Qual Quant (2012) 46:1377–1391
DOI 10.1007/s11135-011-9451-z

Ways to promote valuable innovation: intellectual capital assessment for higher education system

Hung-Yi Wu · Jui-Kuei Chen · I-Shuo Chen

Published online: 8 March 2011

Abstract The importance of intellectual capital (IC) has been emphasized during recent year. Such a trend puts higher education systems under great pressure for two main reasons: first, IC has been shown to be a key driver of innovation; second, the higher education system assumes the unique function of fostering innovation. Knowing how best to improve IC is considered the most significant factor of success in enhancing innovation. However, the higher education system of today has difficulty in measuring IC precisely to improve its innovation performance. This study is to conquer such a problem by establishing critical criteria for IC assessment. Based on the findings, the higher education system is encouraged to successfully evaluate its IC performance and then find ways to improve this performance to achieve better innovation.

Keywords Intellectual capital · Innovation · Higher education · MCDM

1 Introduction

Traditionally, intellectual capital (IC) was utilized and measured in a general way in few private firms, and its importance was not widely known (Sanchez and Elena 2006a, 2006b). It was not until 2 years ago, with the advent of the knowledge-based economy, that the importance of IC increased (Wu et al. 2009). Since then, IC has emerged as a primary way for

H.-Y. Wu
Graduate Institute of Business Administration, National Chiayi University, No. 300, Syuefu Road, Chiayi City 60004, Taiwan

J.-K. Chen
Graduate Institutes of Futures Studies, Tamkang University, 4F, No. 20, Lane 22, WenZhou Street, Taipei City 10616, Taiwan

I.-S. Chen (✉)
Institute of Business & Management, National Chiao Tung University, 4F, No. 20, Lane 22, WenZhou Street, Taipei City 10648, Taiwan
e-mail: ch655244@yahoo.com.tw

most industries to obtain competitive advantage (Sonnier et al. 2007; Tan et al. 2007) and has become a critical issue for not only entrepreneurs, but also scholars (Bornemann and Leitner 2002; Kamath 2007; Kaplan and Norton 1996; Ng 2006; Weatherly 2003).

Since a nation's quality and prestige rely on its solid higher education system, and since a solid higher education system depends on outstanding IC (Wu et al. 2009), the higher education system is thus especially emphasized today, owing to not only extensive interaction with a variety of other knowledge producers (Gibbons 1998), but also its special characteristics of gaining competitive advantage and fostering both innovation assets, visible and invisible alike (Caddy 2000; Canibano and Sanchez 2004; Dzinkowski 2000), and interdisciplinary talent and profession (Sonnier et al. 2007; Tan et al. 2007).

In Taiwan, in response to the emergence of the knowledge-based economy and to the advancement of innovation-based economic edge that has continued through early 2009, has found that constructing a sound higher education system to become a high-innovation country while maintaining its sustainable competitive advantages is highly demanded (CNA 2009a, 2009b); such a system, however, seems to lack a precise way to evaluate and improve IC to accomplish national goals, and even sacrifices a country's basic competitive advantages as it competes with other countries (Chen 2005).

It has been observed that ways for measuring IC are numerous. Beattie (1999) has carried out extensive surveys based on customers' perspectives. Multiple regression models (Huang and Liu 2005) have been used for IC assessment. Some previous research has integrated IC-related information into corporate annual reports (Abeysekera 2001; Abeysekera and Guthrie 2005; Brennan 2001; Olsson 2001). In addition, a great number of studies have synthesized conceptual frameworks (Baxter and Matear 2004), used reporting by financial analysts (Arvidsson 2003; Dempsey et al. 1997), conducted interviews (Breton and Taffler 2001; Rogers and Grant 1997), and performed content-analysis of the operations of target companies (Breton and Taffler 2001; Orens and Lyabert 2004; Previs et al. 1994; Rogers and Grant 1997). However, most of these studies are related to two primary orientations, focusing largely on the financial/monetary perspective and the current improvement of operational situations, and few of them could pinpoint a clear way in which an organization can improve IC and further enhance its innovation.

In light of the above, the aim of this study is to overcome such difficulties by establishing critical IC criteria and providing an evaluation model for today's higher education system in assessing and improving IC to drive successful innovation. Since there are several critical factors taken into account in constructing the IC evaluation framework, such a problem can be solved by multiple-criteria decision-making (MCDM). This study utilized a joint MCDM approach in accordance with decision making trial and evaluation laboratory (DEMATEL) and analytic network process (ANP). DEMATEL method is adopted to develop the interrelations between evaluation criteria to form an impact relations map (IRM), and ANP is utilized to release the restriction of hierarchical structure (Yang et al. 2008). A body of studies has proven the advantages and reliability for both methods in their respective fields (Lin and Wu 2008; Momoh and Zhu 2003). In this research, DEMATEL is used to explore causal relationships and different impacts among IC dimensions. In other words, the IRM of IC dimensions constructed by DEMATEL becomes a network evaluation structure for ANP analysis that is employed to determine the relative weights of IC criteria.

The rest of this research is organized as follows. The concept and categorization of intellectual capital as well as its relationship with the innovation of a higher education system is illustrated in Sect. 2. The joint MCDM approach including DEMATEL and ANP is introduced in Sect. 3. An empirical study of the proposed model is conducted in Sect. 4. Discussions and conclusions are in Sects. 5 and 6.

2 Intellectual capital and innovation of higher education system

2.1 Definition and categorization of IC

The definition of intellectual capital (IC) is currently unclear, owing to incomprehensive knowledge and poor structure (Guthrie 2001; Kamath 2007), although it's original concept concerns the intellectual abilities that drive value creation, rather than general knowledge and intelligence (Galbraith 1969). Numerous studies so far have attempted to categorize, understand, and handle intellectual capital (Diefenbach and vordank 2004; Neely 2002) from different management aspects (Abeysekera and Guthrie 2005; Bukh et al. 2005; Marr 2005). Regardless of the definition of IC, studies have found its value as a key driver of innovation and competitive advantage in today's knowledge-based economy (Teece 2000).

