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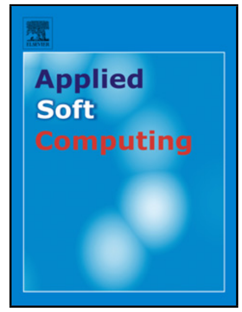

Title: A Network Hierarchical Feedback System for Taiwanese Universities based on the Integration of Total Quality Management and Innovation

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Graphical Abstract

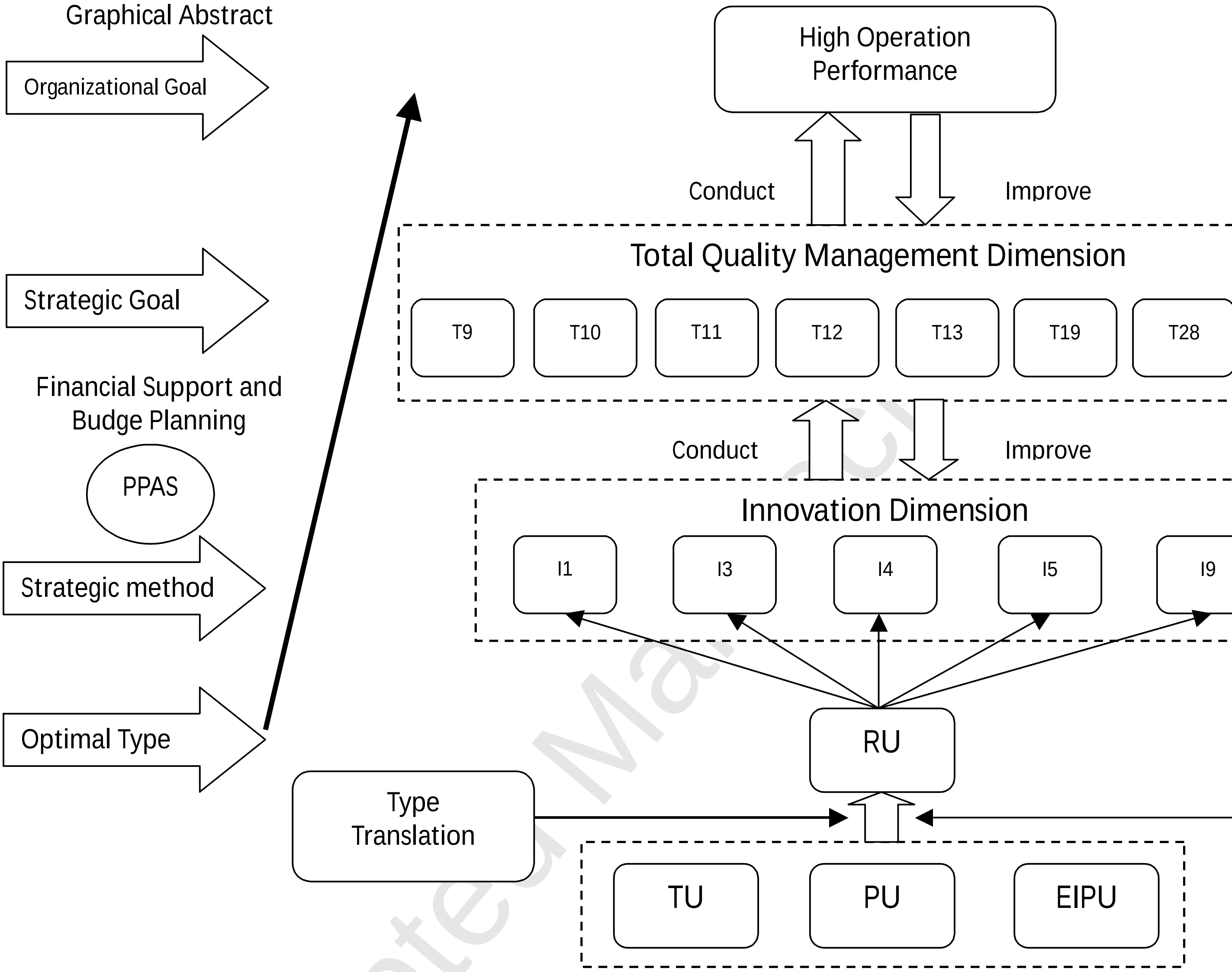

Fig. 7 A network hierarchical feedback system based on the integration of TQM and innovation

Highlights (<125/per)

>This study aims to construct the network hierarchical feedback system (NHFS) based on the integration of TQM and innovation> This study applied a hybrid MCDM approach including DEMATEL, FANP, FAHP, and GRA to achieve the aim>This study is to provide Taiwanese universities a complete performance evaluation system encompassing TQM and innovation>

A Network Hierarchical Feedback System for Taiwanese Universities based on the Integration of Total Quality Management and Innovation

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Abstract

An increasing number of Taiwanese universities are improving operational performance through innovation and total quality management (TQM). In addition, the National Quality Award (NQA), which is based on TQM, is now used to evaluate quality performance in various industries in Taiwan. Thus, several models for performance measurement have been proposed in recent years. However, these models do not take into account several features germane to performance within the Taiwanese university system, such as characteristics unique to the integration of TQM and innovation, comprehensive focuses in operational performance improvement across different types of universities, and interrelations among the different variables used to measure performance. Thus, precisely measuring and improving operation performance has proven to be a difficult task. The aim of this paper is to construct a network hierarchical feedback system (NHFS) based on the integration of TQM and innovation to overcome these problems. To that end, we adopted a decision-making trial and evaluation laboratory (DEMATEL) method to address the complex, interdependent relationships among the variables and thereby construct a relation structure among the measurement criteria for evaluation purposes. A fuzzy analytic network process (FANP) is employed to overcome the problem of dependence and feedback among each of the TQM measurement criteria. A fuzzy analytic hierarchical process (FAHP) is used to evaluate the measurement criteria for innovation performance. Lastly, a gray relational analysis (GRA) is utilized to find optimal alternatives. The value of this study comes from providing all types of universities in Taiwan the most complete evaluation system of operational performance, as well as opportunities to realize improved competitive advantages and enhanced prospects for survival.

Keyword: Fuzzy analytical hierarchical process (FAHP); Fuzzy analytical network process (FANP); Decision-making trial and evaluation laboratory (DEMATEL); Gray relational analysis (GRA); Network hierarchical feedback system (NHFS)

1. Introduction

A country's higher education system fosters high-tech talent, which is the key contributor to rising national quality and one of the main ways to upgrade national competitiveness [21, 39]. Based on records from the Taiwanese Ministry of Education in Taiwan, the number of universities in Taiwan has increased to 157 and continues to rise [40]. These universities' levels of quality and operational performance, however, have not increased equally across the board [47]. In addition, with birth rates continuously dropping, the number of universities increasing, and Taiwan joining the World Trade Organization (WTO), the competitive advantages of a strong university system have decreased drastically [10]. Thus, these problems are serious issues for both governments and universities [17].

The main method of improving and measuring the operational performance of universities involves measuring innovation performance [8] and total quality management (TQM) performance. These two factors have gained significant attention in recent years in Taiwan. A growing number of studies have started to develop separate models for measuring innovation and TQM. However, we argue that a model that addresses both TQM and innovation is necessary for Taiwanese universities to gain competitive advantages and thereby ensure their future survival. In this paper, we propose a measurement system for Taiwanese universities based on the integration of TQM and innovation.

Although the criteria used for the measurement of TQM [34, 43] and innovation [8] are numerous, these criteria seem to ignore the characteristics unique to the integration of TQM and innovation. In addition, Taiwanese universities can be categorized into three main types: the research-intensive university (RU), the teaching-intensive university (TU), and the professional-intensive university (PU). Another university type, the education-in-practice-intensive university (EIPU), has recently emerged. It focuses on operations performance improvement while conducting TQM and innovation independently from one another [9]. In addition, the measurement criteria proposed in the literature are assumed to be independent of each other, even though this separation does not reflect real world circumstances [38]. To maximize the evaluation and improvement of operational performance in Taiwanese universities, measurement criteria must consider characteristics related to the integration of TQM and innovation, the comprehensive focuses across the four types of universities in terms of operational performance, and the interrelationships among the criteria.

To overcome these problems and construct a useful model, a decision-making trial and evaluation laboratory (DEMATEL) method is used to address the complex interdependent relationships of TQM and to construct a relation structure that includes the measurement criteria for evaluation purposes. A fuzzy analytic network process

(FANP) is employed to overcome the problems of dependence between and feedback among TQM measurement criteria. A fuzzy analytic hierarchical process (FAHP) is used to evaluate the measurement criteria for innovation performance based on the effects of TQM criteria. The FANP and FAHP methods are widely used for multiple-criteria decision making, and the practical applications reported in the literature have demonstrated related advantages with regard to handling unquantifiable/qualitative criteria and obtaining reliable results [6, 7, 8]. Finally, gray relational analysis (GRA) is utilized to find optimal alternatives based on weights of innovation criteria. Unlike the overly subjective nature of the simple average weighted method (SAW), the GRA method has been adopted largely due to its proficiency in uncertainty information management and its simple calculations [53]. Hence, we combine the DEMATEL, the fuzzy ANP, the fuzzy AHP and the GRA approaches to construct a network hierarchical feedback system (NHFS) based on the integration of TQM and innovation.

