Expert Systems with Applications 37 (2010) 1635–1642

Contents lists available at ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

Innovation capital indicator assessment of Taiwanese Universities: A hybrid fuzzy model application

Hung-Yi Wu [a,1], Jui-Kuei Chen [b,2], I-Shuo Chen [c,*]

[a] Department of Business and Entrepreneurial Management, Kainan University, No. 1, Kainan Road, Luzhu Shiang, Taoyuan 33857, Taiwan
[b] Graduate Institute of Futures Studies, Tamkang University, 4F, No. 20, Lane 22, WenZhou Street, Taipei City 10616, Taiwan
[c] Institute of Business & Management, National Chiao Tung University, 4F, No. 20, Lane 22, WenZhou Street, Taipei City 10616, Taiwan

ARTICLE INFO

Keywords:
Innovation capital
Higher educational institution
Fuzzy Analytic Hierarchy Process (FAHP)
Vlsekriterijumska Optimizacija I
Kompromisno Resenje (VIKOR)

ABSTRACT

Intellectual capital today has become an essential concept for assessing firm value. Universities in Taiwan that are emphasizing knowledge more in order to gain a competitive advantage, as is the case with most organizations, are adopting intellectual capital to measure school performance as well. The objective of this study is to analyze the intellectual capital of universities based on indicators of innovation capital. After reviewing related literature and conducting in-depth interviews with experts in the field, the study extracts critical relevant dimensions and indicators of innovation capital that fit the characteristics of universities and then categorizes the main types of universities in Taiwan. The proposed analysis method is in accordance with the Fuzzy Analytic Hierarchy Process (FAHP) and with VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) methods. FAHP is used in determining the weights of the innovation capital indicators by educational experts; then, the rankings of the types of universities are determined by VIKOR, based on the result of the weights of indicators.

1. Introduction

The rise of the knowledge-based economy has been attributed to the increasing importance of intellectual capital, a main resource for companies as they seek to sustain competitive advantage (Moon & Kym, 2006; Sonnier, Carson, & Carson, 2007; Tan, Plowman, & Hancock, 2007). The term intellectual capital has been widely used in recent times by the research community in the developed world (Kamath, 2007). Moreover, taxonomies of organizational resources or assets that suggested the resources' performance have been analyzed from the point of view of intellectual capital (Ng, 2006). Therefore, not only entrepreneurs but also scholars have turned their attention to intellectual capital (Bontis, Keow, & Richardson, 2000; Bornemann & Leitner, 2002; Guthrie, 2001; Kaplan & Norton, 2004; Lev & Feng, 2001; Weatherly, 2003).

The latest concern of most organizations, especially universities, is the creation and diffusion of knowledge, the investments in which are related to research and development as well as human resources (Sanchez & Elena, 2006). Thus, the outcomes of universities' investments are generally invisible assets; however, there is still a lack of instruments available to measure invisible assets precisely (Caddy, 2000; Canibano & Sanchez, 2004; Dzinkowski, 2000). It has been adequate until now for studies to assess intellectual capital by using a set of innovation capital indicators that can almost comprehend the value of invisible assets (Ahuja, 2000; Subramaniam & Venkatraman, 2001; Subramaniam & Youndt, 2005).

In light of above, the study has summarized the literature and has gone in depth using interviews in order to categorize related innovation capital indicators. A Fuzzy Analytic Hierarchy Process (FAHP) is used to determine the weights of the measurement innovation capital indicators by the opinions of educational experts; then, rankings of the types of universities are determined using VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) and based on the results regarding the weight of the indicators.

2. Intellectual capital

At present, the field of intellectual capital lacks a cohesive body of knowledge, and the construct of intellectual capital is too often only poorly defined, if it is defined at all (Guthrie, 2001; Kamath, 2007). Several previous studies focus somewhat on identifying, understanding, and managing intellectual capital (Diefenbach, 2004; Neely, 2002). However, the concept of intellectual capital has been defined from different management perspectives (Abeysekera and Guthrie, 2005; Bozzolan et al., 2003; Marr,

* Corresponding author. Tel.: +886 911393602.
E-mail addresses: hywu@mail.knu.edu.tw (H.-Y. Wu), chen3362@ms15.hinet.net (J.-K. Chen), ch655244@yahoo.com.tw (I-S. Chen).
[1] Tel.: +886 33412500.
[2] Tel.: +886 91227296.

0957-4174/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.eswa.2009.06.045

2005; Marr and Chatzkel, 2004; Amanda, 2006). Hence, intellectual capital is most often defined as the resource of knowledge, in the form of employees, customers, processes or technology, which the company can mobilize in its value creation processes (Bukh, Nielsen, Gormsen, & Mouritsen, 2005). Elements of intellectual capital differ between different parts of the existing literature and research. This study summarized a stream of literature and concluded that the focuses have been as follows: human capital, organizational capital, customer capital, structural capital, individual capital, collective capital, relational capital, innovation capital, and strategic alliances (Allee, 1999; Bontis et al., 2000; Brooking, 1996; Canibano, Garcia-Ayuso, & Sanchez, 2000; Carson, Ranzjin, Winefield, & Marsdon, 2004; Cascio, 1998; Chen & Lin, 2004; Davenport & Prusak, 1998; Edvinsson & Malone, 1997; Fischer, 2001; Haanes & Lowendahl, 1997; Kaplan & Norton, 1996; MERITUM, 2001; Mouritsen, Larsden, & Bukh, 2001; Nahapiet & Ghoshal, 1998; Ordonez de Pablos, 2002, 2003, 2004; Petrash, 1996; Petty & Guthrie, 2000; Sanchez, Chaminad, & Olea, 2000; Stewart, 1997; Sveiby, 1997; Youndt, Subramaniam, & Snell, 2004). Nevertheless, recent research has validated that each of the forms of capital will be influenced by the newest kind of capital, called innovation capital, in a drastically changing world such as the one that we inhabit today (Zeng, 2002; Zeng & Gu, 2003). This research has confirmed that there is a positive relationship between innovation and intellectual capital (Tsai, 2001; Tung, 2001 cited in Chen & Chen, 2007). Therefore, for the purpose of the study, innovation capital is used as a basis for intellectual capital analysis.

