C10	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071
C11	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034
C12	0.1659	0.1659	0.1659	0.1659	0.1659	0.1659	0.1659	0.1659	0.1659	0.1659	0.1659	0.1659	0.1659	0.1659	0.1659	0.1659	0.1659	0.1659	0.1659	0.1659	0.1659	0.1659	0.1659	0.1659	0.1659	0.1659	0.1659	0.1659
C13	0.1303	0.1303	0.1303	0.1303	0.1303	0.1303	0.1303	0.1303	0.1303	0.1303	0.1303	0.1303	0.1303	0.1303	0.1303	0.1303	0.1303	0.1303	0.1303	0.1303	0.1303	0.1303	0.1303	0.1303	0.1303	0.1303	0.1303	0.1303
C14	0.2439	0.2439	0.2439	0.2439	0.2439	0.2439	0.2439	0.2439	0.2439	0.2439	0.2439	0.2439	0.2439	0.2439	0.2439	0.2439	0.2439	0.2439	0.2439	0.2439	0.2439	0.2439	0.2439	0.2439	0.2439	0.2439	0.2439	0.2439
C15	0.0762	0.0762	0.0762	0.0762	0.0762	0.0762	0.0762	0.0762	0.0762	0.0762	0.0762	0.0762	0.0762	0.0762	0.0762	0.0762	0.0762	0.0762	0.0762	0.0762	0.0762	0.0762	0.0762	0.0762	0.0762	0.0762	0.0762	0.0762
C16	0.1371	0.1371	0.1371	0.1371	0.1371	0.1371	0.1371	0.1371	0.1371	0.1371	0.1371	0.1371	0.1371	0.1371	0.1371	0.1371	0.1371	0.1371	0.1371	0.1371	0.1371	0.1371	0.1371	0.1371	0.1371	0.1371	0.1371	0.1371
C17	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069
C18	0.0095	0.0095	0.0095	0.0095	0.0095	0.0095	0.0095	0.0095	0.0095	0.0095	0.0095	0.0095	0.0095	0.0095	0.0095	0.0095	0.0095	0.0095	0.0095	0.0095	0.0095	0.0095	0.0095	0.0095	0.0095	0.0095	0.0095	0.0095
C19	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047	0.0047
C20	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210
C21	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210	0.0210
C22	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241
C23	0.0181	0.0181	0.0181	0.0181	0.0181	0.0181	0.0181	0.0181	0.0181	0.0181	0.0181	0.0181	0.0181	0.0181	0.0181	0.0181	0.0181	0.0181	0.0181	0.0181	0.0181	0.0181	0.0181	0.0181	0.0181	0.0181	0.0181	0.0181
C24	0.0738	0.0738	0.0738	0.0738	0.0738	0.0738	0.0738	0.0738	0.0738	0.0738	0.0738	0.0738	0.0738	0.0738	0.0738	0.0738	0.0738	0.0738	0.0738	0.0738	0.0738	0.0738	0.0738	0.0738	0.0738	0.0738	0.0738	0.0738
C25	0.0406	0.0406	0.0406	0.0406	0.0406	0.0406	0.0406	0.0406	0.0406	0.0406	0.0406	0.0406	0.0406	0.0406	0.0406	0.0406	0.0406	0.0406	0.0406	0.0406	0.0406	0.0406	0.0406	0.0406	0.0406	0.0406	0.0406	0.0406
C26	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
C27	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
C28	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

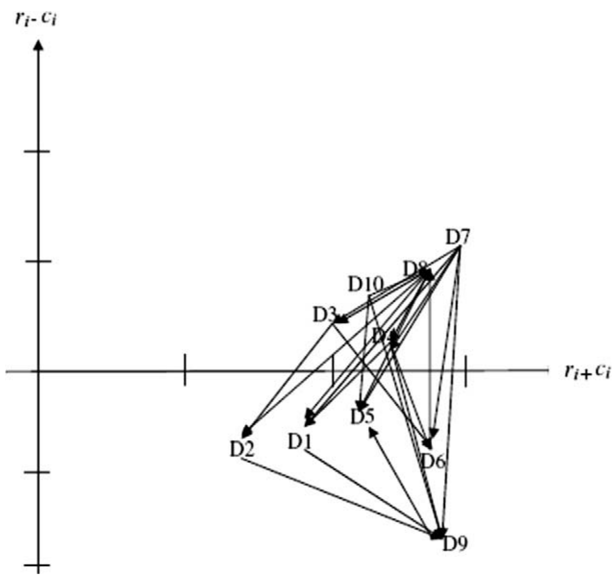


Fig. 5. The impact of direction map of measurement criteria.

36), seven from teaching-intensive universities (7/11), and 18 from professional-intensive universities (18/19). The experts ranked the level of interrelationships among each measurement dimension on a scale from 0 to 4 (No influence, 0, to Very high influence, 4), and the importance between each measurement performance appraisal criterion on a 5-point scale described in Table 1.

4.2. Evaluating the interrelationships of dimensions

Here, the questionnaires from 41 higher educational experts were used to determine the level of relationship among each dimension. With the questionnaire data, we formed the average initial direct-relation 10∗10 matrix $\boldsymbol{A}$ using pair-wise comparisons as shown in Table 4.

Next, using Eqs. (1)–(3), we acquired the normalized direct-relation $\boldsymbol{D}$ from matrix $\boldsymbol{A}$. After that, Eq. (5) was adapted to obtain total influence $\boldsymbol{T}$ (Table 5). Finally, we used Eqs. (7) and (8) to determine the total influence given to and received by each measurement dimension. The results are provided in Table 6.

To avoid relationships too complex for our system, a threshold value under 0.20 was adopted after consulting with higher education experts. Fig. 4 shows the impact relations map (IRM).