The remainder of this paper is organized as follows. An overview of total quality management and innovation is discussed in Section 2. Research methods are proposed in Section 3. Our empirical study is detailed in Section 4. Conclusions are discussed in the last section.

2. An overview of total quality management and innovation

Because the aim of this paper is to construct a network hierarchical feedback system (NHFS) based on the integration of TQM and innovation for higher education, the mechanisms and evaluation criteria for both TQM and innovation proposed by past research are introduced in this section.

2.1 Total quality management (TQM)

There are various criteria for measuring TQM [43]. Based on previous research, the criteria for TQM are summarized in Table 1 [7]. In addition, many quality awards exist for rewarding TQM performance, such as the European Quality Award, the Malcolm Baldrige National Quality Award, the Asia-Pacific Business Excellence Standard, the Vietnam Quality Award, the QS 9000, and the IS 9000 [18]. These awards include various quality measurement criteria and play a (sometimes limited) role in standardizing the measurement of the overall quality of an organization [7]. In Taiwan, the National Quality Award (NQA) has been widely utilized to formally measure operational performance across different industries. The NQA takes into account leadership and operations ideals, strategy management, the development of a customer base and a market, human resources and knowledge management, the applications and management of information strategy, process management, and operational performance; due to its comprehensive scope and standardized usage, we adopt the NQA as the basis of our TQM criteria in accordance with Table 1.

Table 1. Criteria for TQM

Authors	TQM Factors
Brah et al. (2000)	Top management support, customer focus, employee involvement, employee training, employee empowerment, supplier quality management, process improvement, service design, quality improvement rewards, benchmarking, cleanliness and organization, and customer satisfaction.
Antony et al. (2002)	Management commitment, role of the quality department, training and education, employee involvement, continuous improvement, supplier partnership, product/service design, quality policies, quality data and reporting, communication to improve quality, and customer satisfaction orientation.
Sila & Ebrahimpour (2002)	Top management commitment, employee involvement, employee empowerment, education and training, teamwork, customer focus, process management, information and analysis systems, strategic planning, open organization, a service culture, and especially process management.
Shieh & Wu (2002)	Leadership, human resource management, process management, supply chain management and information management
Sureshchandar et al. (2002)	Top management commitment and visionary leadership, human resource management, technical systems, information and analysis systems, benchmarking, continuous improvement, customer focus, employee satisfaction, union intervention, social responsibility, services capes, and service culture.
Besterfield (2003)	Quality culture, the quality chain, quality assurance, commitment to continuous improvement, and the support of top management.
Prajogo & Sohal, (2003b)	Product innovation impacts the performance of total quality management.
Jacqueline et al. (2003)	Statistical process control, the commitment of top management, empowerment, and appropriate culture.
Wagner & Schaltegger (2004)	Leadership.
Kenneth & Cynthia (2004); Escrig-Tena (2004)	Financial performance.
Ozden & Birsen (2006)	Customer focus, continuous improvement, and teamwork.
Nusrah et al. (2006)	Employee empowerment, information and communication, customer focus, and continuous improvement.
Ismail (2006)	Leadership, strategic planning, customer focus, information and analysis, human resource management, process management, supplier management, human resource results, customer results, and organizational effectiveness.
Dinh & Triros (2006)	Strategic planning
Keng et al. (2007)	Teamwork, reward and recognition, customer focus, organizational trust, extensive training, high level of communication, management commitment at all levels, employee involvement, empowerment and organizational culture
Han et al. (2007)	Supplier relationship, customer involvement, training, top management commitment, and product design.
Chen & Chen	Market focus (customer relationship management), organization focus (unique

(2008)		competitive ability development), process focus (information utilization), and result focus (R&D and innovation productivity evaluation and development and financial evaluation and improvement).

Source: Chen & Chen [7]

2.2 Innovation

Recent studies have claimed that if an organization cannot keep innovating, the organization will fail [12, 35]. We summarize the most important innovation performance criteria in Table 2. With regard to Taiwanese universities, these criteria include the extent of international academic interaction, the amount of financial support from the National Science Council (NSC), the number of journal articles accepted and published, the number of conferences, the number of chair professors, and the pervasiveness of a results-oriented organizational culture. The most recently developed tool used to promote effective innovation performance across the three main types of Taiwanese universities is the innovation accelerated force involving transformational leadership [8]. Together, the criteria and the innovation accelerated force comprise an innovation support system (ISS) (as in Table 3). Another study conducted by the same author [6] proposed a pro-performance appraisal system (PPAS) that describes how a university conducts performance evaluation and improvement; the study also provided specific ways for Taiwanese universities to appraise the results of their efforts (see Figure 1). We argue that the measurement criteria of the PPAS are also relevant for measuring innovation. Hence, in this study, criteria from both the ISS (in detailed definitions for criteria see [8]) and PPAS (in detailed definitions for criteria see [6]) are adopted for use as innovation criteria.

Table 2. Criteria for innovation

Innovation Criteria	Reference
Patent	Griliches [25]; Hall et al. [27]; Toivanen et al. [49]
R&D Expenses	Boswoth & Rogers [3]; Griliches [25]; Hall [28]
Number of New Ideas	Damanpour [13]; Van Buren [52]
Number of New Products	Damanpour [13]; Ordaz et al. [42]; Schoenecker & Swanson [45]; Toivanen et al. [49]; Tushman & Nadler [50]
Number of New Designs	Hall & Bagchi-Sen [29]; Van Buren [52]
New Market and Customers Development	Chen & Chen [6]; Dzinkowski [20]
Innovative Culture	Dzinkowski [20]; Van Buren [52]
Number of R&D Workers	Guthrie & Petty [26]
Innovative Reference Product	Acs et al. [1]
Copyright and Brand	Bosworth & Rogers [3]
Royalties Income	Guthrie & Petty [26]; Van Buren [52]
Outer Tech Connection	Gambardella & Torriss [24]
New Services	Subramaniam & Youndt [46]
New Work Practices	Subramaniam &Youndt [46]

New Processes	O'Sullivan [41]; Ordaz et al. [42]

Table 3. An innovation support system (ISS)

IS System	IS Dimension	IS Criteria	Optimal IS Type
A Novel Innovation Support System (ISS)	Academic Research	International Academic Interaction Financial Support of NSC Journals Accepted and Published	Research-Intensive University (RU)
	External Academic Support	Number of Conferences Number of Chair Professors	
	Organizational Culture	Result-Oriented	
	Innovation Accelerated Force: Transformational Leadership		