Since the definition of IC could change under certain conditions, its dimensions and criteria are also dynamic. Based on the research by Wu, Chen, and Chen in 2009 (Wu et al. 2009), from their summary of extensive related literature, IC dimensions can generally be categorized as human capital, organizational capital, customer capital, structural capital, individual capital, collective capital, relational capital, innovation capital, and strategic alliance, with each containing several appropriate criteria. Among them, innovation capital has been proven to have a great impact on others (Zeng and Gu 2004), and it has been found that, similar to Teece's finding in 2000, there is a strong positive relationship between innovation and IC. Therefore, this research attempts to extend the coverage of IC assessment to innovation evaluation of higher education systems.

2.2 IC evaluation and innovation of higher education system

Intellectual capital today is a topic of increasing interest to firms that derive their profits from innovation and knowledge (Edvinsson and Sullivan 1996). The concept of innovation has been closely related to that of knowledge creation (Davila et al. 2006; Nonaka 1991; Nonaka and Takeuchi 1995; Van de Ven and Angle 2000), and the process of innovation thus consists of an ongoing pursuit of harnessing new and unique knowledge (Subramaniam and Youndt 2005; Sumita 2008). Additionally, knowledge, both intangible and tangible, is a key driver of the competitive success and wealth-creating capacity (Bohn 1994) of firms and even nations (Sumita 2008). A body of studies so far has proven that sufficient knowledge and IC can further foster success and valuable innovation (Darroch and McNaughton 2002).

Owing to factors such as universities' playing critical institutional roles in national innovation systems (Sanchez and Elena 2006a, 2006b), universities' primary goals of producing and diffusing knowledge (European Commission 2003; Sanchez and Elena 2006a, 2006b), and their most important investments in research and knowledge resources, the higher education system has turned into an integral part of the knowledge society (OECD 2000). Accordingly, there is a growing interest in knowledge-related research, particularly the analysis of universities' IC (Sanchez and Elena 2006a, 2006b). However, there are a very limited number of instruments that can measure and manage IC performance appropriately (Canibano and Sanchez 2004); therefore, a definitive way to help a higher education system improve its IC and further enhance innovation efficiently has become a crucial issue that needs to be addressed.

For a higher education system, such an IC evaluation without an orientation towards innovation will not help improving IC in today's universities, especially in Taiwan. Although there are still numerous ways to categorize IC from an innovative standpoint for the higher education system, typically, the criteria were found to be innovation-oriented and to address newly developed knowledge or theory for research (Hall and Bagchi-Sen 2002; Van Buren 2000). For instance, the twelve related IC evaluation criteria summarized in this study involve innovative culture (Dzinkowski 2000; Van Buren 2000), the number of new ideas (Van Buren 2000; Acs et al. 2001), the number of publications (Guthrie and Petty 2000a,b; Schoenecker and Swanson 2002), financial support (Van Buren 2000; Guthrie and Petty 2000a,b), research performance (Guthrie and Petty 2000a,b), patents (Hall et al. 2000; Toivanen et al. 2002), R&D expenses (Bosworth and Rogers 2002; Hall 1999), the number of R&D members (Guthrie and Petty 2000a,b), copyrights and brands (Bosworth and Rogers 2002), patent income (Guthrie and Petty 2000a,b; Van Buren 2000), and academy-industry interaction (Gambardella and Torrisi 2000). In order to make the IC evaluation of higher education systems much more comprehensive, both innovation-oriented criteria and non-innovation-oriented criteria, which may have mutual influences (i.e., causal relationships) on one another, are taken into account in this study to develop the study's hierarchical framework. The details of IC evaluation criteria are addressed in the later section.

3 A joint MCDM approach

3.1 DEMATEL

The decision making trial and evaluation laboratory (DEMATEL) was adopted to develop the interrelations between evaluation criteria to form an impact relations map (Yang et al. 2008). The calculation steps can be described as follows (Yu and Tseng 2006; Liou et al. 2007; Yang et al. 2008):

Step 1: Calculate the initial average matrix by scores.

This study assumed that a group of sample experts are asked to indicate the direct effect among elements (evaluation criteria) in accordance with their perception of the degree to which each element i exerts on each other element j, as presented by a_{ij}, by utilizing a scale ranging from 0 (no influence) to 4 (very high influence). On the basis of groups of direct matrices from samples of experts, an average matrix $\boldsymbol{A}$, in which each element is the mean of the corresponding elements in the experts' direct matrices, can then be generated.

Step 2: Calculate the initial influence matrix.

While completing the normalization of the average matrix $\boldsymbol{A}$, the initial influence matrix $\boldsymbol{D}$, $[d_{ij}]_{n\times n}$, is calculated so that all principal diagonal elements equal zero. In accordance with $\boldsymbol{D}$, the initial effect that an element exerts and/or acquires from each other element is given. The map as shown in Fig. 1 illustrates a contextual relationship among the elements within a complex system; each matrix entry can be seen as its strength of influence. In Fig. 1, an arrow from d to g means that d influences g with an influence score of 1. Therefore, it can then translate the relationship between the causes and effects of various measurement criteria into a comprehensible structural model of the system based on the degree of influence.

