Using Nonadditive Fuzzy Integral to Assess Performances of Organizational Transformation Via Communities of Practice

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***Abstract*—Organizational transformations have been widely adopted by firms who wish to improve their competitive advantage to be better prepared to face external challenges. This research has chosen Communities of Practice (CoPs) as the subject of discussion for an assessment model to reform organizations that undertake CoPs for collective knowledge to enhance their core competencies. Given the interrelationships between criteria, this research uses the nonadditive fuzzy integral to develop a framework for the CoPs performance assessment. The purposes of this paper are to identify the key dimensions/criteria in the CoPs, to use fuzzy logic method to analyze the relative importance of each criterion, and to rank the criteria so that proper resources can be allocated while managing the CoPs. Through interviews with experts, four strategy alternatives and 16 criteria along four dimensions are generated. A survey of the CoPs practitioners is then conducted to compare the results of each criterion. The results will not only help organizations that intend to initiate changes via the CoPs activities to decide the ranking of their appraisal criteria, but it can also assist them in guiding the behavior of their staff while effectively monitoring and improving the performances of the CoPs.**

***Index Terms*—Analytic hierarchy process (AHP), communities of practice (CoPs), core competency, fuzzy integral, organizational transformation, knowledge management (KM), multiple criteria decision making (MCDM).**

I. Introduction

ORGANIZATIONAL transformation is a common approach used in technology management; it includes defreezing, changing, and refreezing processes. If the implementation of organizational transformation cannot reach the proposed target or generate an impact, this will usually end in the failure of a firm to achieve strategic results. Knowledge management (KM), especially that resulting from innovation needs, is regarded as an organizational transformation issue. It involves both personal and organizational aspects, and is an iteration of the transmission between explicit and tacit knowledge. Organizations may generate collective knowledge and recognition by constructing Communities of Practice (CoPs), since the latter is the test bed of optimal management strategy and best practice. This research looks at CoPs to discuss evaluation of their effectiveness.

CoPs are the most effective enabling organizational approach to facilitate knowledge sharing and innovation creation. Each CoP is a group in which members can learn from each other and gain respect. CoPs include managers and common knowledge workers who willingly and freely gather and agree their primary mission is to create, share, and apply knowledge to achieve a particular business goal. As effective tools in the 21st century, CoPs break functional boundaries and establish an open culture with limited resources. However, CoPs members need guidelines about how to balance their current work requirements and future information or knowledge-based applications. Without an evaluation strategy for implementing the newly generated knowledge, CoPs will be unable to achieve sustainable benefits for the organization. Therefore, the purpose of this paper is to firstly, understand the key dimensions (criteria) in the CoPs KM area. Secondly, we use fuzzy logic methodology to analyze the relative importance of each criterion and rank it in order to adequately allocate resources for strategic achievements while managing the CoPs.

Performance of organizational transformation is always a key issue but is hard to measure. Since numerical values cannot clearly express each considered criterion for the CoPs anticipated strategy alternatives, fuzziness is applicable. In imprecise/fuzzy environments, fuzzy logic is widely employed to deal with the problems of uncertainty, especially the problems of subjective perception/uncertainty. One usually has to deal with interdependent information to cope with a complex situation with multi-goals/objectives. Traditional analytical methods are inadequate for modeling such complex situations. Therefore, this research adopts nonadditive fuzzy integral to evaluate each of the possible strategy alternatives in an inconsistent environment with multiple dimensions. In the conventional approach to decision-making, the criteria in the decision model are assumed to be independent of each other. However, in the complex system of the real world, the criteria are generally inter-related with each other. The reason we employed the fuzzy logic methodology was to address the inter-related criteria in decision-making. Using fuzzy logic methodology, one can resolve the issue of criteria dependency in the complex CoPs system.

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TABLE I
ANALYSIS OF CoPs CRITICAL ELEMENTS

Critical Elements	Mutual Engagement	Joint Enterprise	Shared Repository
Description	Refers to the actual participation and commitment of people. CoPs do not only gather people and exchange names. The important key principle for CoPs is peoples' common interest.	At the beginning, members pursue the direction of CoPs, simultaneously creating the common responsibility within the group, usually by affiliation, visions or goals.	In the process of pursuing common visions, members create resources, namely knowledge banks, containing know-how, methodology to share knowledge in the community.