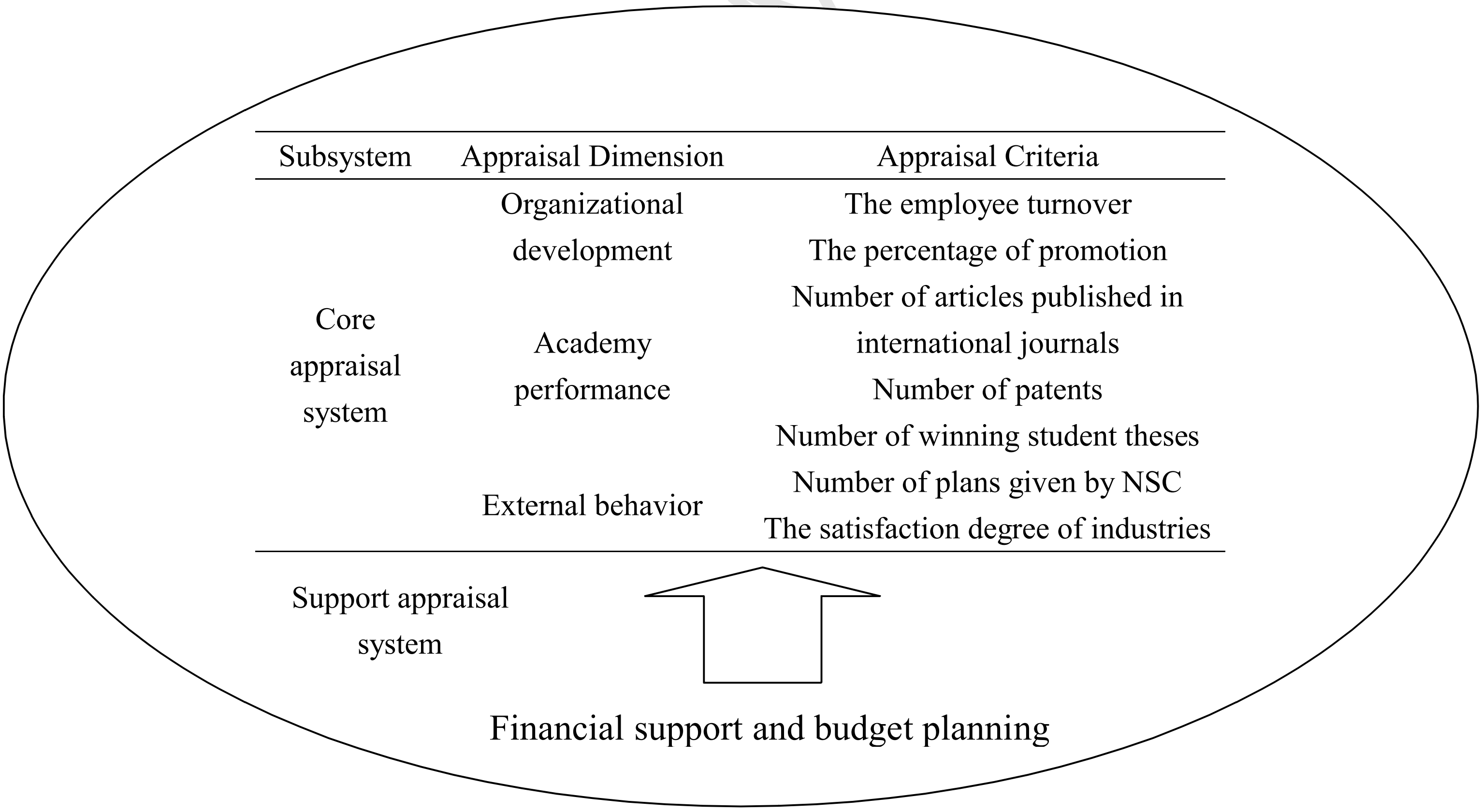


Fig. 1 A pro-performance appraisal system (PPAS)

3. Research methods

While quantifying precise values in a complex evaluation system can be difficult, complex systems can nonetheless be separated into several subsystems to more easily evaluate scores [38]. A DEMATEL approach is used here to address the interrelations between each of the TQM measurement criteria. The weights of each TQM criterion are generated through fuzzy ANP. Fuzzy AHP is then used to measure innovation criteria weights according to the effects of TQM criteria, which is the result of DEMATEL. Then, a GRA approach is utilized to rank alternatives (university types) based on the weights of innovation criteria, which is the result of Fuzzy AHP. Finally, we use our results to construct a network hierarchical feedback system (NHFS) based on the integration of TQM and innovation.

3.1 The DEMATEL method

Evaluating a single effect from a single factor is difficult within a complex system. Avoiding interference from the rest of the system is difficult because factors in a complex system may directly or indirectly relate to others [38]. 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 distinct from those found in non-hierarchical systems [51].

The Battelle Geneva Institute created DEMATEL to solve difficult problems involving interactive, man-model techniques and to measure qualitative and factor-linked aspects of societal problems [23]. In addition, DEMATEL has been utilized in numerous contexts, including industrial planning, decision making, and regional and global environmental assessment [23]; in all cases, DEMATEL has confirmed the interdependence of the criteria and has restricted relations to reflect essential characteristics and development trends within a core system [38].

The foundation of the DEMATEL method is graph theory, which allows analysts to analyze and solve problems through a clear, precise, and numerical approach. As a result, analysts can separate multiple measurement criteria into cause and effect groups to understand causal relationships much more easily. In addition, directed graphs, called digraphs, are much more helpful than are directionless graphs because digraphs depict the directed relationships among subsystems. In other words, a digraph represents a communication network or domination relationship among entities and their groupings [33].

The calculation steps used in the DEMATEL method are as follows [38, 55].

Step 1: Calculate the initial average matrix by scores.

Based on sampled group of expert opinions, experts are asked to pinpoint the direct effect that each element *i* exerts on each element *j* (represented by a_{ij}) using a scale ranging from zero to four. Zero represents no influence, while four represents a very high degree of influence. Based on the direct matrices from the sampled group of expert, we can generate an average matrix *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* is calculated so that all principal diagonal elements equal zero. In the initial influence matrix *D*, the initial effect that an element exerts and/or acquires from its corresponding element is given. The resulting map depicts a contextual relationship among the elements within a complex system, wherein each matrix entry can be seen as that entry's strength of influence. As a result, we can easily translate the relationship between the causes and effects of various measurement criteria using DEMATEL into a comprehensible structural model based on the degree of influence.

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

The indirect effects of problems decrease as the powers of *D* increase—for instance, $D^1, D^2, D^3, \ldots, D^\infty$—which guarantees convergent solutions to the inverse of the matrix. Therefore, we can generate an infinite series of both direct and indirect effects. If the (*i*,*j*) element of matrix *A* is represented by a_{ij}, then the direct-indirect matrix can be generated through equations (1) through (4).

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

or

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

where

$$s = \text{Min}\left[1/\max 1 \le i \le n \sum_{j=1}^{n} |aij| \quad , 1/\max 1 \le j \le n \sum_{i=1}^{n} |aij|\right] \tag{3}$$

and

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

The total-influence matrix *T* can be acquired using equation (5). Here, *I* is the identity matrix.

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

If the sum of the rows and the sum of the columns in the total influence matrix *T* are represented as vectors *r* and *c*, respectively, then

$$T = [t_{ij}], \; i,j = 1,2,\ldots,m, \tag{6}$$

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

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

where the superscript apostrophe denotes transposition.

If r_i represents the sum of the ith row of matrix *T*, then r_i presents the sum of both the direct and indirect effects of factor *i* on all other criteria. In addition, if c_j represents the sum of the jth column of matrix *T*, then c_j represents the sum of both the direct and indirect effects that all other factors have on *j*. Moreover, note that *j* = *i* (r_i+c_i) shows the degree to which factor *i* affects or is affected by *j*. Note that if (r_i-c_i) is positive, then factor *i* affects other factors, and if it is negative, then factor *i* is affected by other factors [38, 51].

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

Lastly, we must set a threshold value. This value is generated by taking into account the sample of expert opinions in order to filter any minor effects present among the elements in matrix *T*. This process is necessary to isolate the relation structure of the most relevant factors. In accordance with matrix *T*, each factor t_{ij} provides information about how factor *i* affects factor *j*. To decrease the complexity of the impact relations map, a threshold value must be determined for the influence of each factor. That is, if the influence 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) [38].

3.2 The fuzzy AHP and ANP

3.2.1 Fuzzy set theory

The fuzzy set theory was first developed when Zadeh [56] considered fuzzy phenomena that are hard to define precisely, such as uncertain, incomplete, unspecific, and fuzzy situations or problems. Fuzzy set theory is better than traditional set theory at describing set concepts in human language. It shows unspecific and fuzzy characteristics in language on the evaluation, and it uses a membership function concept to represent the field, i.e., the "Universe of Discourse" in which a fuzzy set can permit situations such as "incompletely belongs to" and "incompletely does not belong to."

3.2.2. Fuzzy number

Fuzzy numbers are a fuzzy subset of real numbers, and they represent an expanded version of a confidence interval. According to the definition by Dubois and Prade [19], the fuzzy number $\tilde{A}$ is of a fuzzy set, and its membership function is $\mu_{\tilde{A}}(x):R \rightarrow [0, 1]$ ($0 \leqq \mu_{\tilde{A}}(x) \leqq 1$, $x \in X$), where x represents the criterion and is described by the following characteristics: (1) $\mu_{\tilde{A}}(x)$ is a continuous mapping from R (real line) to the closed interval [0, 1]; (2) $\mu_{\tilde{A}}(x)$ is of a convex fuzzy subset; (3) $\mu_{\tilde{A}}(x)$ is the normalization of a fuzzy subset, which means that there exists a number x_0 such that $\mu_{\tilde{A}}(x_0)=1$. For instance, the triangular fuzzy number (TFN), $\tilde{A}=(l,m,u)$, can be defined as Eq. (9), and the TFN membership function is shown in Fig. 2.

$$\mu_{\tilde{A}}(x)=\begin{cases}(x-l)/(m-l), & l\le x\le m,\\ (u-x)/(u-m), & m\le x\le u,\\ 0 & , otherwise,\end{cases} . \quad (9)$$

Given two positive triangular fuzzy numbers $\tilde{A}_1=(l_1,m_1,u_1)$ and $\tilde{A}_2=(l_2,m_2,u_2)$, some algebraic operations of the triangular fuzzy numbers $\tilde{A}_1$ and $\tilde{A}_2$ can be expressed as follows:

$$\tilde{A}_1 \oplus \tilde{A}_2=(l_1,m_1,u_1)\oplus(l_2,m_2,u_2)=(l_1+l_2,m_1+m_2,u_1+u_2) \quad (10)$$

$$\tilde{A}_1 \otimes \tilde{A}_2=(l_1,m_1,u_1)\otimes(l_2,m_2,u_2)=(l_1l_2,m_1m_2,u_1u_2) \quad (11)$$

$$\tilde{A}_1 - \tilde{A}_2=(l_1,m_1,u_1)-(l_2,m_2,u_2)=(l_1-u_2,m_1-m_2,u_1-l_2) \quad l_i>0,\ m_i>0, \quad (12)$$

$$\tilde{A}_1 \div \tilde{A}_2=(l_1,m_1,u_1)\div(l_2,m_2,u_2)=(l_1/u_2,m_1/m_2,u_1/l_2) \quad l_i>0,\ m_i>0,\ u_i>0 \quad (13)$$

$$\tilde{A}_1^{-1}=(l_1,m_1,u_1)^{-1}=(1/u_1,1/m_1,1/l_1) \quad l_i>0,\ m_i>0,\ u_i>0 \quad (14)$$