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

The indirect effects of problems decrease when the powers of $\boldsymbol{D}$ increase, e.g., $\boldsymbol{D}^2, \boldsymbol{D}^3, \ldots, \boldsymbol{D}^k$, which guarantees convergent solutions for the inverted matrix. As Fig. 3 presented, the effect of c on d is greater than that of c on g. Based on this, an infinite series

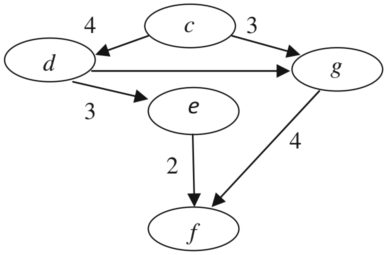

Fig. 1 An influential map

of both direct and indirect effects are derived. Let the (i, j) element of matrix $\boldsymbol{A}$ be presented by a_{ij}; the direct/indirect matrix can then be acquired through Eqs. 1–4 as follows:

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

or

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

where

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

and

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

Then, the total-influence matrix $\boldsymbol{T}$ can be obtained by utilizing Eq. 5. Here, $\boldsymbol{I}$ is the identity matrix.

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

If the sum of rows and the sum of columns are represented by vectors r and c, respectively, in the total influence matrix $\boldsymbol{T}$, then

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

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

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

where the superscript apostrophe denotes transposition.

If r_i represents the sum of the ith row 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 of matrix $\boldsymbol{T}$, then c_j represents the sum of both direct and indirect effects that all other factors have on j. Furthermore, when $j = i$, the amount of the row and column aggregates, $(r_i + c_i)$ provides an indicator of influential strength that is given and received. That is, 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 (Tzeng et al. 2007; Liou et al. 2007; Yang et al. 2008).

Step 4: Confirm the threshold value (α) and generate the impact-relations map (IRM).

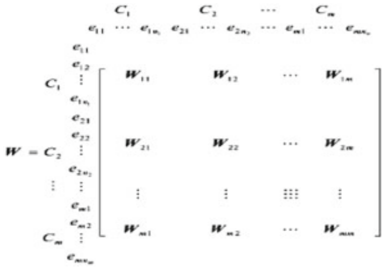

Fig. 2 The general form of the supermatrix

Last, a threshold value, α, should be set by taking into account the sample experts' opinions in order to ignore minor effects presented in matrix $\boldsymbol{T}$'s elements (Yang et al. 2008). That is, decreasing the complexity of the IRM requires a threshold value determined by the decision-maker for the influence degree of each factor. If the influence level of an element in matrix $\boldsymbol{T}$ is higher than the threshold value, then this element is included in the final IRM (Liou et al. 2007; Yang et al. 2008).

In the following section, the analytic network process (ANP) and its calculation steps are introduced to overcome the problem of interdependence and feedback among each measurement criterion generated by the DEMATEL.

3.2 ANP

The analytic network process (ANP) was utilized in MCDM to release hierarchical structural restrictions (Yang et al. 2008); its steps for calculation can be illustrated as follows (Huang et al. 2005; Yang et al. 2008).

Step 5: Form a supermatrix by using criteria comparison in the system.

This can be accomplished using pairwise comparisons. The relative importance values of pairwise comparisons can be categorized from 1 (equal importance) to 9 (extreme inequality in importance) (Saaty 1980). The following is the general form of the supermatrix (Fig. 2) (Yu and Tseng 2006; Liou et al. 2007), where C_m represents the mth cluster, e_{mn} represents the mth element in the mth cluster, and W_{ij} is the principal eigenvector of the effect of the elements compared in the j^{h} cluster to the ith cluster. If the jth cluster has no impact on the ith cluster, then $W_{ij} = [0]$ (Huang et al. 2005; Yu and Tseng 2006).

Step 6: Acquire the weighted supermatrix by multiplying the normalized matrix based on the result of the DEMATEL (Yang et al. 2008).

Traditionally, the way to derive the weighted supermatrix is by transforming each column to sum to unity. Since elements appropriately placed in columns are divided by the number of clusters, the columns will sum to unity. Such a normalization method which used during the past assumes that impacts among clusters have equal weights, which may not suit the real world, since there may exist different effect levels between clusters. Therefore, to overcome such an irrational problem, Yang et al. (2008) have proposed a novel hybrid model to combine the DEMATEL with ANP, which we demonstrate as follows.

Initially, IRM is first developed by DEMATEL, as stated previously; then, using total influence matrix $\boldsymbol{T}$ and a threshold value, α, a new matrix is developed. In matrix $\boldsymbol{T}$, the value of each cluster is set to zero if the value is less than α, and this new matrix is named an α-cut total influence matrix $\boldsymbol{T}\alpha$ (as Eq. 9).

$$T_\alpha = \begin{bmatrix} t_{11}^\alpha & \cdots & t_{1j}^\alpha & \cdots & t_{1n}^\alpha \\ \vdots & & \vdots & & \vdots \\ t_{i1}^\alpha & \cdots & t_{ij}^\alpha & \cdots & t_{in}^\alpha \\ \vdots & & \vdots & & \vdots \\ t_{n1}^\alpha & \cdots & t_{nj}^\alpha & \cdots & t_{nn}^\alpha \end{bmatrix} \rightarrow d_1 = \sum_{j=1}^{n} t_{1j}^\alpha \tag{9}$$

if $t_{ij} < \alpha$, then $t_{ij}^\alpha = 0$; Otherwise, $t_{ij}^\alpha = t_{ij}$. Then, α-cut total influence matrix $\boldsymbol{T}_\alpha$ is normalized by using Eq. 10 below and renamed as T_s (as Eq. 11 presented):

$$d_i = \sum_{j=1}^{n} t_{ij}^\alpha, \tag{10}$$

$$\boldsymbol{T}_1 = \begin{bmatrix} t_{11}^\alpha/d_1 & \ldots & t_{1j}^\alpha/d_i & \ldots & t_{1n}^\alpha/d_1 \\ \vdots & & \vdots & & \vdots \\ t_{i2}^\alpha/d_i & \ldots & t_{ij}^\alpha/d_i & \ldots & t_{in}^\alpha/d_i \\ \vdots & & \vdots & & \vdots \\ t_{n1}^\alpha/d_3 & \ldots & t_{nj}^\alpha/d_3 & \ldots & t_{nm}^\alpha/d_3 \end{bmatrix} \tag{11}$$