3. Innovation capital

Since the nature of innovation is not so clear and the existent literature provides different interpretations of its meaning, a definition is necessary (Ordaz, Lara, & Cabrera, 2005). Subramaniam and Youndt (2005) indicate that innovation is about identifying and using opportunities to create new products, services, or work practices. Damanpour (1996) points out that innovation involves the adoption of an idea that is new for the organization that adopts it. Generally, innovation can be defined in terms of three aspects (Ordaz et al., 2005): a product new to a business unit (Damanpour, 1996; Tushman & Nadler, 1986), a new process (O'Sullivan, 2000), or an attribute of organizations (Bantel & Jackson, 1989; Kimberly, 1981). Summarizing the relevant literature, this study has defined innovation as a process that not only provides new and tangible products but also provides intangible new ideas. Furthermore, the indicators of innovation capital for measuring intellectual capital performance are numerous (See Table 1 which is cited in Chen & Chen, 2007).

4. University and innovation

In the past, measuring intellectual capital has focused on private firms; however, this growing interest has now extended to public firms such as universities (Sanchez & Elena, 2006). Therefore, a great number of universities are going through important transformations in order to increase their level of quality both in education and research (Sorbonne Joint Declaration, 1998; Bologna Declaration, 1999; Prague Declaration, 2001, as cited in Sanchez & Elena, 2006). A stream of studies has also confirmed that universities now interact with a variety of other knowledge producers (Gibbons, 1998). Furthermore, intellectual capital has become crucial in order to reinforce universities' roles in the new economy for two reasons: firstly, universities' main inputs and outputs are largely intangible, and only a small portion of them have a great effect on the universities' operation processes (Canibano & Sanchez, 2004); secondly, universities are being forced to be more transparent and to disseminate more information to stakeholders such as students, public authorities that fund universities, labor markets, etc. (European Commission, 2003). In Taiwan, due to an increasing number of universities, the government has decreased educational funding support year after year. Hence, universities have called for developing a closer relationship with industry in order to raise enough administrative funds. Based on these difficulties Taiwanese Universities can no longer keep their academic freedom or the independent role that they enjoyed in the past. On the contrary, they have to employ an effective solution – such as improving innovation capital – that can strengthen academic competition in the future.

5. An introduction to Taiwanese Universities

Universities in Taiwan can be divided into two groups, national and private. Nevertheless, Li (2007), a well-known Taiwanese educational expert, has indicated that universities can be categorized more precisely. Accordingly, this study summarized four main types of universities: Research-Intensive (RU), Teaching-Intensive (TU), Communal-Intensive (CU), and Professional-Intensive (PU). Due to the number of Communal-Intensive (CU) universities not accepted formally by the Taiwanese government, only the other three are considered in this study. Detailed descriptions on these three types of universities are provided as follows:

5.1. Research-Intensive University (RU)

This type of university emphasizes the development of graduate programs and focuses on educational research. Today, there are only seven such universities in Taiwan. The scope of this kind of university is always expansive. In addition, their budgets are greater than those of the other two types of universities. In addition, nearly complete professional field of department, and full of different kinds of teachers and book resources are also Research-Intensive Universities' advantages.

5.2. Teaching-Intensive University (TU)

This type of university emphasizes the original subjects learned at the bachelor's level, which means that the university's intent is to focus on enhancing a professional field that students learned before. Moreover it emphasizes four functions: education, promotion, service, and fostering full fields of talent. Formally, it includes two types, normal schools and other universities that do not fit the classifications of the other three types of universities. The advantage of this kind of university is that, first, students can become pre-teachers in junior or elementary schools by taking critical educational subjects; second, some such universities can have the opportunity to interact with enterprises; and third, some of them may even develop unique characteristics based on their locations and educational resources.

5.3. Professional-Intensive University (PU)

This type can be seen as an institute of technology. According to the higher education macroscopic committee at the highest level of the executive branch in Taiwan, this type of university should be separate from normal universities; in addition, it should focus on developing applied technology and collaborating with industries so that it may become a professional technology university. The advantage is that this type of university has almost complete professional technology resources that can be used to foster professional talent.

From the analysis above, it is clear that each of universities has its own unique competitive advantages. Nonetheless, with the biggest challenge – the fact that birth rates continue to drop – many universities in Taiwan are facing a crisis of enrollment. Thus, it is necessary to identify the type of university that will most easily lend itself to innovation development, and to use this information for both newly built and existing universities. Here, a fuzzy hybrid model, combining FAHP and VIKOR, considers the weight of innovation capital indicators in assessing the intellectual capital performance of universities.

6. Fuzzy Analytic Hierarchy Process (FAHP)

6.1. Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) was developed by Thomas L. Saaty in 1971. The AHP method is known as an eigenvector method. It indicates that the eigenvector corresponding to the largest eigenvalue of the pairwise comparisons matrix gives the relative priorities of the factors, and that it preserves ordinal preferences among the alternatives. This means that if one alternative is preferred to another, its eigenvector component is larger than that of the other. A vector of weights obtained from the pairwise comparisons matrix reflects the relative performance of the various factors. Research related to the AHP usually uses the five measurement criteria listed in Table 2.