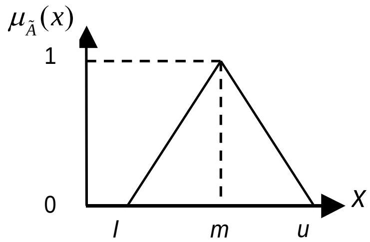


Fig. 2 Membership function of a triangular fuzzy number

3.2.3. Fuzzy linguistic variable

Before discussing the fuzzy linguistic variable, we must first define the linguistic variable. The linguistic variable is a variable whose value is a word or sentence in a natural or artificial language. Linguistic variables regarding human words or sentences can be evaluated in terms of importance by using ratings such as equally important, moderately important, strongly important, very strongly important, and extremely important, as shown in Figure 3. The evaluators are asked to conduct their judgments, and each linguistic variable can be indicated by a TFN as in Table 4. Because the above variables could be made quantifiable by applying triangular fuzzy numbers from a range of 1-9 (as in Figure 3), they are called the fuzzy linguistic variables. For the purposes of the present study, a 5-point scale (i.e., equally important, moderately important, strongly important, very strongly important and extremely important) is used for linguistic variables represented by triangular fuzzy numbers.

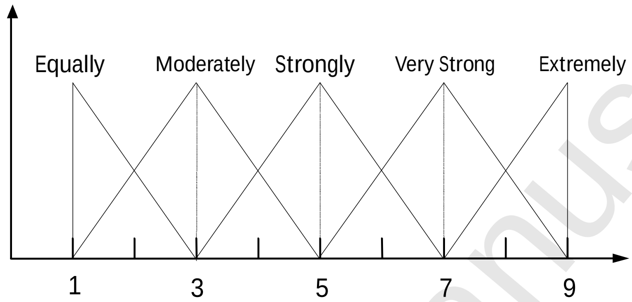


Fig. 3 Fuzzy membership function for linguistic variables for attributes

Table 4. Definition and membership function of fuzzy number

Fuzzy Number	Linguistic Variable	TFN ($\tilde{a}_{ij}$)	Reciprocal of a TFN ($\tilde{a}_{ij}^{-1}$)
$\tilde{9}$	Extremely important/preferred	(7,9,9)	(1/9, 1/9, 1/7)
$\tilde{7}$	Very strongly important/preferred	(5,7,9)	(1/9, 1/7, 1/5)
$\tilde{5}$	Strongly important/preferred	(3,5,7)	(1/7, 1/5, 1/3)
$\tilde{3}$	Moderately important/preferred	(1,3,5)	(1/5, 1/3, 1)
$\tilde{1}$	Equally important/preferred	(1,1,3)	(1/3, 1, 1)
$\tilde{2}, \tilde{4}, \tilde{6}, \tilde{8}$	Intermediate value between two adjacent judgments		

3.2.4 Fuzzy analytic hierarchy process

The Analytic Hierarchy Process (AHP) was devised by Saaty [44]. It is a useful approach in solving complex decision problems. It prioritizes the relative importance of a list of criteria (critical factors and sub-factors) by utilizing pairwise comparisons amongst the factors, which are determined by relevant experts using a 9-point scale. Buckley [2] incorporated the fuzzy theory into the AHP and called it the Fuzzy Analytic Hierarchy Process (FAHP). The FAHP generalizes the calculation of the consistent ratio (C.R.) into a fuzzy matrix. The FAHP's procedure for determining the evaluation weights are explained as follows:

Step 1: Construct fuzzy pairwise comparison matrices. Through expert questionnaires, each expert is asked to assign linguistic terms by TFN (as shown in Fig. 3 and Table 4) to the pairwise comparisons among all criteria in the given dimensions of a hierarchy system. The results of the comparisons are constructed as fuzzy pairwise comparison matrices ($\tilde{\boldsymbol{A}}$), as shown in Eq. (7).

Step 2: Examine the consistency of the fuzzy pairwise comparison matrices. According to Buckley's research [2], if $\boldsymbol{A}=[a_{ij}]$ is a positive reciprocal matrix, then $\tilde{\boldsymbol{A}}=[\tilde{a}_{ij}]$ is a fuzzy positive reciprocal matrix. That is, if the result of the comparisons of $\boldsymbol{A}=[a_{ij}]$ is consistent, then the result of the comparisons of $\tilde{\boldsymbol{A}}=[\tilde{a}_{ij}]$ can also be considered consistent. This research employs this method to validate the questionnaire.

$$\tilde{\boldsymbol{A}}=\begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1 \end{bmatrix}=\begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ 1/\tilde{a}_{12} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{a}_{1n} & 1/\tilde{a}_{2n} & \cdots & 1 \end{bmatrix} \quad (15)$$

Step 3: Compute the fuzzy geometric mean for each criterion. The geometric technique is used to calculate the geometric mean ($\tilde{r}_i$) of the fuzzy comparison values of criterion *i* to each of the other criteria, as shown in Eq. (16), where $\tilde{a}_{in}$ is a fuzzy value of the pair-wise comparison of criterion *i* to criterion *n* [2].

$$\tilde{r}_i=\left[\tilde{a}_{i1}\otimes\ldots\otimes\tilde{a}_{in}\right]^{1/n} \quad (16)$$

Step 4: Compute the fuzzy weights by normalization. The fuzzy weight of the *i*th criterion ($\tilde{\boldsymbol{w}}_i$) can be derived as shown by Eq. (17), where $\tilde{\boldsymbol{w}}_i$ is denoted as $\tilde{\boldsymbol{w}}_i=(l_{W_i},m_{W_i},u_{W_i})$ by a TFN, and l_{W_i} , m_{W_i} , and u_{W_i} represent the lower, middle, and upper values of the fuzzy weight of the *i*th criterion.

$$\tilde{\boldsymbol{w}}_i=\tilde{r}_i\otimes(\tilde{r}_1\oplus\tilde{r}_2\oplus\cdots\oplus\tilde{r}_n)^{-1} \quad (17)$$

Step 5: Defuzzy: The study finds the best crisp value, Best Nonfuzzy Performance (BNP), in accordance with the Center of Area (COA) or Center Index (CI), a concept developed by Teng & Tzeng [48]. The *BNP* value of the fuzzy number, the weight for each criterion, can be calculated by Eq. (18).

$$BNP_i=[(U_i-L_i)+(M_i-L_i)]/3+L_i,\forall i \quad (18)$$

3.2.5 Analytic network process (ANP)

The purpose of the ANP approach is to solve problems involving interdependence and feedback among 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) to consider non-hierarchical structures. MCDM has been applied to numerous disciplines [32].

ANP first involves comparing the measurement criteria to form a super matrix. This act can be accomplished by using pair-wise comparisons. The relative importance-values of pair-wise comparisons can be categorized from one to nine in order to represent the pairings, with (1) signifying equal importance and (9) signifying extreme inequality in importance (9) [44]. Figure 4 shows the general form of the super matrix [38, 55], where C_m represents the mth cluster, e_{mn} represents the nth element in the mth cluster, and W_{ij} is the principal eigenvector of the influence of the elements compared in the jth cluster to the ith cluster. In addition, if the jth cluster has no influence on the ith cluster, then W_{ij} = 0 [55].

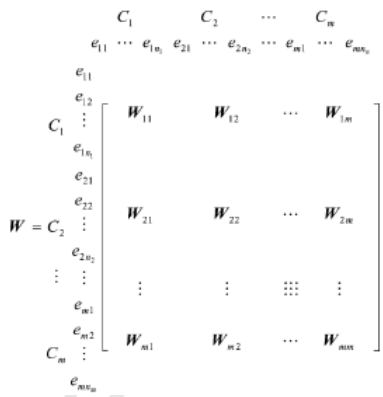
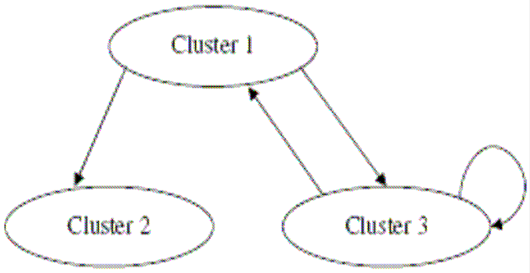
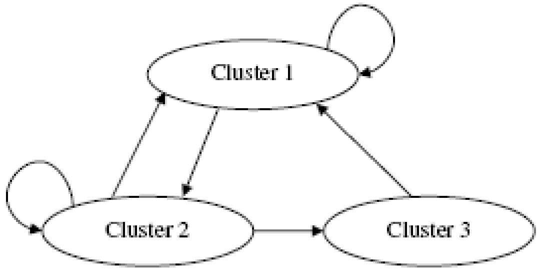


Fig. 4 The general form of the super matrix

Thus, the form of the super matrix depends on its structure type. To demonstrate how the structure is affected by the super matrix, Huang et al. [32], Yu and Tseng [55], and Liou et al. [38] offer two simple cases, both of which involve three clusters that form a super matrix in accordance with these different structures (see Table 5). Case 1 is much simpler than Case 2; the resulting super matrices based on each structure are also shown in Table 5.