Then, the weighted supermatrix (W_w) can be derived by Eq. 12 using the normalized α-cut total influence matrix $\boldsymbol{T}_s$:

$$W_w = \begin{bmatrix} t_{11}^s \times W_{11} & t_{21}^s \times W_{12} & \ldots & \ldots & t_{n1}^s \times W_{1n} \\ t_{12}^s \times W_{21} & t_{22}^s \times W_{22} & \vdots & & \vdots \\ \vdots & \ldots & t_{ji}^s \times W_{ij} & \ldots & t_{ni}^s \times W_{in} \\ \vdots & & \vdots & & \vdots \\ t_{1n}^s \times W_{n1} & t_{2n}^s W_{n2} & \ldots & \ldots & t_{nn}^s \times W_{nn} \end{bmatrix} \tag{12}$$

where $t_{ij}^s = t_{ij}^\alpha/d_i$

Step 7 Limiting the weighted supermatrix by raising it to a sufficiently large power k.

This can be done by using Eq. 13 until the weighted supermatrix (W_w) becomes convergent and stable enough to finally acquire global priority vectors (weight):

$$\lim_{k\to\infty} W_w^k \tag{13}$$

4 An empirical study

This study aims to resolve a prominent problem regarding how best to accelerate innovation in the Taiwanese higher education system by assessing critical IC criteria through a joint-MCDM approach based on DEMATEL and ANP. In this study, DEMATEL was initially used to form the network structure. ANP was then utilized to calculate the limiting supermatrix to explore the weights of criteria in the network structure. In order to comprehensively evaluate critical IC criteria, a total of 63 IC criteria were synthesized from extensive literature. Then, in-depth interviews were conducted with 17 senior experts with backgrounds in higher education (five from research-intensive universities and four from each teaching-intensive universities, professional-intensive universities, and teaching-in-practical universities), 15 having served years in academia, to further extract critical IC criteria. After performing the

Table 1 The definitions of IC evaluation criteria

Evaluation dimensions	Evaluation criteria	Definitions
Relational Capital (D1)	Industry–University Interaction (C1)	Number and duration of practice training and learning opportunities
	International Academy and Practice Interaction (C2)	International exchange between students and faculties
	Government and Institute Cooperation (C3)	Number of the research or tender grants offered by government and institutes
Innovation Capital (D2)	R&D Patents (C4)	Number of tangible creations developed by faculties and students at a university that are then used for patent applications
	Published Journals (C5)	Number of studies published by faculties and students at a university
	Hired Chair Professors (C6)	Number and diversity of chair professors hired by a university
Human Capital (D3)	Go Abroad for Knowledge and Skill Updated (C7)	Proportion of faculties, administrators, and students who study abroad
	Job Rotation (C8)	Turnover rate of administrator and faculty who has part-time position
	Refresher Course of Occupation (C9)	Number of courses offered by a university for administrators
Structure Capital (D4)	Operation Electrification (C10)	Level of administrative items and SOP conduction online
	Result-Oriented Culture (C11)	Degree of freedom offered to administrators, faculties, and students to create value for their university
	Transformational Leadership (C12)	Rate and level of authority, decision making participate, commitment coherence, and unity developed by university administrators

above process, four IC evaluation dimensions including Relational Capital (D1), Innovation Capital (D2), Human Capital (D3), and Structure Capital (D4) were induced, with each IC evaluation dimension containing three IC evaluation criteria. The detailed definitions for the twelve IC criteria are presented in Table 1.

Then, the interrelationships among the IC evaluation dimensions needed to be determined. In this study, 31 senior experts with more than 15 years in higher education (nine from research-intensive universities and eight from each teaching-intensive universities, professional-intensive universities, and teaching-in-practical universities) were asked to decide the influence level of relationships among the four dimensions. In accordance with the experts' ratings, the average initial direct-relation $4 * 4$ matrix $\boldsymbol{A}$ was then constructed as shown in Table 2.

Adopting the *steps* (Eqs. 1–6) in the section of DEMATEL, here, the total influence $4 * 4$ matrix $\boldsymbol{T}$, which is presented as Table 3, was acquired. Then, for maintaining the prominence of important relationships, the threshold value is set to 1.04 after discussion with experts and reaching a consensus. The α-cut total influence $4 * 4$ matrix $\boldsymbol{T}_{\alpha}$ is presented as Table 4.