However, a growing body of literature now argues that the AHP has its drawbacks. Studies have concluded that the AHP can be applied to specific, but not fuzzy, decision-making. They have also indicated that the AHP evaluates questions using different criteria for different parts of the test set, that AHP cannot include uncertainty factors regarding the relationship of people to objects, and that the priorities of AHP are unspecific. The present study used a modified form of AHP called fuzzy AHP (FAHP) in order to arrive at more precise results.

Table 1
Summary of innovation capital indicators.

Indicators	Reference
Patent	Griliches (1990), Hall et al. (2000), Toivanen et al. (2002)
R&D expense	Bosworth and Rogers (2002); Griliches (1987), Hall (1999)
Number of new ideas	Van Buren (2000)
Number of new products	Kelly and Rice (2002), Schoenecker and Swanson (2002)
Product design and time of development	Hall and Bagchi-Sen (2002), Van Buren (2000)
New market and customers development	Dzinkowski (2000)
Innovative culture	Dzinkowski (2000), Van Buren (2000)
Number of R&D workers	Guthrie and Petty (2000)
Rate of innovative thought	Acs et al. (2001)
Copyright and brand	Bosworth and Rogers (2002)
Patent income	Guthrie and Petty (2000), Van Buren (2000)
Outer tech connection	Gambardella and Torrisi (2000)

Table 2
AHP criteria and definitions.

Criterion	Definition	Description
1	Equal importance	Two projects have the same importance
3	Weak importance	Experiment and judgment slightly favor one project
5	Essential importance	Experiment and judgment intensively favor one project
7	Very strong importance	Reveal intensively toward a project
9	Absolute importance	Favor one project absolutely
2, 4, 6, 8	Intermediate importance	The value of the projects is subject to compromise

6.2. Fuzzy set theory

Professor L.A. Zadeh developed the fuzzy set theory in 1965 while trying to solve problems of fuzzy phenomena existing in the real world, which refer to situations that are uncertain, about which the information is incomplete, or that behave in unpredictable ways. Fuzzy set theory is much better suited than traditional set theory to expressing set concepts in human language. Fuzzy set theory presents unspecific and fuzzy characteristics in relatively clear language, and it represents a field using a membership function that permits situations like "incompletely belong to" and "incompletely not belong to".

6.3. Fuzzy numbers

We order the universe of discourse such that U is the whole target that we discuss, and each target in the universe of discourse is called an element. Fuzzy $\widetilde{A}$, which in U states that random $x \rightarrow U$ assigns a real number $\mu_{\widetilde{A}}(x) \rightarrow [0,1]$. We call anything above that level of x *under A*.

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

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

The triangular fuzzy number above can be shown as $\widetilde{A} = (L, M, U)$, where L and U represent the fuzzy probability between the lower and upper boundaries of evaluation, respectively, as Fig. 1 shows. Assume two fuzzy numbers $\widetilde{A}_1 = (L_1, M_1, U_1)$ and $\widetilde{A}_2 = (L_2, M_2, U_2)$:

(1) $\widetilde{A}_1 \oplus \widetilde{A}_2 = (L_1, M_1, U_1) \oplus (L_2, M_2, U_2) = (L_1 + L_2, M_1 + M_2, U_1 + U_2)$.
(2) $\widetilde{A}_1 \otimes \widetilde{A}_2 = (L_1, M_1, U_1) \otimes (L_2, M_2, U_2) = (L_1L_2, M_1M_2, U_1U_2)$, $L_i > 0, M_i > 0, U_i > 0$.
(3) $\widetilde{A}_1 - \widetilde{A}_2 = (L_1, M_1, U_1) - (L_2, M_2, U_2) = (L_1 - L_2, M_1 - M_2, U_1 - U_2)$.
(4) $\widetilde{A}_1 \div \widetilde{A}_2 = (L_1, M_1, U_1) \div (L_2, M_2, U_2) = (L_1/U_2, M_1/M_2, U_1/L_2)$. $L_i > 0, M_i > 0, U_i > 0$.
(5) $\widetilde{A}_1^{-1} = (L_1, M_1, U_1)^{-1} = (1/U_1, 1/M_1, 1/L_1), L_i > 0, M_i > 0, U_i > 0$.

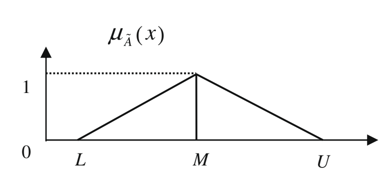

Fig. 1. Triangular fuzzy numbers.

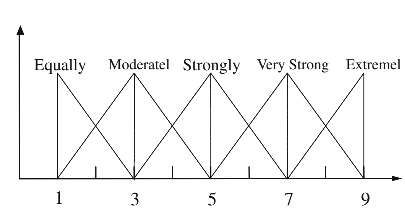

Fig. 2. Fuzzy membership function for linguistic values for attributes.

Table 3
Definition and membership function of fuzzy numbers.

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

6.4. Fuzzy linguistic variables

A fuzzy linguistic variable is a variable that reflects the different levels of human language. Its value represents the range from natural to artificial language. When one is precisely reflecting the value or meaning of a linguistic variable, there must be an appropriate number of ways for it to change. Variables for a human word or sentence can be divided along numerous linguistic criteria, such as equally important, moderately important, strongly important, very strongly important, and extremely important. This is shown in Fig. 2, and the definitions and descriptions are shown in Table 3. For the present study, the five criteria above were used: equally important, moderately important, strongly important, very strongly important, and extremely important.