Source: Wenger, 1998, Cambridge University Press.

Scholars consider many dimensions for evaluating CoPs strategic preferences with multiplicative hierarchy criteria [20]. Many adopt Analytic Hierarchy Process (AHP) [37], [38] to obtain decision-making alternatives. Hwang and Yoon [3] discussed the methods and applications of multiattribute decision-making. Mon and Cheng [6] used AHP to assess weapon systems. Tsaur and Tzeng [36] analyzed the risk of tourism from fuzzy viewpoints. Tang and Tzeng [32] explored e-commerce alternatives of information services. Using AHP is convenient for responses to completed questionnaires based on relative importance, and rankings are closer to human logic. Moreover, researchers such as Cheng and Mon [2] (in the selection of weapon systems) and Buckley [21]) have started to apply fuzzy AHP (fuzzy analytic hierarchy process), to resolve fuzzy Linguistic Scale problems to facilitate expressions by survey respondents.

By adopting fuzzy AHP (Buckley, 1985) and nonadditive fuzzy integral (Sugeno, and Kwong, 1995), this research explores independent and interrelated criteria. Sugeno [29], [31] introduced the concepts of fuzzy measure and fuzzy integral. The fuzzy integral can be applied to multiattribute assessment such as in [27], [28], [1], and [44]. Fuzzy measures and fuzzy integrals can analyze the human evaluation process and specify decision-makers for preference structures. Therefore, the purposes of this paper are to: 1) understand the key dimensions (criteria) in the CoPs knowledge management area; 2) use the fuzzy logic methodology to analyze the relative importance of each criterion; 3) rank criteria so that proper resources can be allocated while conducting the CoPs management.

This research uses 16 criteria built upon four dimensions, which are **Locus of Leadership, Incentive Mechanisms, Member Interaction**, and **Complementary assets**, so as to establish a multilevel and multicriteria framework. The research then assesses proper ranking and priorities of CoPs alternatives through experts' questionnaires. The results of the 57 questionnaires analyzed using EcPro (AHP), Excel, and Mat Lab (Fuzzy Integral) software, reveal the utility value of **Increased Core Competency** to be the highest, and followed by **Enhanced Work Efficiency, Promoted Responsiveness**, and **Induced Innovation**. The results can provide reference for choosing the strategies for enhancing CoPs performances. In addition to surveying all related publications, this research applies a quantitative model to compensate for the deficiencies, such as subjective or qualitative viewpoints, of existing CoPs analyses.

The rest of this paper is organized as follows. Section II discusses the reviews literature related to CoPs. Section III proposes a fuzzy logic methodology. Section IV derives assessment architectures. Section V uses an empirical case to illustrate the proposed method for analyzing the practical results and discussions. Section VI presents conclusions.

II. Literature Review of CoPs

Most KM projects in the past stressed mainly explicit knowledge, but inquired little into tacit knowledge of individuals or within organizations. In the last two years, tacit knowledge and people interfaces have been gradually emphasized, especially for those crossing organizational boundaries. As a consequence, the idea of CoPs is becoming a mainstream concept and operational model in the KM field. In this section, we introduce implications, benchmarks, values, and strategy alternatives of CoPs.

A. Implications of CoPs

Although the names and terms of the various CoPs may differ, they share similar content and concepts. In 2000, Verna Allee [42] thought knowledge should include and utilize CoPs to create organizational knowledge. In 1998, Etienne C. Wenger [9] first proposed CoPs in the *Harvard Business Review*. He believes that CoPs are informal groups sharing knowledge and passion and pointed out that CoPs are composed of the three critical elements shown in Table I.

B. Benchmarks of CoPs

Other team formations exist in an organization besides CoPs, including formal divisions, project teams, and informal networks and so on. This research outlines four kinds of benchmarking associations which will help to differentiate CoPs characteristics and appearances [10], [33], [42], as shown in Table II.

C. Value of CoPs

CoPs create value not only for the organization but also for the individuals inside the organization. It is an effective method to share knowledge while achieving organizational benefits. Table III collects the studies stating the multiple values of CoPs [42], and compares their plural values as shown in Table III.