Table 2 The average initial direct-relation 4 * 4 matrix ***A***

	D1	D2	D3	D4
D1	0	3.14	1.25	1.27
D2	2.44	0	3.32	2.31
D3	1.65	2.23	0	1.17
D4	1.42	3.11	2.73	0

Table 3 Total influence 4 * 4 matrix ***T***

	D1	D2	D3	D4
D1	0.745	1.280	1.066	0.796
D2	1.166	1.259	1.463	1.042
D3	0.829	1.099	0.820	0.709
D4	1.037	1.468	1.367	0.782

Table 4 α-cut total influence 4 * 4 matrix $\boldsymbol{T}_\alpha$

	D1	D2	D3	D4
D1	0.000	1.280	1.066	0.000
D2	1.166	1.259	1.463	1.042
D3	0.000	1.099	0.000	0.000
D4	0.000	1.468	1.367	0.000

Table 5 The normalized α-cut total influence 4 * 4 matrix $\boldsymbol{T}_s$

	D1	D2	D3	D4
D1	0.000	0.546	0.454	0.000
D2	0.236	0.255	0.297	0.211
D3	0.000	1.000	0.000	0.000
D4	0.000	0.518	0.482	0.000

As previously discussed, the results of DEMATEL show different impact levels among dimensions, and the traditional normalized method is thus irrational (Yang et al. 2008). In this research, a joint-MCDM approach based on DEMATEL and ANP was adopted. The DEMATEL was to calculate the α-cut total influence 4 * 4 matrix $\boldsymbol{T}_\alpha$, as listed in Table 5. Through Eqs. 9–12, the IRM (i.e., the network evaluation structure of ANP) is then constructed to accurately reflect the complicated causal relationships among IC dimensions. Referring to Table 5, the network evaluation structure of ANP is proposed in Fig. 3.

According to the interrelationship and influence levels between IC evaluation dimensions (as Fig. 3), the unweighted 12 * 12 supermatrix of IC criteria $\boldsymbol{W}$ was acquired as shown in Table 6 after adopting the perspectives of 31 senior educational experts and *step 5*. Then, the weighted 10 * 10 supermatrix of IC criteria $\boldsymbol{W_w}$, presented as Table 7, was calculated by Eq. 12. To confirm the global weights of IC criteria, Eq. 13 was applied determine the limiting supermatrix ($\boldsymbol{W}_{final}$). The final results are summarized in Table 8 along with the overall ranking.

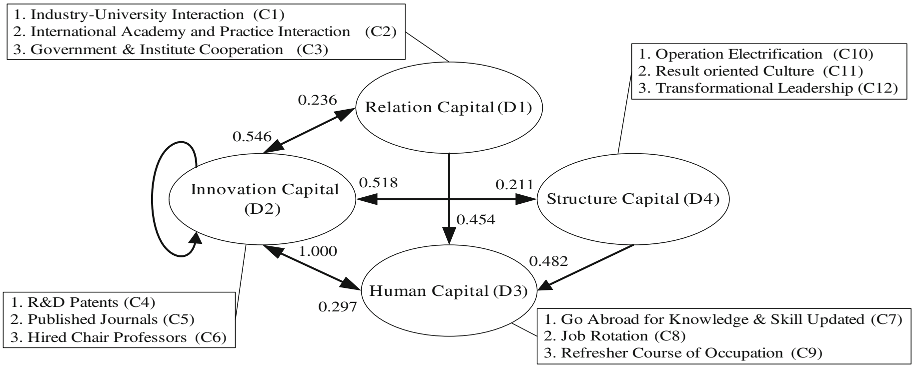

Fig. 3 The IRM and network evaluation structure of IC proposed by this research

Table 6 The unweighted 12 * 12 matrix of IC criteria ***W***

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
C1	1.000	0.000	0.000	0.470	0.510	0.400	0.380	0.530	0.350	0.460	0.540	0.380
C2	0.000	1.000	0.000	0.210	0.240	0.210	0.250	0.130	0.260	0.210	0.180	0.330
C3	0.000	0.000	1.000	0.320	0.250	0.390	0.370	0.340	0.390	0.330	0.280	0.290
C4	0.320	0.330	0.160	1.000	0.000	0.000	0.390	0.280	0.340	0.230	0.290	0.360
C5	0.560	0.390	0.710	0.000	1.000	0.000	0.420	0.510	0.390	0.490	0.550	0.430
C6	0.120	0.280	0.130	0.000	0.000	1.000	0.190	0.210	0.270	0.280	0.160	0.210
C7	0.610	0.440	0.410	0.530	0.640	0.390	1.000	0.000	0.000	0.440	0.390	0.570
C8	0.120	0.180	0.240	0.180	0.120	0.300	0.000	1.000	0.000	0.270	0.230	0.180
C9	0.270	0.380	0.350	0.290	0.240	0.310	0.000	0.000	1.000	0.290	0.380	0.250
C10	0.190	0.270	0.200	0.210	0.210	0.230	0.240	0.390	0.160	1.000	0.000	0.000
C11	0.430	0.370	0.530	0.500	0.460	0.540	0.620	0.510	0.600	0.000	1.000	0.000
C12	0.380	0.360	0.270	0.290	0.330	0.230	0.140	0.100	0.240	0.000	0.000	1.000

Table 7 The weighted 12 * 12 matrix of IC criteria $\boldsymbol{W_w}$

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
C1	0.000	0.000	0.000	0.111	0.120	0.094	0.000	0.000	0.000	0.000	0.000	0.000
C2	0.000	0.000	0.000	0.050	0.057	0.050	0.000	0.000	0.000	0.000	0.000	0.000
C3	0.000	0.000	0.000	0.076	0.059	0.092	0.000	0.000	0.000	0.000	0.000	0.000
C4	0.175	0.180	0.087	0.256	0.000	0.000	0.390	0.280	0.340	0.119	0.150	0.186
C5	0.306	0.213	0.388	0.000	0.256	0.000	0.420	0.510	0.390	0.254	0.285	0.223
C6	0.066	0.153	0.071	0.000	0.000	0.256	0.190	0.210	0.270	0.145	0.083	0.109
C7	0.277	0.200	0.186	0.157	0.190	0.116	0.000	0.000	0.000	0.212	0.188	0.275
C8	0.054	0.082	0.109	0.053	0.036	0.089	0.000	0.000	0.000	0.130	0.111	0.087
C9	0.123	0.173	0.159	0.086	0.071	0.092	0.000	0.000	0.000	0.140	0.183	0.121
C10	0.000	0.000	0.000	0.044	0.044	0.049	0.000	0.000	0.000	0.000	0.000	0.000
C11	0.000	0.000	0.000	0.106	0.097	0.114	0.000	0.000	0.000	0.000	0.000	0.000
C12	0.000	0.000	0.000	0.061	0.070	0.049	0.000	0.000	0.000	0.000	0.000	0.000