6.5. Calculation steps of the FAHP

The four-step-procedure of the Fuzzy Analytic Hierarchy Process (FAHP) is as follows:

Step 1: Comparing the performance score. Assuming K experts, we precede to decision-making on Palternatives with n criteria.
Step 2: Construct fuzzy comparison matrix. We use a triangular fuzzy number to represent the meaning of questionnaires, and we construct positive reciprocal matrixes.
Step 3: Examine consistency of fuzzy matrix $\widetilde{A}_i$. Assume that $A = [a_{ij}]$ is a positive reciprocal matrix and $\widetilde{A} = [\tilde{a}_{ij}]$ is a fuzzy positive reciprocal matrix. If $A = [a_{ij}]$ is consistent, $\widetilde{A} = [\tilde{a}_{ij}]$ will also be consistent.
Step 4: Calculate fuzzy evaluation of number $\tilde{r}_i$

$$\tilde{r}_i = [\tilde{a}_{i1} \otimes \ldots \otimes \tilde{a}_{in}]^{1/n}$$

Step 5: Calculate fuzzy weight $\tilde{W}_i$

$$\tilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_i \oplus \cdots \oplus \tilde{r}_m)^{-1}$$

Step 6: Defuzzy. The study finds the best crisp value or nonfuzzy value in accordance with the Center of Area (COA) or the Center Index (CI), developed by Teng and Tzeng (1993), which means that we calculate clear weights for each index. The calculation method is as follows:

$$BNP_i = [(UR_i - LR_i) + (MR_i - LR_i)]/3 + LR_i, \quad \forall i$$

7. Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR)

The VIKOR method was developed by Opricovic and Tzeng (2002). This method is based on the compromise programming of multi-criteria decision-making (MCDM). We assume that each alternative is evaluated according to a separate criterion function; the compromise ranking could be reached by comparing the measure of closeness to the ideal alternative. The multi-criteria measure for the compromise ranking is developed from the $L_p - metric$ used as an aggregating function for a compromise programming method (Opricovic & Tzeng, 2002). The various J alternatives are represented as $a_1, a_2, \ldots, a_J$. For alternative a_j, the rating of the ith aspect is denoted by f_{ij}; i.e., f_{ij} is the value of th criterion function for the alternative a_j; n is the number of criteria. The VIKOR method developed with the form of $L_p - metric$, shown as follows:

$$L_{pj} = \left\{ \sum_{i=1}^{n} [w_i(f_i^* - f_{ij})/(f_i^* - f_i^-)]^p \right\}^{1/p}, \quad 1 \leqslant p \leqslant \infty; j = 1, 2, \ldots, J.$$

In the VIKOR method, $l_{1,j}$ (represent S_j as follows) and $L_{\infty j}$ (represent R_j as follows) are used to formulate the ranking measure. The solution gained by $\min_j S_j$ is with a max group utility, and the solution gained by $\min_j R_j$ is with a mix individual regret for the "opponent". The compromise solution is a solution F^c that is the closest to the ideal F^*, and compromise means an agreement established by mutual concessions, as shown in Fig. 3 by $\Delta f_1 = f_1^* - f_1^c$ and $\Delta f_2 = f_2^* - f_2^c$.

The VIKOR calculation steps, of which there are five, are shown as follows:

Step 1. Decide the best f_i^* and the worst f_i^- values of all criterion functions $i = 1, 2, \ldots, n$. If the ith function represents a benefit, then:

$$f_i^* \max_j f_{ij}, \quad f_i^- = \min_j f_{ij}$$

Step 2. Calculate the values S_j and $R_j; j = 1, 2, \ldots, J$, by the equations$S_j = \sum_{i=1}^{n} w_i(f_i^* - f_{ij})/(f_i^* - f_i^-)$, and $R_j = \max_i[w_i(f_i^* - f_{ij})/(f_i^* - f_i^-)]$, where w_i are the weights of criteria, expressing their relative importance.
Step 3. Calculate the values $Q_{j,}j = 1, 2, \ldots, J$, by the relation

$$Q_j = v(S_j - S^*)/(S^- - S^*) + (1 - v)(R_j - R^*)/(R^- - R^*),$$
$$S^* = \min_j S_j, \quad S^- = \max_j S_j$$
$$R^* = \min_j R_j, \quad R^- = \max_j R_j$$

v is introduced as the weight of the strategy of the maximum group utility; here, $v = 0.5$.
Step 4. Alternatives ranking, sorted by the values S, R and Q, in decreasing order. The results are three ranking lists.
Step 5. We propose a compromise solution, the alternative (d), which is ranked the best by the measure Q (min) if it satisfies the following two conditions:
1. $Q(a'') - Q(a') \geqslant DQ$, which is called acceptable advantage, where a'' is the alternative with second position in the ranking list given by $DQ = 1/(J - 1); J$ is the number of alternatives.

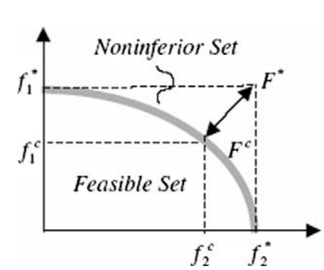

Fig. 3. Ideal and compromise solutions.

2. Acceptable stability in decision-making: Alternative d also has to be the best ranked by S and/or R. This solution is stable in a decision-making process, which could be: "voting by majority rule" (when $v > 0.5$ is needed) or "by consensus" $v \approx 0.5$ or "with veto" ($v < 0.5$). Here, v is the weight of the decision-making strategy that gives the max group utility.

If conditions could be not fully satisfy above two conditions, then a set of compromise solutions is proposed, shown as the following:

1. alternatives a' and a'' if only condition 2 is not satisfied, or,
2. alternatives a' and $a'', \ldots, a^{(M)}$ if condition 1 is not satisfied; and $a^{(M)}$ is determined by the relation $Q(a^{(M)}) - Q(a') < DQ$ for Max M.