Table 5. Two simple cases

Number	Case 1	Case 2

Structure type		
Matrix form	$W = \begin{matrix} & C_1 & C_2 & C_3 \\ C_1 & 0 & 0 & W_{13} \\ C_2 & W_{21} & 0 & 0 \\ C_3 & W_{31} & 0 & W_{33} \end{matrix}$	$W = \begin{matrix} & C_1 & C_2 & C_3 \\ C_1 & W_{11} & W_{12} & W_{13} \\ C_2 & W_{21} & W_{22} & 0 \\ C_3 & 0 & W_{32} & 0 \end{matrix}$

Next, the weighted super matrix is generated by transforming all column sums to unity [32, 55]; then, we use the weighted super matrix to generate a limiting super matrix by using Eq. (19) to calculate global weights [32].

$$\lim_{k\to\infty} W^k \tag{19}$$

In this step, if the super matrix shows signs of cyclicity, then more than one limiting super matrix will exist. That is, there will be two or more limiting super matrices, and the Cesaro sum must be calculated to ascertain priority among these matrices [55]. The Cesaro sum is calculated using Eq. (20) [32, 55].

$$\lim_{N\to\infty}(1/N)\sum_{k=1}^{N} W^k \tag{20}$$

Eq. (20) calculates the average effect of a limiting super matrix; otherwise, the super matrix can be raised to a large power to generate priority weights [38, 55].

3.3 Gray relational analysis

Gray system theory mainly involves ambiguous or uncertain problems and situations with discrete data and incomplete information [16]. It is currently used in fields such as forecasting, system control, data processing, modeling, and decision making [4, 30]. One of the popular advantages of gray system theory is that it can generate satisfactory outcomes by utilizing a relatively small amount of data or by using great variability in factors [54]. It achieves these results by increasing the regularity of the data [36]. Just like fuzzy set theory, gray theory is an effective mathematical model for resolving uncertain and indeterminate problems [30].

The concept of gray relational space was developed by Deng [14] and is based on the combined concepts of system theory, space theory, and control theory. Gray relational space can be used to capture correlations between reference factors and other systemic factors [15]. That is, GRA analyzes the uncertain relations between one main factor and all the other factors in a given system [37]. Gray relational analysis has been successfully used to solve various decision problems, such as multiple-attribute decision-making problems [11, 53], image compression [31], generation scheduling for hydroelectricity, [37] and performance evaluations for airlines [22].

The relevant/similarity definitions are described as follows.

Definition 1. Let X be a factor set of gray relation, $x_0 \in X$ the referential sequence, and $x_i \in X$ the comparative sequence, with $x_0(k)$ and $x_i(k)$ representing the numerals at point k for x_0 and x_i, respectively. If $\gamma(x_0(k), x_i(k))$ and $\gamma(x_0, x_i)$ are of real numbers and satisfy the following four gray axioms, then $\gamma(x_0(k), x_i(k))$ will be called the gray relation coefficient and the grade of gray relation $\gamma(x_0, x_i)$ will be the average value of $\gamma(x_0(k), x_i(k))$.

1. Norm Interval

$0<\gamma(x_0, x_i) \leq 1, \ \forall k$;

$\gamma(x_0, x_i)=1$ *iff* $x_0 = x_i$;

$\gamma(x_0, x_i)=0$ *iff* $x_0, x_i \in \varnothing$; where $\varnothing$ is an empty set.

2. Duality Symmetric

$x, y \in X; \ \gamma(x, y) = \gamma(y, x)$ *iff* $X=\{x, y\}$.

3. Wholeness

$\gamma(x_i, x_j) \overset{often}{\neq} \gamma(x_j, x_i)$ *iff* $X=\{x_i \mid i=0,1,2,\ldots, n\}$, $n>2$.

4. Approachability

$\gamma(x_0(k), x_i(k))$ decreases along with $\left|(x_0(k), x_i(k))\right|$ increasing.

Deng also developed a computational equation for the gray relation coefficient as follows (as Eq. 21):

$$\gamma(x_0(k), x_i(k)) = \min_i \min_k \Delta_i(k) + \zeta \max_i \max_k \Delta_i(k) \Big/ \Delta_i(k) + \zeta \max_i \max_k \Delta_i(k), \tag{21}$$

where $\Delta_i(k) = \left| x_0(k) - x_i(k) \right|$, and ζ is the distinguished coefficient ($\zeta \in [0,1]$).

Definition 2. If $\gamma(x_0, x_i)$ satisfies the four axioms of gray relation, then γ is said to be the gray relational map.

Definition 3. If Γ is the entirety of the gray relational map, $\gamma \in \Gamma$ satisfies the four axioms of gray relation, and X is the factor set of gray relation, then (X, Γ) will be called the gray relational space, while γ will be the specific map for Γ.

Definition 4. If (X, Γ) is the gray relational space and $\gamma(x_0, x_i)$, $\gamma(x_0, x_p)$, …, $\gamma(x_0, x_q)$ satisfy $\gamma(x_0, x_j) > \gamma(x_0, x_p) > \ldots > \gamma(x_0, x_q)$, then the gray relational order will be $x_j \succ x_p \succ \ldots \succ x_q$.

As soon as the degree of the gray relation between the referential sequence and other sequences is acquired the alternatives can be ranked according to Eq. 22.

$$\gamma(x_0, x_i) = \sum_{k=1}^{n} w_k \, \gamma(x_0(k), x_i(k)), \tag{22}$$

Here, w_k denotes the weights of the kth criteria. Weights $w=(w_{1,\ldots,} w_j, \ldots, w_n)$ can be acquired through AHP or ANP.

The calculation steps for GRA are summarized as follows [53].

Step 1. Generate the referential series X_0 and comparative series X_i.

Given an original decision-making matrix D, the referential series $x_0=(x_0(1), x_0(2), \ldots, x_0(j), \ldots, x_0(n))$, where $j=1, 2, 3, \ldots, n$, is generated from the ideal value under each measurement criteria. The comparative series X_i of $x_i=(x_i(1), x_i(2), \ldots, x_i(j), \ldots, x_i(n))$, where $i=1, 2, 3, \ldots, n$, is the performance value of each alternative.

Step 2. Normalize the original decision-making matrix D.

The series data in the original decision-making matrix D can be normalized using one of three treatments: "larger-is-better," "smaller-is-better," and "nominal-is-best." Because the former two are utilized regularly and the last is less discussed, we will mainly focus on the former two transformations. For the "larger-is-better" data transformation, $x_i(j)$ is transformed into $x_i^*(j)$. The formula is defined in Eq. (23).

$$x_i^*(j) = \left[x_i(j) - \min_i x_i(j)\right] / \left[\max_i x_i(j) - \min_i x_i(j)\right], \tag{23}$$

Here, $\max_i x_i(j)$ is the maximum value of entity j, and $\min_i x_i(j)$ is the minimum value of entity j. For the "smaller-is-better" transformation, $x_i(j)$ is transformed into $x_i^*(j)$ using Eq. (24).

$$x_i^*(j) = \left[\max_i x_i(j) - x_i(j)\right] / \left[\max_i x_i(j) - \min_i x_i(j)\right] \tag{24}$$

In the meantime, the referential series must also be normalized. After normalization, the referential series of x_0 will become x_0^*.

Step 3. Calculate the gray distance $\Delta_{0i}(j)$.

The gray distance $\Delta_{0i}(j)$ is the absolute value of the difference between x_0^* and x_i^* at point *j*. It could be acquired by adopting Eq. (25).

$$\Delta_{0i}(j) = \left| x_0^*(j) - x_i^*(j) \right| \tag{25}$$

Step 4. Compute the gray relational coefficient $\gamma_{0i}(j)$ using Eq. (26).

$$r_{0i}(j) = \left[\Delta_{\min} + \xi\,\Delta_{\max}\right] / \left[\Delta_{0i}(j) + \xi\,\Delta_{\max}\right] \tag{26}$$

Here, $\Delta_{\min} = \min_i \min_j \Delta_{0i}(j)$, $\Delta_{\max} = \max_i \max_j \Delta_{0i}(j)$, and ξ is the distinguished coefficient ($\xi \in [0,1]$).

Step 5. Calculate the gray relational grade Γ_{0i}.

If the weights $W_i(j)$ of the criteria are determined, the gray relational grade is defined in Eq. (25).

$$\Gamma_{oi} = \sum_{j=1}^{n} \left[W_i(j) \times r_{oi}(j) \right] \tag{27}$$

Based on the GRA, once any one of the alternatives has a higher gray relational grade than any other, it becomes the most crucial (i.e., the optimal) alternative.

4. Empirical study

To construct the network hierarchical feedback system (NHFS), several steps are required. First, the criteria exploration and original system construction are introduced; second, the evaluation of the relationships between TQM dimensions is conducted; third, the weighting of the TQM measurement criteria in the original NHFS is calculated using the results of the evaluation; fourth, the weighting of the innovation criteria is computed based on the weights of the TQM measurement criteria; and finally, the performance evaluations among university types are measured by taking the weights of the innovation criteria into account. In accordance with the results, the network hierarchical feedback system (NHFS) is finally constructed.