Table 8 The limiting 12 * 12 supermatrix for IC criteria $\boldsymbol{W_{final}}$ and ranking

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	Ranking
C1	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	6
C2	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	11
C3	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	9
C4	0.171	0.171	0.171	0.171	0.171	0.171	0.171	0.171	0.171	0.171	0.171	0.171	2
C5	0.238	0.238	0.238	0.238	0.238	0.238	0.238	0.238	0.238	0.238	0.238	0.238	1
C6	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	4
C7	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136	0.136	3
C8	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	8
C9	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	0.076	5
C10	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	12
C11	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	7
C12	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	10

5 Discussions

In order to keep up with the transition to an innovation-based economy, Taiwan's higher education system has pursued the goal of fostering a country of innovators. Special emphasis has been put on innovation enhancement due to the primary function of the higher education system as a place for creating visible and invisible innovation like new knowledge, skills, and products as well as fostering interdisciplinary talent and profession. As mentioned above, there is a significant positive relationship between a solid higher education system, innovation, and intellectual capital (IC); therefore, knowing how to improve IC to accelerate innovation today has become an urgent issue for the Taiwanese higher education system, which is under pressure to achieve Taiwan's goal as an innovator country. However, according to this study, Taiwan's higher education system currently lacks a precise direction for improving IC and accelerating innovation; such a difficulty even diminishes the universities' basic competitive advantage as they compete with those from other countries.

To overcome this difficulty, the aim of this study is to provide an effective way to improve IC by evaluating critical IC criteria using a joint-MCDM approach combined with DEMATEL and ANP. From the results of this research, it is found as expected that innovation capital (criteria) has great influence on other kinds of IC (as Fig. 3); also, the top priorities for the higher education system in seeking to improve competitive advantage and accelerate innovation is "Published Journals (C5)" (0.238); followed by "R&D Patents (C4)" (0.171), "Go Abroad for Knowledge and Skill Updated (C7)" (0.136), "Hired Chair Professors (C6)" (0.104), "Refresher Course of Occupation (C9)"(0.076), "Industry–University Interaction (C1)" (0.057), "Result oriented Culture (C11)" (0.053), "Job Rotation (C8)" (0.048), "Government and Institute Cooperation (C3)" (0.037), "Transformational Leadership (C12)" (0.031), "International Academy and Practice Interaction (C2)" (0.026), and "Operation Electrification (C10)" (0.023).

Among the four IC types, the importance of innovation is highly rated; of its related criteria, journal publication is the top concern. However, since academic research has been a perfectly competitive market, the performance of Taiwan's higher education system currently appears to be out of the top ranks internationally. Hence, to significantly improve IC, it is highly encouraged to continue encouraging faculties to publish their masterpieces to high-quality international journals and enhancing students' essay-writing ability by either opening more related classes or increasing graduation restrictions based on thesis quality. Also, according to senior experts, for those universities focusing on journal publication, more financial support and/or types of scholarships for the purpose of increasing the number of R&D patents, especially international patents, are strongly advised.

The improvement of IC performance is not only by self-rating but by being compared with others. Therefore, in order to be a nation of innovation, going abroad for knowledge and updating skills is unavoidable; nevertheless, the practice of sending faculties or students out for absorbing international experience and upgrading knowledge in Taiwan is still just gaining traction. The results of this study clearly show that to yield twice the result with half the effort, offering more opportunities for oversea learning is required and should be become a general rule for quickly improving IC in Taiwan.

Also, having more chair professors in universities is believed to be an optimal way of improving IC. Although the number of chair professors is generally close to the average, IC improvements seem unrelated to this number. Attracting scholars with diverse backgrounds or foreign origins is encouraged.

The rest of the IC criteria, such as offering professional refresher courses, industry-university interaction, job rotation, international academy and practice interaction, operation electrification, and government and institute cooperation have lower ratings. However, these criteria are extracted from the original 61 IC criteria; that is, these criteria in senior experts' opinions are important but not quite as immediately essential for improving Taiwan's higher education system. Therefore, it is suggested that Taiwanese universities maintain their performances in these areas at a certain standard to sustain basic competitive advantages

Due to divergent organizational cultures and leadership styles, after extraction based on the interview of senior experts, according to analysis, result-oriented culture and transformational leadership are regarded as two essential managerial elements for most of universities seeking to advance their IC performance. Although these two criteria are ranked relatively low, it is still recommended that top management in higher education create a result-oriented culture and utilize transformational leadership styles while improving IC; after all, a better management and positive atmosphere can lead to members' satisfaction can then increase the possibility of creating a successful organization performance (Amabile and Kramer 2007). In a higher education system, improvement in IC performance would surely result.

6 Conclusions

Amidst the global transition to a knowledge-based economy, higher education systems in every country have turned to be critical mechanisms for acquiring sustainable competitive advantage. Becoming a nation of innovation and gaining competitive advantage in terms of intellectual capital are real challenges for the higher education system in Taiwan. A common problem faced by Taiwan's higher education system is the lack of a precise way to evaluate IC and further accelerate innovation. On the basis of the above claim, this study aims to establish the critical IC criteria and further prioritize these criteria to demonstrate an effective and efficient way for the higher education system to achieve IC improvement. In conclusion, the proposed IC evaluation network structure would be a useful assessment model for universities in improving IC and even accelerating innovation in compliance with our findings. This model can also be adapted to other situations for future research.