The best alternative ranked by Q is the one with the minimum value of Q. The main ranking result is the compromise ranking the list of alternatives, and the compromise solution with the advantage rate.

Ranking by VIKOR needs to be performed with different values for criteria weights, and one must analyze the impact of criteria weights on the proposed compromise solution. This determines the weight stability intervals by using the methodology cited in Opricovic (1998). The compromise solution obtained with initial weights $(w_i, i = 1, \ldots, n)$ will be replaced if the value of a weight is not in the stability interval. The analysis of weight stability intervals for a single criterion is utilized for all criterion functions, with the given initial values of weights. In this way, the preference stability of an obtained compromise solution may be analyzed using the VIKOR program.

VIKOR is a tool that is beneficial in multi-criteria decision-making, in situations where the decision-maker is unstable, or when one has no idea how to express one's preference (at the beginning of system design, especially). Decision-makers accept the obtained compromise solution because of the fact that it provides a maximum "group utility," represented by Min Q, and a minimum of the individual regret that is represented by Min R.

8. Empirical study of innovation capital indicator assessment of Taiwanese Universities

In order to assess the intellectual capital of universities by using innovation capital, the research extracts some of the indicators listed in Table 1 and tailors them to the features of universities after in-depth interviews with ten related background experts (Table 4). A questionnaire was employed to ascertain from three groups comprised of 54 experts – nineteen from the Research-Intensive Universities, seventeen from Teaching-Intensive universities, and sixteen from Professional-Intensive Universities – their

Table 4
Summary of the selected innovation capital indicators of intellectual capital evaluation.

First level (Dimension)	Second level (indicator)	Definition	Reference
Intellectual property (IP)	Innovative reference (IP1)	The exploration of undiscovered knowledge	Hall and Bagchi-Sen (2002);Van Buren (2000)
	Innovative culture (IP2)	Organization encourages providing original ideas	Dzinkowski (2000); Van Buren (2000)
	Number of new ideas (IP3)	Number of valuable new ideas	Van Buren (2000)
Tangible assets (TA)	Number of publications (TA1)	Number of reference books produced	Guthrie and Petty (2000); Schoenecker and Swanson (2002)
	Financial support (TA2)	Research fund, monetary donations, and other tuition	Van Buren (2000); Guthrie and Petty (2000)
	Research performance (TA3)	Number of teachers, and domestic and international journals	Guthrie and Petty (2000)

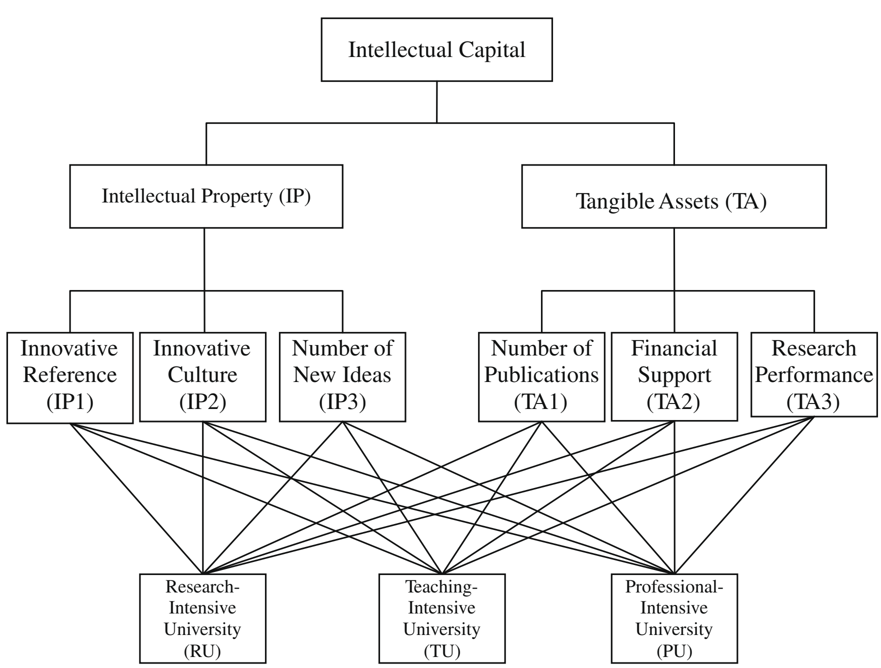

Fig. 4. Hierarchical evaluation structure of intellectual capital for universities.

Table 5
Pairwise comparison matrix and global weights of measurement dimension.

Measurement dimensions	IP			TA			BNP	Local weight
IP	1.000	1.000	3.000	2.737	3.940	6.003	1.056	0.801
TA	0.167	0.254	0.365	1.000	1.000	3.000	0.262	0.199

Table 6
Pairwise comparison matrix and global weights of measurement indicators (IP).

Measurement indicators (IP)	IP1			IP2			IP3			BNP	Local weight	Global weight
IP1	1.000	1.000	3.000	0.342	0.483	0.737	0.372	0.530	0.880	0.275	0.204	0.163
IP2	1.358	2.069	2.926	1.000	1.000	3.000	0.678	1.246	2.036	0.577	0.427	0.342
IP3	1.136	1.885	2.690	0.491	0.803	1.476	1.000	1.000	3.000	0.497	0.368	0.295

Table 7
Pairwise comparison matrix and global weights of measurement indicators (TA).