D. Four Strategy Alternatives of CoPs

This research assumes that different CoPs' perceptions of knowledge will influence members' behaviors and affect

TABLE II
COMPARISON OF COPS AND OTHER GROUPS

Item/group category	Communities of practice	Formal Division	Project Team	Informal Network
Purpose	1. Share knowledge; 2. Promote problem solving skill; 3. Accumulate organizational knowledge.	1. Responsible for divisional function; 2. Specialized task assignment.	1. Complete project target; 2. Cooperation crosses divisions.	Integrate and exchange valuable information.
Teaming	Participate by free will	Lead by division manager	Chosen by project leader	Common interest or mutual trust
Characters of members	Similar	Similar	Different	Different
Boundary	Vague	Clear	Clear	Undecided
Driving force	Passion, trust, sense of Identity, commitment	Goal of division	Goal of project	Meet each other's needs
Duration	As long as common interest exists	Until reorganization	Until end of project	Lack of definite starting & ending point

Source: Wenger et al., 2002; Cohendet & Meyer-Krahmer, 2001; Allee, 2000

TABLE III
COPS VALUE COMPARISON BY EACH ENTITY

Entities	Enterprise	Community	Individual
Value	1. Realize organization strategy; 2. Solve cross-field problems quickly; 3. Help to recruit talents; 4. Construct core competency and competitive advantage; 5. Reuse best practices; 6. Increase innovation.	1. Build common language, method, and model; 2. Establish knowledge and expert bank; 3. Help knowledge transmission; 4. Increase opportunity to find experts; 5. Provide power sharing and influence.	1. Work efficiently; 2. Sense of trust and loyalty towards company and colleagues; 3. Promote learning; 4. Increase skill and competency; 5. Offer contribution and face challenges.

Source: Verna Allee, 2000.

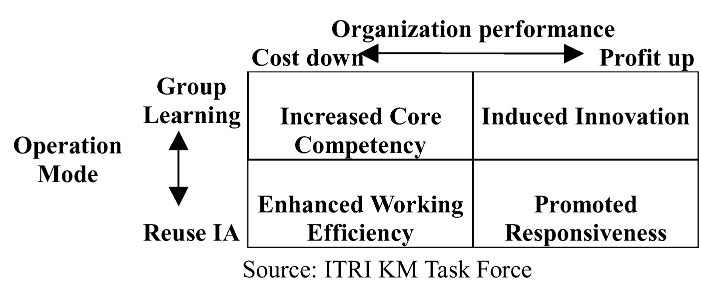

Fig. 1. Four kinds of CoPs strategy alternatives.

organizational benefits differently. When CoPs target explicit knowledge content, their operational focus tends to reuse intellectual property, emphasizing its storage, access, and reuse. The benefits may be reflected in improvements in work efficiency and responsiveness. When CoPs target tacit knowledge, the operation's key point is to create collective learning fields which provide opportunities for members to interact and exchange their knowledge and expertise. This kind of CoPs may enhance the capability of its members and facilitate innovation through cross-domain exchanges.

In general, when CoPs emphasize ability and efficiency enhancement, their organization's benefits are usually reflected in cost reductions. Those that focus on innovation and responsiveness usually bring new value or increase earnings for the organization [9]. Using the key aspects of operation mode and organizational performance, the survey differentiates four strategy alternatives of CoPs (as shown in Fig. 1).

The first strategy alternative is **Induced Innovation**. This features cross-domain sharing to facilitate innovation according to common interests. CoPs using such a strategy also provide a safe, or low-cost, infrastructure for trial and error attempts.

The second strategy alternative is **Promoted Responsiveness**. This stresses the importance of collecting and classifying knowledge to provide prewarning signals or issue-oriented solutions to members to speed up their reactions to particular events and issues.

The third strategy alternative is **Increased Core Competency**. Members in the CoPs share their experiences with others

TABLE IV
CHARACTERISTICS COMPARISON OF EACH COPS STRATEGY ALTERNATIVE

Dimension / alternatives	Connection	Interface	Entity	Performance	Key point
Induced Innovation	Support new ideas and creativity	Establish safe infrastructure for new thinking	Common Interest	Profit Up	Group Leaning
Promoted Responsiveness	Find people with similar experience	Willing to respond to problems	Common Language	Profit Up	Reuse IA
Increased Core Competency	Find experts	Coach of new knowledge	Regulation	Cost Down	Group Learning
Enhanced working Efficiency	Find developed practice	Positive Recognition	Know How	Cost Down	Reuse IA

and access domain experts easily. CoPs enable the spreading of knowledge between senior and junior members and disseminate the organization's commonalities and norms effectively.