4.3. Weighting the criteria and constructing a Pro-performance appraisal system (PPAS)

After calculating the level of interrelationships among each measurement dimension, we utilized fuzzy ANP to acquire the weights of each measurement criterion. The importance of relationships between measurement criteria is paralleled based on the impact relations map above. Such pair-wise comparisons are in accordance with the data in Table 5. In Table 7, we provide an example of the local weight calculated by the principle eigenvector of comparison, specifically of criteria 23–25 when under the effect of criterion 3. The complete result is an un-weighted super matrix, shown in Table 8.

Next, we calculate the limiting power of the un-weighted matrix until it remains stable using Eq. (9). The result is shown

Table 10
Study result summary.

System	Measurement dimensions	Measurement criteria	Global weights	Ranking
The original performance appraisal system (OPAS)	Learning performance (D1)	The enrollment rate of new students (C1)	0.0024	C14
		The graduation rate of current students (C2)	0.0007	C12
	Life development (D2)	The job acquiring rate of students (C3)	0.0021	C16
		The relations degree of students' major and jobs (C4)	0.0011	C13
		Rate of continuing education (C5)	0.0012	C15
	Learning behavior (D3)	Student innovative/creative ability (C6)	0.0004	C24
		The rate of borrowing books (C7)	0.0003	C25
		The rate of club participation (C8)	0.0001	C22
	Quality of teaching (D4)	The rate of course performance appraisal (C9)	0.0077	C21
		The rate of practical training course opening (C10)	0.0071	C20
		The rate of optional course opening (C11)	0.0034	C23
	Research performance (D5)	Number of plans given by NSC (C12)	0.1659	C18
		The job promotion rate of faculty (C13)	0.1303	C9
		Number of articles published in international journals (C14)	0.2439	C10
	Professional skill performance (D6)	Number of thesis winning of students (C15)	0.0762	C17
		Number of patents (C16)	0.1371	C19
	Organizational development (D7)	The performance of occupational refresher courses (C17)	0.0069	C11
		The supplemental budget of faculty research (C18)	0.0095	C1
		The budget of scholarships (C19)	0.0047	C3
	External interactions (D8)	The budget of industry-university relations (C20)	0.0210	C5
		The budget of international relations (C21)	0.0210	C4
		Number of international conferences (C22)	0.0241	C2
	School prestige (D9)	The satisfaction degree of students and faculty (C23)	0.0181	C6
		Employee turnover (C24)	0.0738	C7
		The satisfaction degree of industries (C25)	0.0406	C27
	Budget handling performance (D10)	The unit cost of each student (C26)	0.0001	C28
		The rate of tuition and schooling in school income (C27)	0.0002	C8
		The rate of government supplement in school overall income (C28)	0.0001	C26

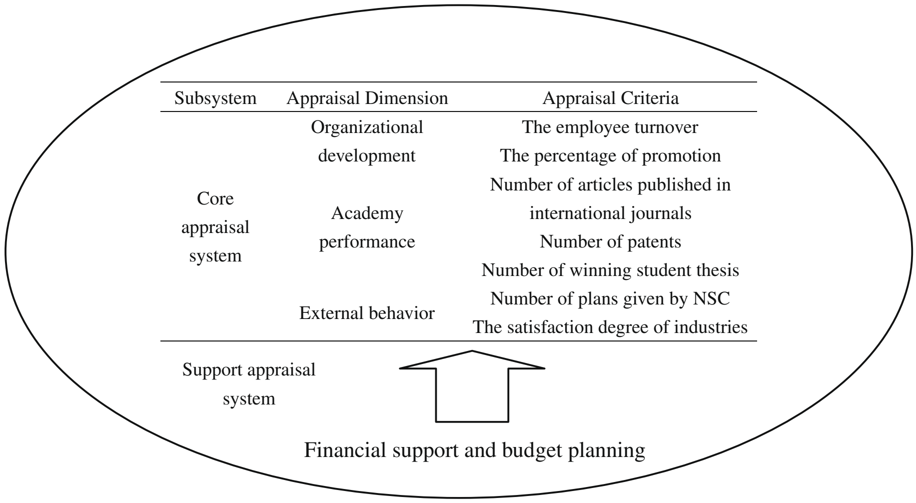


Fig. 6. A Pro-performance appraisal system (PPAS).

in Table 9. Last, using the above result, the impact-direction map is derived and is shown in Fig. 5.

In Table 10, we summarize all of the above results. We propose a novel Pro-performance appraisal system (PPAS) in which the top seven most heavily weighted measurement criteria are extracted from the whole set of criteria. We argue that the operational performance appraisal and improvement considering only the highly weighted criteria will be better than that using all measurement criteria. Also, the content of organizational development (D7) is chosen due to its highest influential degree on the performance improvement conducting (as Fig. 6). In the PPAS we propose, a core appraisal system, containing three dimensions with seven measurement criteria, represents the key suitable items for all three university types to conduct operational performance appraisals and improvements with accuracy. This appraisal system supports financial and budget planning for all three university types to evaluate appropriate financial decisions to support key initiatives and to control the budget.

5. Conclusions

With increasing economic pressures and declining birth rates, Taiwanese universities are seeking ways to improve operational performance to acquire competitive advantages and to attract more students. Current performance appraisal models are inadequate due to inconsistencies among different types of universities, inconsistencies in measurement criteria, and the treatment of interdependent criteria. To address these problems, we first reviewed previous research and interviewed several higher education experts. Then, we combined a DEMATEL, and a fuzzy ANP to construct a Pro-performance appraisal system (PPAS), considering the interdependence and the relative weights of measurement criteria and the characteristics of three university types. The PPAS will be helpful in performing future performance appraisals and suggesting improvements for all three university types.

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