Measurement indicators (TA)	TA1			TA2			TA3			BNP	Local weight	Global weight
TA1	1.000	1.000	3.000	0.860	1.605	2.390	0.306	0.455	0.851	0.380	0.275	0.049
TA2	0.418	0.623	1.163	1.000	1.000	3.000	0.246	0.308	0.617	0.264	0.191	0.034
TA3	1.175	2.197	3.268	1.621	3.243	4.071	1.000	1.000	3.000	0.737	0.534	0.096

ranking of each measurement innovation capital indicator with respect to intellectual capital measurement, utilizing a 5-point scale ranging from 9 (extremely important) to 1 (no effect), as Table 3 shows, and with respect to the performance of intellectual capital for each type of university, using a range from 100 (the best) to 0 (the worst). The results of the weight of innovation capital indicators from each dimension were utilized to assess the performance of the intellectual capital of three main types of Taiwanese Universities (as Fig. 4).

Table 8
Matrix of performance with best and worse values.

Indicators types of University	IP1	IP2	IP3	TA1	TA2	TA3
RU	90.66	91.33	92.66	96.66	96.33	95.66
TU	84.33	76.66	77.33	85.33	86.00	84.33
PU	73.66	78.66	76.00	71.66	67.66	72.66
f_i^*	90.66	91.33	92.66	96.66	96.33	95.66
f_i^-	73.66	76.66	76.00	71.66	67.66	72.66
$f_i^* - f_i^-$	17.00	14.67	16.66	25.00	28.67	23.00

After constructing the hierarchical evaluation structure, local weights for the dimensions and indicators were calculated first. All the fuzzy measuring matrices were developed in the same way. In addition, pairwise comparison matrices and local weights were also analyzed. The local weights for the dimensions and indicators were calculated in a similar way to the calculation of the fuzzy measuring matrices (Table 5–7).

Next, utilizing local weights for each dimension, global weights for the indicators were calculated. Global indicator weights were computed by measuring the local weight of the dimensions. All of the global weights are provided in the last column of Tables 6 and 7.

Then, alternatives (universities) were ranked using the VIKOR method with the data from Table 8 and a set of weight values (Tables 6 and 7). Values of f_i^* and f_i^- were calculated in accordance with the best and worst value under each column of indicators, as Table 8 shows. After that, the values of S_j and R_j were found based on the equations of $f_i^* = \max_j f_{ij}$ and $f_i^- = \min_j f_{ij}$; the results are shown in Table 9. To find out the value Q, we adopted the equation $Q_j = \frac{v(S_j - S^*)}{S^- - S^*} + \frac{(1-v)(R_j - R^*)}{R^- - R^*}$, with $v = 0.5$ (voting by consensus). The results of Q_s and the ranking of alternatives (universities) are

Table 9
Result of S_j and R_j.

Indicators/types of University	IP1	IP2	IP3	TA1	TA2	TA3	S_j	R_j
RU	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.000
TU	0.06	0.34	0.27	0.02	0.01	0.05	0.756	0.342
PU	0.16	0.30	0.30	0.05	0.03	0.10	0.932	0.295
Weights	0.163	0.342	0.295	0.049	0.034	0.096		

Table 10
Ranking by VIKOR method.

Types of University	S_j	R_j	$S_j - S^*$	$R_j - R^*$	$S^- - S^*$	$R^- - R^*$	$(S_j - S^*)/(S^- - S^*)$	$(R_j - R^*)/(R^- - R^*)$	v	Q	Ranking
RU	0.000	0.000	0.000	0.000	.932	.342	0.000	0.000	0.5	0.000	1
TU	0.756	0.342	0.756	0.345			0.811	1.000		0.905	3
PU	0.932	0.295	0.932	0.950			1.000	0.864		0.600	2

C1. $0.600 - 0.000 = 0.600 \geqq 1/(3-1) = 0.5$; acceptable advantage.
C2. v≈voting by consensus; acceptable stability in decision-making.

Table 11
The fuzzy AHP and VIKOR results of the study.

First level (dimension)	Local weight	Second level (indicator)	BNP	Local weight	Global weight	Prior	Types of University	v	Q	Ranking
Intellectual Property (IP)	0.801	Innovative reference (IP1)	0.275	0.204	0.163	3	Research-Intensive University (RU)	0.5	0.000	1
		Innovative culture (IP2)	0.577	0.427	0.342	1				
		Number of new ideas (IP3)	0.497	0.368	0.295	2	Teaching-Intensive University (TU)		0.905	3
Tangible Assets (TA)	0.199	Number of publication (TA1)	0.380	0.275	0.049	5				
		Financial support (TA2)	0.264	0.191	0.034	6	Professional-Intensive University (PU)		0.600	2
		Research performance (TA3)	0.737	0.534	0.096	4				

provided in Table 10. The overall results are summarized in Table 11.

9. Conclusions

With the advent of the knowledge-based economy, there is an apparent tendency towards promoting intellectual capital in order for companies to sustain their competitive advantage. In particular, such tendency has extended from enterprises to higher education institutions – namely, universities. Universities play a key role for the creation and diffusion of knowledge in national innovation systems. Hence, to achieve higher intellectual capital, an increasing number of universities are focusing on innovation, which is a crucial factor of intellectual capital in affecting the level of quality of university education and research. Therefore, to achieve a better quality of higher education, it becomes imperative for existing universities to effectively measure their intellectual capital against a set of evaluation criteria and for new universities to set a direction and decide what type of university they want to be in the future. Based on several innovation capital indicators proposed by numerous studies, we have gone into depth in our interviews and have combined the methods of FAHP and VIKOR to construct a hybrid fuzzy model that serves to assess the performance of the intellectual capital of Taiwanese Universities based on innovation. Future studies of how universities actually make these improvements will be useful.

References

Abeysekera, I., & Guthrie, J. (2005). Annual reporting trends of intellectual capital in Sri Lanka. *Critical Perspectives on Accounting, 16*(3), 151–163.