References

Abeysekera, I.: A framework to audit intellectual capital. J. Knowl. Manag. Pract. (online). **2**, Aug (2001). http://www.tlainc.com/articl25.htm

Abeysekera, I., Guthrie, J.: Annual reporting trends of intellectual capital in Sri Lanka. Crit. Perspect. Account. **16**(3), 151–163 (2005)

Acs, Z.J., Anselin, L., Varga, A.: Patents and innovation counts as measures of regional production of new knowledge. Res. Policy **31**(7), 1069–1085 (2001)

Amabile, T.M., Kramer, S.J.: Inner work life: understanding the subtext of business performance. Harv. Bus. Rev. **85**(5), 72–83 (2007)

Arvidsson, S.: Demand and supply of information on intangibles—the case of knowledge-intensive Companies. Ph.D. Dissertation, University of Lund: The Institute of Economic Research (2003)

Baxter, R., Matear, S.: Measuring intangible value in business-to-business buyer–seller relationships: an intellectual capital perspective. Ind. Mark. Manag. **33**(6), 491–500 (2004)

Beattie, V.: Resources. Eur. Manag. J. **17**(4), 15–27 (1999)

Bohn, R.E.: Measuring and managing technological knowledge. Sloan Manag. Rev. **36**(1), 61–73 (1994)

Bornemann, M., Leitner, K.H.: Measuring and reporting intellectual capital: the case of a research technology organization. Singap. Manag. Rev. **24**(3), 7–19 (2002)

Bosworth, D., Rogers, M.: Market value, R&D and intellectual property: an empirical analysis of large Australian firms. Econ. Rec. **77**(239), 323–337 (2002)

Brennan, N.: Reporting intellectual capital in annual reports: evidence from Ireland. Audit. Account. J. **14**(4), 423–436 (2001)

Breton, G., Taffler, R.J.: Accounting information and analysts stock recommendation decisions: a content analysis approach. Account. Bus. Res. **31**(2), 91–101 (2001)

Bukh, P.N., Nielsen, C., Gormsen, P., Mouritsen, J.: Disclousure of information on intellectual capital in Danish IPO prospectuses. Account. Audit. Account. J. **18**(6), 713–732 (2005)

Caddy, I.: Intellectual capital: recognizing both assets and liabilities. J. Intellect. Cap. **1**(2), 129–146 (2000)

Canibano, L., Sanchez, M.P. : Measurement, management and reporting on intangibles. State of the art. In: Canibano, L., Sanchez, M.P. (eds.) Readings on Intangibles and Intellectual Capital, pp. 81–113. AECA, Madrid (2004)

Chen, M.C.: Creativity comes from living field. J. Shih-Yu **456**, 13–19 (2005)

CNA.: Taiwan Breaking News. http://gov.cna.com.tw/ReadNews/FeatureNews_Read.aspx?TopicNo=86&ID=200901170227 (2009a). Accessed 8 Aug 2009

CNA.: Taiwan Breaking News. http://gov.cna.com.tw/ReadNews/FeatureNews_Read.aspx?TopicNo=86&ID=200901170030&pageNum=1 (2009b). Accessed 8 Aug 2009

Darroch, J., McNaughton, R.: Examing the link between knowledge management practices and types of innovation. J. Intellect. Cap. **3**(3), 210–222 (2002)

Davila, T., Epstein, M.J., Shelton, R.: Making Innovation Work: How to Manage it, Measure it, and Profit from it. Pearson Education, Upper Saddle River (2006)

Dempsey, S.J., Gatti, J.F., Grinell, D.J., Cats-Baril, W.L.: The use of strategic performance variables as leading indicators in financial analysts forecasts. J. Financ. Statement Anal. **2**(4), 61–79 (1997)

Diefenbach, T.: Different meanings of intangible assets and knowledge—and their implications for management and innovation. Int. J. Knowl. Cult. Change Manag. **4**(5), 553–567 (2004)

Dzinkowski, R.: The measurement and management of Intellectual capital: an introduction. Manag. Account. **78**(2), 32–36 (2000)

Edvinsson, L., Sullivan, P.: Developing a model for managing intellectual capital. Eur. Manag. J. **14**(4), 356–364 (1996)

European Commission: *The Role of Universities in the Europe of Knowledge*. (Commission of the European Communities, Brussels 2003)

Galbraith, J.K.: The New Industrial State. Harmonds worth, Penguin (1969)

Gambardella, A., Torrisi, S.: The economic value of knowledge and inter-firm technological linkages: an investigation of science-based firms. Dynamo TSER Project (contract no. SOE1-CT97-1078) (2000)

Gibbons, M.: Higher education relevance in the 21st century. Paper presented at the UNESCO World Conference on Higher Education, Paris, 1998, pp. 5–9

Guthrie, J.: The management, measurement and the reporting of intellectual capital. J. Intellect. Cap. **2**(1), 27 (2001)

Guthrie, J., Petty, R.: Are companies thinking smart? Australian CPA, 2000, pp. 62–65 (2000a)

Guthrie, J., Petty, R.: Intellectual capital: Australian annual reporting practices. J. Intellect. Cap. **1**(3), 241–251 (2000b)

Hall, B.H.: Innovation and market value. NBER Working Paper, 6984, Cambridge (1999)

Hall, L.A., Bagchi-Sen, S.: A study of R&D, innovation, and business performance in the Canadian biotechnology industry. Technovation **22**(4), 231–244 (2002)

Hall, B.H., Jaffe, A., Trajtenberg, M.: Market value and patent citations: a first look. University of California at Berkeley, Department of Economics Working Paper, 0-277, Berkeley (2000)

Huang, C.J., Liu, C.J.: Exploration for the relationship between innovation, IT and performance. J. Intellect. Cap. **6**(2), 237–252 (2005)