4.1 Criteria exploration and construction of our original system

Constructing a network hierarchical feedback system (NHFS) for higher education based on the integration of TQM and innovation is complicated because of numerous factors, such as the characteristics of TQM and innovation, the types of Taiwanese universities, and the interrelationships of the measurement criteria. In addition, a network hierarchical feedback system (NHFS) based on the integration of TQM and innovation should obviously reflect real practices. For this paper, 20 senior higher education experts were consulted, including 5 from research-intensive universities, 5 from professional-intensive universities, 5 from teaching-intensive universities, and 5 from education-in-practice-intensive universities. Moreover, the work items of the National Science Council, the content of the NQA, and the R&D departments of twelve universities were consulted to construct an original eight-dimension TQM network hierarchical feedback system (NHFS) based on the integration of TQM and innovation. We include the following dimensions: Leadership and Operation Ideals (D1), Strategy Management (D2), R&D and Innovation (D3), the Development of a Customer Base and a Market (D4), Human Resource and Knowledge Management (D5), the Application and Management of Information Strategy (D6), Process Management (D7), and Operation Performance (D8). Each dimension includes 3 to 8 TQM measurement criteria (e.g. T1, T2, … T33); we also include ten innovation measurement criteria. These criteria include Research Patents (I1), International Academic Interaction (I2), Financial Support of National Science Council (I3), Journals Accepted and Published (I4), Government Tender Planning (I5), Travel Abroad for Further Education (I6), Number of Conferences (I7), Number of International Students in School (I8), Number of Chair Professors (I9), and Results-Oriented Organizational Culture (I10), as shown by Table 6. To obtain expert rankings for these criteria, a questionnaire was sent to four groups comprising a total of 75 experts, including 41 experts from research-intensive universities, 13 from teaching-intensive universities, 15 from a professional-intensive university, and 6 from an education-in-practice-intensive university. The experts' rankings were conducted using the 5-point scale shown in Table 4 and sorted for TQM-innovation performance by utilizing a range from 100 (the best) to 50 (the worst). Their rankings were based on their professional experiences.

Table 6. Original NHFS

Goal	Evaluation Dimensions For TQM	Evaluation Criteria For TQM	Evaluation Criteria For Innovation	University Type
A Network Hierarchical System based on the Combination of TQM and Innovation	Leadership and Operation Ideals (D1)	Operational Values and Ideals Restructure (T1) Organizational Quality Improving Mission (T2) Top Managers' Leading Style (T3) TQM Culture Construction (T4) The Increasing of Social Contribution (T5)	Research Patents (I1)	Research-Intensive University (RU)
	Strategy Management (D2)	Organization Operation Strategy Planning (T6) Operation Structure Adjustment (T7) The Quality Improvement of Strategy (T8)	International Academic Interaction (I2)	
	R&D and Innovation (D3)	Process Redefinition of R&D and Innovation (T9)	Financial Support of National	Teaching-Intensive

	Input of R&D and Innovation (T10)	of National Science Council (I3)	University (TU)
	Evaluation of R&D and Innovation Results (T11)		
The development of Customers and a Market (D4)	Market Operation Strategy Development (T12)		
	Business Relation Management (T13)	Journals Accepted and Published (I4)	
	Customer Relationship Management (T14)		
Human Resource and Knowledge Management (D5)	Human Resource Planning (T15)		
	Human Resource Development (T16)		
	Human Resources Utilization (T17)	Government Tender Planning (I5)	
	Employee Relationship Management (T18)		
	Knowledge Management (T19)	Go Abroad for Further Education (I6)	Professional-Intensive University (PU)
The Application and Management of Information Strategy (D6)	Information Receiving Channel (T20)		
	Internet Applications (T21)		
	Information Utilization (T22)	Number of Conferences (I7)	
Process Management (D7)	Job Rotation (T23)		
	Supportive Activity Planning (T24)		
	Job Enrichment (T25)	Number of International Students in School (I8)	
Operation Performance (D8)	Customer Satisfaction (T26)		
	Market Enlargement Performance (T27)		
	Financial Performance (T28)		
	Human Resource Development Performance (T29)	Number of Chair Professors (I9)	Education-in-practical -Intensive University (EIPU)
	Information Management Performance (T30)		
	Process Management Performance (T31)		
	Unique Competitive Ability Gaining Performance (T32)	Result-Oriented Organizational Culture (I10)	
	Prestige Measurement (T33)		

4.2 Evaluating the relationships between TQM dimensions

We asked 75 senior education experts to indicate the critical level of relationships for TQM measurement dimensions based on their experience. Summarizing their responses, we derive the average initial direct-relation 8x8 matrix *A* through pair-wise comparisons, as shown in Table 7.

Table 7. The average initial direct-relation 8x8 matrix *A*

	D1	D2	D3	D4	D5	D6	D7	D8
D1	0	3.34	2.14	2.31	1.12	1.04	3.24	1.10

D2	3.63	0	3.52	3.26	1.31	1.11	3.37	2.01
D3	1.42	1.23	0	3.47	3.39	1.20	2.01	3.63
D4	1.00	1.09	3.68	0	3.24	1.03	1.00	3.23
D5	1.41	1.32	3.56	2.76	0	1.10	2.06	2.13
D6	1.00	1.00	1.32	1.02	1.43	0	3.56	1.22
D7	1.01	1.00	1.21	1.07	3.24	3.61	0	1.39
D8	1.24	2.13	2.06	3.88	1.04	1.10	1.09	0

Using Eqs. (1) to (3), we acquire the normalized direct-relation matrix *D* from matrix *A*. Then, Eq. (5) is adapted to generate the total influence matrix *T*, as Table 8 shows. After that, Eq. (7) and Eq. (8) are used to analyze the total influence given and received along TQM measurement dimensions; the result is shown in Table 9.

Table 8. Total influence matrix *T*

	D1	D2	D3	D4	D5	D6	D7	D8
D1	0.408	0.912	0.925	0.944	0.800	0.561	0.865	0.789
D2	0.934	0.521	1.068	1.073	0.888	0.609	0.923	0.913
D3	0.536	0.628	0.562	1.106	0.990	0.611	0.863	1.003
D4	0.472	0.566	1.009	0.845	0.905	0.544	0.740	0.911
D5	0.491	0.652	1.000	0.980	0.742	0.556	0.796	0.856
D6	0.354	0.417	0.652	0.646	0.901	0.373	0.691	0.589
D7	0.402	0.473	0.744	0.744	0.778	0.908	0.590	0.679
D8	0.436	0.562	0.846	0.944	0.720	0.496	0.673	0.661

Table 9. The sum of influences on measurement dimensions

Measurement Dimensions	r_i+c_i	r_i-c_i
D1	10.24	2.17
D2	11.66	2.20
D3	13.11	-0.51
D4	13.27	-1.29
D5	12.80	-0.65
D6	9.28	-0.04
D7	11.46	-0.82
D8	11.74	-1.06

To avoid inordinately complex relationships within a system, a threshold value 0.9 is adopted after consultation with senior education experts. The impact relations map (IRM) is provided in Figure 5. Each arrow represents how one dimension impacts another. For instance, dimension 7 (D7) impacts D6 but is impacted in turn by D2.

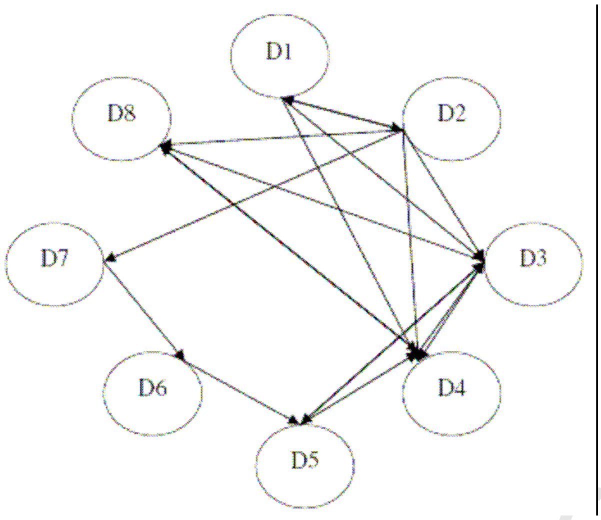


Fig. 5 The impact relations map for TQM measurement dimensions

4.3 Weighting the TQM measurement criteria in the original NHFS

Here, the fuzzy ANP is used to calculate the weights of TQM measurement criteria after illustrating the relationship structure of the original NHFS. After first, the importance of the relationships among TQM measurement criteria is depicted in the impact relations map. Pairwise comparisons are made according to Table 8. Table 10 presents the results, which are formed as an unweighted super matrix.