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

Ahuja, G. (2000). Collaborative networks, structural holes, and innovation: A longitudinal study. *Administrative Science Quarterly, 45*, 425–455.

Allee, V. (1999). The art and practice of being a revolutionary. *Journal of Knowledge Management, 3*(2), 121–132.

Bantel, K. A., & Jackson, S. (1989). Top management and innovation in banking, does the composition of top team make a difference? *Strategic Management Journal, 10*, 107–124.

Bontis, N., Keow, W., & Richardson, S. (2000). Intellectual capital and the nature of business in Malaysia. *Journal of Intellectual Capital, 1*(1), 85–100.

Bornemann, M., & Leitner, K. H. (2002). Measuring and reporting intellectual capital: The case of a research technology organization. *Singapore Management Review, 24*(3), 7–19.

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

Bozzolan, S., Favotto, F., & Ricceri, F. (2003). Italian annual intellectual capital disclosure: An empirical analysis. *Journal of Intellectual Capital, 4*(4), 543–558.

Brooking, A. (1996). *Intellectual capital: Core assets for the Third Millennium Enterprise*. London: Thomson Business Press.

Bukh, P. N., Nielsen, C., Gormsen, P., & Mouritsen, J. (2005). Disclousure of information on intellectual capital in Danish IPO prospectuses. *Accounting, Auditing, and Accountability Journal, 18*(6), 713–732.

Caddy, I. (2000). Intellectual capital: Recognizing both assets and liabilities. *Journal of Intellectual Capital, 1*(2), 129–146.

Canibano, L., Garcia-Ayuso, M., & Sanchez, P. (2000). Accounting for intangibles: A literature review. *Journal of Accounting Literature, 19*, 102–130.

Canibano, L., & Sanchez, M. P. (2004). Measurement, management and reporting on intangibles. In L. Canibano & M. P. Sanchez (Eds.), *Readings on intangibles and intellectual capital* (pp. 81–113). Madrid: AECA. State of the art.

Carson, E., Ranzjin, R., Winefield, A., & Marsdon, H. (2004). Intellectual capital: Mapping employee and work group attribution. *Journal of Intellectual Capital, 5*(3), 443–456.

Cascio, W. (1998). Valuing and costing intellectual capital. *HR Monthly*, 12–16.

Chen, J. K., & Chen, I. S. (2007). Constructing Taiwanese small-enterprise innovative capital indices by using Fuzzy AHP. *The Business Review, Cambridge, 8*(2), 159–164.

Chen, H. M., & Lin, K. J. (2004). The role of human capital cost in accounting. *Journal of Intellectual Capital, 5*(1), 116–130.

Damanpour, F. (1996). Innovation effectiveness, adoption and organizational performance. In M. A. West & J. L. Farr (Eds.), *Innovation and creativity at work* (pp. 125–141). Chichester: John Wiley & Sons.

Davenport, T. H., & Prusak, L. (1998). *Working knowledge: How organizations manage what they know*. Boston: Harvard Business School Press.

Diefenbach, T. (2004). Different meanings of intangible assets and knowledge – And their implications for management and innovation. *The International Journal of Knowledge, Culture and Change Management, 4*(5), 553–567.

Dzinkowski, R. (2000). The measurement and management of intellectual capital: An introduction. *Management Accounting, 78*(2), 32–36.

Edvinsson, L., & Malone, M. (1997). *Intellectual capital*. New York: Harper Business.

European Commission. (2003). *Inventory of public aid granted to different energy sources* (p. 1275). Staff working paper, SEC(2002).

Fischer, M. M. (2001). Innovation, knowledge creation and systems of innovation. *The Annals of Regional Science, 35*, 199–216.

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

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

Griliches, Z. (1987). R&D and productivity: Measurement issues and econometric results. *Science, 237*, 31–35.

Griliches, Z. (1990). Patent statistics as economic indicators: A survey. *Journal of Economic Literature, 28*, 1661–1707.

Guthrie, J. (2001). The management, measurement and the reporting of intellectual capital. *Journal of Intellectual Capital, 2*(1), 27.

Guthrie, J., & Petty, R. (2000). Intellectual capital: Australian annual reporting practices. *Journal of Intellectual Capital, 1*(3), 241–251.

Haanes, K., & Lowendahl, B. (1997). The unit of activity: Towards an alternative to the theories of the firm. In H. Thomas (Ed.), *Strategy, structure, and style*. Copenhagen: Wiley.

Hall, B. H. (1999). *Innovation and market value* (p. 6984). NBER working paper, Cambridge, MA.

Hall, L. A., & Bagchi-Sen, S. (2002). A study of R&D, innovation, and business performance in the Canadian biotechnology industry. *Technovation, 22*, 144–231.

Hall, B. H., Jaffe, A., & Trajtenberg, M. (2000). *Market value and patent citations: A first look* (pp. 0–277). University of California at Berkeley, Department of Economics working paper, Berkeley, CA.

Kamath, G. B. (2007). The intellectual capital performance of Indian banking sector. *Journal of Intellectual Capital, 8*(1), 96–98.

Kaplan, R. S., & Norton, D. P. (1996). The balanced scorecard: Translating strategy into action, the president and fellows of Harvard College. *Harvard Business Review*, 75–85.

Kaplan, R. S., & Norton, D. P. (2004). Using the balanced scorecard as a strategic management system. *Harvard Business Review*, 75–85.

Kelly, D. J., & Rice, M. P. (2002). Advantage beyond founding: The strategic use of technologies. *Journal of Business Venturing, 17*, 41–57.

Kimberly, J. R. (1981). Managerial innovation. In P. C. Nystorm & W. H. Starbuck (Eds.), *Handbook of organizational design*. New York: Oxford University Press.