Huang, J.J., Tzeng, G.H., Ong, C.S.: Multidimensional data in multidimensional scaling using the analytic network process. Pattern Recognit. Lett. **26**, 755–767 (2005)

Kamath, G.B.: The intellectual capital performance of Indian banking sector. J. Intellect. Cap. **8**(1), 96–98 (2007)

Kaplan, R.S., Norton, D.P.: Using the Balanced Scorecard as a strategic management system. Harv. Bus. Rev. **74**, 75–85 (1996)

Lin, C.J., Wu, W.W.: A causal analytical method for group decision-making under fuzzy environment. Expert Syst. Appl. **34**(1), 205–213 (2008)

Liou, J.H., Tzeng, G.H., Chang, H.C.: Airline safety measurement using a hybrid model. J. Air Transp. Manag. **13**(4), 243–249 (2007)

Marr, B. (ed.): Perspective on Intellectual Capital: Multidisciplinary Insights into Management, Measurement, and Reporting. Elsevier, Boston (2005)

Momoh, J.A., Zhu, J.: Optimal generation scheduling based on AHP/ANP. IEEE Transactions on Systems, Man and Cybernetics—Part B. Cybernetics **33**(3), 531–535 (2003)

Neely, A. (ed.): Business Performance Measurement. Theory and Practice. Cambridge University Press, Cambridge (2002)

Ng, A.W.: Reporting intellectual capital flow in technology-based companies. J. Intellect. Cap. **7**(4), 492–500 (2006)

Nonaka, I.: The knowledge-creating company. Harv. Bus. Rev. **69**(6), 96–104 (1991)

Nonaka, I., Takeuchi, H.: The Knowledge-Creating Company. Oxford University Press, Oxford (1995)

OECD: *From initial education to working life: making transitions work*. (OECD, Paris 2000)

Olsson, B.: Annual reporting practices: information about human resources in corporate annual reports in major Swedish companies. J. Hum. Resour. Cost. **6**(1), 39–52 (2001)

Orens, R., Lyabert, N.: The use of non-financial information by financial analysts: a content analysis approach. Presented at the 27th Annual Congress of the European Accounting Association, Prague (2004)

Previs, G.J., Bricker, R.J., Robinson, T.R., Young, S.J.: A content analysis of sell-side financial analyst company reports. Account. Horiz. **8**(2), 55–70 (1994)

Rogers, R.K., Grant, J.: Content analysis of information cited in reports of sell-side financial analysts. J. Financ. Statement Anal. **3**, 17–30 (1997)

Saaty, J.T.: The Analytic Hierarchy Process. McGraw-Hill, Columbus (1980)

Sanchez, M.P., Elena, S.: Intellectual capital in universities: improving transparency and internal management. J. Intellect. Cap. **7**(4), 529–548 (2006)

Sanchez, M.P., Elena, S.: Intellectual capital in universities improving transparency and internal management. J. Intellect. Cap. **7**(4), 529–539 (2006)

Schoenecker, T., Swanson, L.: Indicators of firm technological capability: validity and performance implications. IEEE Trans. Eng. Manag. **49**(1), 36–44 (2002)

Sonnier, B.M., Carson, K.D., Carson, P.P.: Accounting for intellectual capital: the relationship between profitability and disclosure. J. Appl. Manag. Entrep. **12**(2), 3–14 (2007)

Subramaniam, M., Youndt, M.A.: The influence of intellectual capital on the types of innovative capabilities. Acad. Manag. J. **48**(3), 450–463 (2005)

Sumita, T.: Intellectual assets based management for innovation: lessons from experiences in Japan. J. Intellect. Cap. **9**(2), 206–277 (2008)

Tan, H.P., Plowman, D., Hancock, P.: Intellectual capital and financial returns of companies. J. Intellect. Cap. **8**(1), 76–95 (2007)

Teece, D.J.: Managing intellectual capital-Organizational, strategic, and policy dimensions. Oxford University Press, Oxford, UK (2000)

Toivanen, O., Stoneman, P., Bosworth, D.: Innovation and the market value of UK. Oxf. Bull. Econ. Stat. **64**(39), 39–61 (2002)

Tzeng, G.H., Chiang, C.H., Li, C.W.: Evaluating intertwined effects in e-learning programs: a novel hybrid MCDM model based on factor analysis and DEMATEL. Expert Syst. Appl. **32**(4), 1028–1044 (2007)

Van Buren, M.E.: Making knowledge counts: knowledge management systems and the human element. Unpublished manuscript, University of Missouri, Columbia (2000)

Van de Ven, A.H., Angle, H.L.: An introduction to the Minnesota innovation research program. In: Van de Ven, H.L., Scott-Poole, M. (eds.) Research on the Management of Innovation: The Minnesota Studies, pp. 3–30. Oxford University Press, Oxford (2000)

Weatherly, L.A.: The value of people: the challenges and opportunities of human capital measurement and reporting. Res. Q. **123**, 1–11 (2003)

Wu H.Y., Chen J.K., Chen I.S.: Innovation capital indicator assessment of Taiwanese universities: a hybrid fuzzy model application. Expert Syst. Appl. (2009). doi:10.1016/j.eswa.2009.06.045

Yang, Y.P., Shieh, H.M., Leu, J.D., Tzeng, G.H.: A novel hybrid MCDM model combined with DEMATEL and ANP with applications. Int. J. Oper. Res. **5**(3), 160–168 (2008)

Yu, R., Tseng, G.H.: A soft computing method for multi-criteria decision making with dependence and feedback. Appl. Math. Comput. **180**(1), 63–75 (2006)

Zeng, J.Y., Gu, Y.C.: The relationship between intellectual capital and corporate intangibles: manufacturing in Taiwan. J. Manag. Syst. **11**(1), 1–30 (2004)