Following Eq. (19), the limiting power of the unweighted matrix is calculated until it becomes stable, as shown in Table 11. The rows contain the same value and represent the global weights of each TQM measurement criterion. Note that values that are less than 0.0001 will be marked as *n*, i.e., as less critical according to expert opinion. The impact-direction map depicting the importance of each TQM measurement criteria based on these results (as indicated in Table 9) is given in Figure 6.

Table 10. The unweighted matrix of TQM measurement criteria

	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20	T21	T22	T23	T24	T25	T26	T27	T28	T29	T30	T31	T32	T33
T1	0.00	0.00	0.00	0.00	0.00	0.04	0.03	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T2	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T3	0.00	0.00	0.00	0.00	0.00	0.03	0.04	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T4	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T5	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T6	0.11	0.16	0.14	0.13	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T7	0.01	0.02	0.02	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T8	0.13	0.14	0.10	0.14	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T9	0.04	0.07	0.03	0.04	0.03	0.06	0.06	0.09	0.00	0.00	0.00	0.04	0.05	0.07	0.02	0.01	0.01	0.02	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T10	0.21	0.18	0.21	0.20	0.21	0.15	0.12	0.13	0.00	0.00	0.00	0.20	0.19	0.24	0.25	0.23	0.23	0.31	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T11	0.32	0.21	0.36	0.30	0.37	0.17	0.14	0.14	0.00	0.00	0.00	0.31	0.33	0.30	0.48	0.54	0.43	0.42	0.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T12	0.06	0.08	0.04	0.06	0.05	0.03	0.01	0.03	0.01	0.03	0.01	0.00	0.00	0.00	0.09	0.07	0.10	0.05	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.37	0.28	0.36	0.34	0.34	0.17	0.24	0.36
T13	0.09	0.10	0.07	0.09	0.06	0.04	0.03	0.03	0.04	0.02	0.01	0.00	0.00	0.00	0.10	0.13	0.20	0.17	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.56	0.71	0.63	0.59	0.62	0.73	0.67	0.63
T14	0.03	0.04	0.03	0.03	0.02	0.01	0.04	0.05	0.01	0.03	0.04	0.00	0.00	0.00	0.06	0.02	0.03	0.03	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.01	0.01	0.07	0.04	0.10	0.09	0.01
T15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.07	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.06	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.19	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.06	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.21	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.41	0.29	0.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.51	0.47	0.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.13	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.63	0.58	0.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

T22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.29	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T23	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T24	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T25	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T26	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.03	0.04	0.03	0.01	0.01	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T27	0.00	0.00	0.00	0.00	0.00	0.04	0.05	0.02	0.01	0.02	0.01	0.04	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T28	0.00	0.00	0.00	0.00	0.00	0.09	0.13	0.10	0.12	0.13	0.12	0.09	0.11	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T29	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.02	0.02	0.03	0.01	0.02	0.01	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T30	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.04	0.01	0.02	0.03	0.04	0.05	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T31	0.00	0.00	0.00	0.00	0.00	0.04	0.02	0.03	0.04	0.05	0.03	0.03	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T32	0.00	0.00	0.00	0.00	0.00	0.11	0.12	0.12	0.13	0.18	0.24	0.17	0.20	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T33	0.00	0.00	0.00	0.00	0.00	0.05	0.03	0.01	0.03	0.02	0.03	0.05	0.01	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

*1. At the 100th position after the decimal point, drop numbers less than or equal to 4, and round up 1 for numbers higher/more than 4

Table 11. The weighted matrix of TQM measurement criteria

	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20	T21	T22	T23	T24	T25	T26	T27	T28	T29	T30	T31	T32	T33
T1	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
T2	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
T3	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
T4	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
T5	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
T6	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n

T7	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
T8	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
T9	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
T10	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
T11	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
T12	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
T13	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
T14	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
T15	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
T16	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
T17	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
T18	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
T19	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
T20	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
T21	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
T22	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
T23	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
T24	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
T25	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
T26	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
T27	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
T28	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
T29	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

T30	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
T31	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
T32	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
T33	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02

*1. n: Value less than 0.0001 (less important)

2. At the 100th position after the decimal point, drop numbers less than or equal to 4, and round up 1 for numbers higher/more than 4

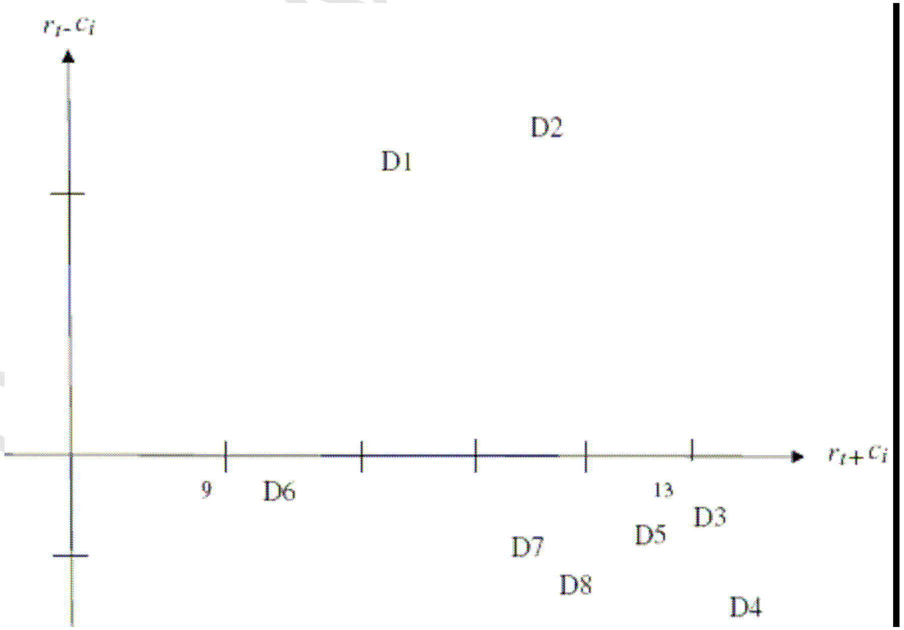


Fig. 6 The impact-direction map of TQM measurement criteria

4.4 Weighting the innovation criteria

After acquiring the global weights of the TQM measurement criteria as described above, the top eight TQM measurement criteria are extracted (T9, T10, T11, T12, T13, T19, T28, and T32) in accordance with the opinions of over half of the senior education experts to make our system approximate directions more precisely. We used these criteria to conduct the following calculations. First, the top eight TQM measurement criteria were normalized, as shown in Table 12.

Table 12. Normalized global weights for the top eight TQM measurement criteria

	T9	T10	T11	T12	T13	T19	T28	T32
Initial Global Weight	0.11	0.09	0.14	0.09	0.16	0.07	0.07	0.08
Normalized Global Weights	0.136	0.111	0.173	0.111	0.198	0.086	0.086	0.099

Then, 75 senior education experts were asked to give the relative weights of the innovation measurement criteria by using pair-wise comparisons of the top eight TQM measurement criteria, as shown in Table 13.

The normalized global weights of the top eight TQM measurement criteria and the relative weights of the innovation measurement criteria are calculated using fuzzy AHP calculation. Initially, the local weights of the innovation criteria under each TQM measurement criterion are computed, as presented in each column in Table 13. In accordance with the results, the global weights of the innovation measurement criteria can then be acquired using the following calculation, the results of which are summarized at the bottom of Table 13.

$$I1 = [(0.28 \times 0.136) + (0.12 \times 0.111) + \cdots + (0.10 \times 0.099)] = 0.138$$

$$\vdots$$

$$I10 = [(0.01 \times 0.136) + (0.01 \times 0.111) + \cdots + (0.07 \times 0.099)] = 0.023$$

Table 13. Weights of innovation measurement criteria

	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10
Local Weights										
T9	0.28	0.08	0.11	0.17	0.07	0.05	0.07	0.03	0.13	0.01
T10	0.12	0.10	0.17	0.17	0.08	0.07	0.14	0.03	0.11	0.01
T11	0.12	0.12	0.13	0.24	0.1	0.06	0.08	0.04	0.10	0.01
T12	0.12	0.15	0.11	0.14	0.09	0.07	0.07	0.03	0.17	0.05
T13	0.10	0.06	0.07	0.21	0.36	0.04	0.04	0.02	0.09	0.01
T19	0.14	0.06	0.09	0.22	0.06	0.03	0.05	0.21	0.12	0.02
T28	0.12	0.1	0.21	0.18	0.07	0.06	0.09	0.04	0.10	0.03
T32	0.10	0.09	0.10	0.14	0.09	0.17	0.06	0.02	0.16	0.07

Global Weights										
	0.138	0.094	0.118	0.189	0.137	0.065	0.073	0.045	0.119	0.023

*1. At the 100th position after the decimal point, drop numbers less than or equal to 4, and round up 1 for numbers higher/more than 4

4.5 Performance evaluations among university types

In Taiwan, each university can be categorized as belonging to one of four main types: the research-intensive university (RU), the teaching-intensive university (TU), the professional-intensive university (PU) and the education-in-practice-intensive university (EIPU). We can rank the types of universities to determine the optimal type for maximizing TQM and innovation performance. We consulted six of the 75 senior education experts, each of whom had either past experiences in all four types of universities or been part of an academic performance measurement committee.