Lev, B., & Feng, G. (2001). *Intangible assets: Measurement, drivers, usefulness*. New York: New York University.

Li, U. C. (2007). *Enter university by 2.8 point each subject*. <www.news.msn.com.tw/print.aspx?id=210245>.

Marr, B. (Ed.). (2005). *Perspective on intellectual capital: Multidisciplinary insights into management, measurement, and reporting*. Boston, MA: Elsevier.

Marr, B., & Chatzkel, J. (2004). Intellectual capital at the crossroad: Managing measuring, and reporting of IC. *Journal of Intellectual Capital, 5*(4), 224–229.

MERITUM (2001). *Measuring intangibles to understand and improve innovation management*. Final report, European community. <www.kunne.no/meritum>.

Moon, Y. J., & Kym, H. G. (2006). A model for the value of intellectual capital. *Canadian Journal of Administrative Sciences, 23*(3), 253–269.

Mouritsen, J., Larsden, H. T., & Bukh, P. N. D. (2001). Intellectual capital and the capital firm: Narrating, visualizing and numbering for managing knowledge. *Accounting Organizations and Society, 26*(7/8), 735–762.

Nahapiet, J., & Ghoshal, S. (1998). Social capital, intellectual capital, and the organizational advantage. *Academy of Management Review, 23*, 242–266.

Neely, A. (Ed.). (2002). *Business performance measurement. Theory and practice*. Cambridge: Cambridge University Press.

Ng, A. W. (2006). Reporting intellectual capital flow in technology-based companies. *Journal of Intellectual Capital, 7*(4), 492–500.

Opricovic, S. (1998). *Multicriteria Optimization of Civil Engineering Systems*, Faculty of Civil Engineering, Belgrade.

Opricovic, S., & Tzeng, G. H. (2002). Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS. *European Journal of Operational Research, 156*, 445–455.

Ordaz, C. C., Lara, A. B. H., & Cabrera, R. V. (2005). The relationship between top management teams and innovative capacity in companies. *The Journal of Management Development, 24*(8), 683–704.

Ordonez de Pablos, P. (2002). Evidence of intellectual capital disclosure measurement from Asia, Europe and the Middle East. *Journal of Intellectual Capital, 3*(3), 287–302.

Ordonez de Pablos, P. (2003). Intellectual capital reporting in Spain: A comparative review. *Journal of Intellectual Capital, 4*(1), 61–81.

Ordonez de Pablos, P. (2004). Measuring and reporting structural capital: Lessons from European learning firms. *Journal of Intellectual Capital, 5*(4), 629–647.

O'Sullivan, M. A. (2000). *Contents for corporate control: Corporate governance and economic performance in the United States and Germany*. New York: Oxford University Press.

Petrash, G. (1996). Dow's journey to a knowledge value management culture. *European Management Journal, 14*(4), 365–373.

Petty, R., & Guthrie, J. (2000). Intellectual capital literature review: Measurement, reporting and management. *Journal of Intellectual Capital, 1*(2), 155–176.

Sanchez, P., Chaminad, C., & Olea, M. (2000). Management of intangibles: An attempt to build a theory. *Journal of intellectual Capital, 1*(4), 312–327.

Sanchez, M. P., & Elena, S. (2006). Intellectual capital in universities improving transparency and internal management. *Journal of Intellectual Capital, 7*(4), 529–539.

Schoenecker, T., & Swanson, L. (2002). Indicators of firm technological capability: Validity and performance implications. *IEEE Transactions on Engineering Management, 49*(1), 36–44.

Sonnier, B. M., Carson, K. D., & Carson, P. P. (2007). Accounting for intellectual capital: The relationship between profitability and disclosure. *The Journal of Applied Management and Entrepreneurship, 12*(2), 3–14.

Stewart, G. B. (1997). The EVA financial management system. *Journal of Applied Corporate Finance, 8*(2), 32–46.

Subramaniam, M., & Venkatraman, N. (2001). Determinants of transnational new product development capability: Testing the influence of transferring and deploying tacit overseas knowledge. *Strategic Management Journal, 22*, 359–378.

Subramaniam, M., & Youndt, M. A. (2005). The influence of intellectual capital on the types of innovative capabilities. *Academy of Management Journal, 48*(3), 450–463.

Sveiby, K. E. (1997). *The new organizational wealth: Managing and measuring knowledge-based assets*. San Francisco: Berrett-Koehler.

Tan, H. P., Plowman, D., & Hancock, P. (2007). Intellectual capital and financial returns of companies. *Journal of Intellectual Capital, 8*(1), 76–95.

Teng, J. Y., & Tzeng, G. H. (1993). Transportation investment project selection with fuzzy multiobjectives. *Transportation Planning and Technology, 17*, 91–112.

Toivanen, O., Stoneman, P., & Bosworth, D. (2002). Innovation and the market value of UK. *OXFORD Bulletin of Economics and Statistics, 64*(39), 39–61.

Tushman, T., & Nadler, D. (1986). Organizing for innovation. *California Management Review, 28*(3), 74–92.

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

Wang, J. C. (Amanda). (2006). Utilizing scandia navigator system and Ohlson model to evaluate the intellectual capital performance for Taiwan electronic corporation. *The Business Review, Cambridge, 6*(1), 186–192.

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

Youndt, M. A., Subramaniam, M., & Snell, S. A. (2004). Intellectual capital profiles: An examination of investments and returns. *Journal of Management Studies, 41*, 335–362.

Zeng, J. Y. (2002). The study of domestic banking intellectual capital. *Industrial Finance Quarterly, 114*, 35–52.

Zeng, J. Y., & Gu, Y. C. (2003). The relationship between intellectual capital and corporate intangibles: Manufacturing in Taiwan. *Management and System*, 1–30.