To ensure that the system would approximate directions more precisely, the top five innovation measurement criteria were extracted (I1, I3, I4, I5, and I9) after consulting with the senior education experts and used to conduct the following calculation. At this stage, the top five innovation measurement criteria were normalized, as shown in Table 14.

Based on the initial values provided by the senior education experts, we utilized GRA to rank the four types of universities. Referential series are obtained in accordance with the initial values shown in Table 15. Using Eq. (23), the initial values in Table 15 are first normalized according to step 2 of the GRA, as shown in Table 16. Then, to obtain the distance $\Delta_{0i}(j)$, Eq. (25) is utilized, the results of which are shown in Table 17. From these results, the gray relational coefficients $\gamma_{0i}(j)$ are calculated using Eq. (26), with ξ equal to 0.5 (as shown in Table 18). Lastly, based on Eq. (27), the gray relational grade Γ_{0i} and the ranking of the four university types are calculated and presented in Table 19.

In accordance with the original NHFS construction, weight calculation, and university rankings, we propose a novel NHFS (as shown in Figure 7) in which measurement criteria are extracted from the top eight TQM measurement weights and the top five innovation measurement weights among all the criteria. In our NHFS, we clearly and precisely provide critical strategic methods (i.e., innovation) to achieve a strategic goal (i.e., TQM) and to accomplish an organizational goal (i.e., high performance) in Taiwanese universities. Moreover, the concepts of ISS and PPAS, transformational leadership (or innovation accelerated force), and financial support and budget planning (or a support appraisal system) are all included to accelerate future performance evaluation and improvement. Because the optimal type of university is the research-intensive university, we provide two ways for the other three types of universities to conduct innovation with greater ease, especially the traditional type. The suitability of these two methods rests on the age, culture, and structure of each university. We believe that this system can provide fresh new ways for all four types of Taiwanese universities to gain competitive advantages in the future.

Table 14 Normalized global weights of top five innovation measurement criteria

	I1	I3	I4	I5	I9
Initial Global Weight	0.138	0.118	0.189	0.137	0.119
Normalized Global Weights	0.197	0.168	0.270	0.195	0.170

Table 15 Initial grade and referential series

	I1	I3	I4	I5	I9
RU	86	96	98	90	96
TU	78	92	88	76	88
PU	97	93	90	94	93
EIPU	82	80	87	86	83
Referential series	97	96	98	94	96

Table 16 The data set after normalization

	I1	I2	I3	I4	I5
RU	0.421	1.000	1.000	0.778	1.000
TU	0.000	0.750	0.091	0.000	0.385
PU	1.000	0.813	0.273	1.000	0.769
EIPU	0.211	0.000	0.000	0.556	0.000
Referential series	1.000	1.000	1.000	1.000	1.000

Table 17 The distance of $\Delta_{0i}(j)$

	I1	I2	I3	I4	I5
RU	0.579	0.000	0.000	0.222	0.000
TU	1.000	0.250	0.909	1.000	0.615
PU	0.000	0.188	0.727	0.000	0.231
EIPU	0.789	1.000	1.000	0.444	1.000
Max	1.000	1.000	1.000	1.000	1.000
Min	0.000	0.000	0.000	0.000	0.000

Table 18 The gray relational coefficients $\gamma_{0i}(j)$

	I1	I2	I3	I4	I5

RU	0.463	1.000	1.000	0.692	1.000
TU	0.333	0.667	0.355	0.333	0.448
PU	1.000	0.727	0.407	1.000	0.684
EIPU	0.388	0.333	0.333	0.529	0.333
ξ			0.5		
Global weights	0.197	0.168	0.270	0.195	0.170

Table 19 The degree of the gray equation coefficient Γ_{0i}

	I1	I2	I3	I4	I5	Γ_{0i}	Ranking
RU	0.091	0.168	0.270	0.135	0.170	0.834	1
TU	0.066	0.112	0.096	0.065	0.076	0.415	3
PU	0.197	0.122	0.110	0.195	0.116	0.740	2
EIPU	0.076	0.056	0.090	0.103	0.057	0.382	4

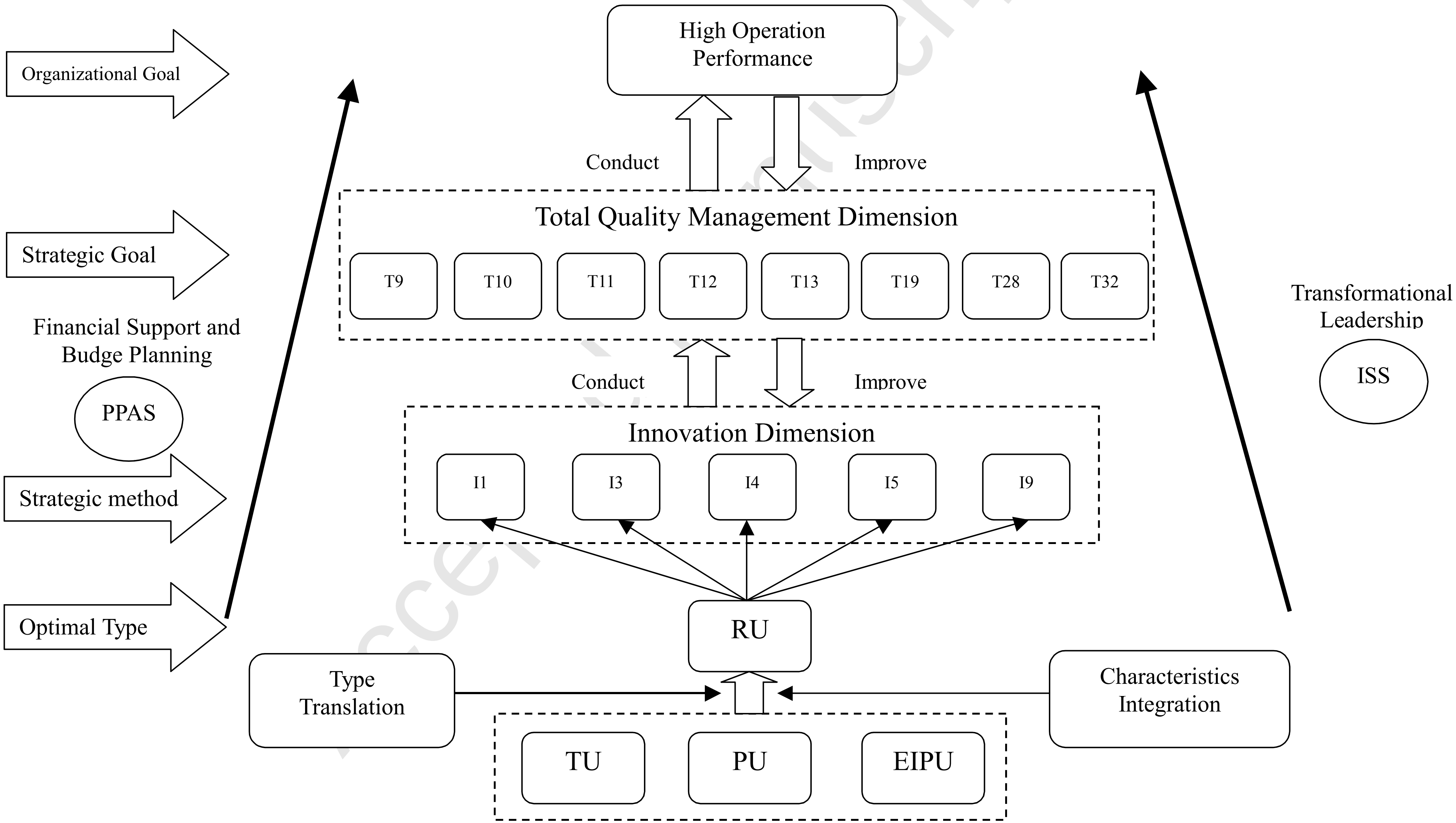


Fig. 7 A network hierarchical feedback system based on the integration of TQM and innovation

5. Conclusions

With universities facing numerous sources of pressure, such as a dropping birthrate, an increase in the number of universities, the recently granted membership of Taiwan in the WTO, and the current economic recession, a growing number of universities are trying to maximize TQM and innovation performance to gain competitive advantages and enhance their chances for future survival. Although various criteria have been widely proposed, the following factors have not been considered: the characteristics specific to the integration of TQM and innovation, the comprehensive focuses with regard to operational performance across the four university types, and the interrelationships among the criteria. In this paper, a network hierarchical feedback system (NHFS) based on the integration of TQM and innovation is proposed to overcome these issues. Given our system, we conclude that a NHFS can provide guidance to universities in Taiwan to maximize operational performance evaluation and improvement, thereby allowing these universities to gain competitive advantages and enhance their chances of future survival. Because this is a novel system, future research could empirically discuss the (potential) impact of the proposed system for the Taiwanese university system. In addition, because the TQM criteria and innovation indices can change over time to fit the needs of the higher education marketplace, future research is also encouraged to explore how the results may change if some criteria or indices vary. Future research should also explore solutions to the problems that will occur because of such changes.

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