The fourth strategy alternative is **Enhanced Working Efficiency**. CoPs reuse existing intellectual property, share related documents and authors' information, and enhance productivity with easy to study practical knowledge.

The differences among these four strategy alternatives are interrelated with the organization's preferred performances and operational modes, including cost-down, profit-up, group-learning, and intellectual asset (IA) reusability. By combining the literature review with empirical experience, this research constructs a matrix system of CoPs performance as shown in Fig. 1.

An important function of CoPs is to overcome the inherent problems of a slow-moving traditional hierarchy in a fast-moving knowledge economy. Associated with the CoPs, four specific alternatives are identified to lead strategic outcomes with multidimension criteria. A comprehensive comparison of these four strategy alternatives in different dimensions of network connections, human interface, knowledge entities, organizational performance, and the key points of their operations is shown as Table IV.

III. NONADDITIVE FUZZY INTEGRAL METHOD

In traditional multiattribute evaluation approaches, each attribute must be independent of the others. Consequently, the characteristics that have interactions and mutual influence among attributes or criteria in a real system cannot be handled by the concept of traditional additive measures alone. Therefore, to assess CoPs criteria and strategy alternatives, it is more appropriate to apply a fuzzy integral model in which it is not necessary to assume additivity and independence.

A. Fuzzy MCDM

Methods such as cost minimization, profit maximization, and cost effect analysis may be adopted to evaluate a single project in a simplified environment. However, those carrying out the analysis usually have to deal with interdependent information to realize multigoals in a complex situation. Traditional methods are inadequate to find solutions [14], [13], [32]). Therefore, this research adopts fuzzy multiple criteria decision making (MCDM) to evaluate each of the possible strategy alternatives in a dynamic environment with multiple dimensions. In addition to the divergence of respondents' linguistic opinions, this research uses fuzzy linguistic cognition to express various degrees of value to the quantitive/qualitative criteria and to discuss each kind of strategy alternative. The following section explains the related procedures and steps.

B. General Fuzzy Measure

Fuzzy measure is an assessment for representing the membership degree of objects in candidate sets. It assigns a value to each crisp set in the universal set and signifies the degree of evidence or belief about that element's membership in the set. Let X be a universal set. The fuzzy measure is then defined by the following function: g: $P(X) \to [0, 1]$. That assigns each crisp subset of X a number in the unit interval [0, 1]. The definition of function g is the power set $P(X)$. When a number is assigned to a subset $A \in P(X)$, $g(A)$ represents the degree of available evidence or the subject's belief that a given element in X belongs to the subset A. This particular element is most likely found in the subset assigned the highest value [17].

For quantifying a fuzzy measure, function g must conform to several properties. Conventionally, function g is assumed to have met the conditions of the axiom of probability theory, a probability theory measurement. However, actual practice always goes against this assumption. It is a fuzzy measurement in reality that should be defined by weaker axioms. The probability measure becomes a special type of fuzzy measure. Axioms of the fuzzy measure should include the following.

Axiom 1: boundary conditions, $g(\phi) = 0$ and $g(X) = 1$.

Axiom 2: monotonic, If $A \subseteq B$, then $g(A) \leq g(B), \forall A, B \in P(X)$.

If the universal set is infinite, it is necessary to add continuous axioms [18]. It is quite implicit that the elements in question are not within an empty set but within the universal set, regardless of the amount of evidence from the boundary conditions in Axiom 1. Axiom 2 refers to the necessary evidence for particular elements to belong to a certain set. There would have to be equivalent evidence required for the subset belonging to a set, making this monotonic.

The fuzzy measure is often defined by an even more general function $g : \beta \to [0, 1]$, where $\beta \subset P(X)$ so that $\phi \in \beta$ and $X \in \beta$; if $A \in \beta$, then $\bar{A} \in \beta$; β is closed under the operation of a set function; i.e., if $A \in \beta$ and $B \in \beta$, then $A \cup B \in \beta$.

The set β is usually called a Borel field. The triplet (X, β, g) is called a fuzzy measure space if g is a fuzzy measure in a measurable space (X, β).

In actual practice, it is sufficient to consider the finite set. Let X be a finite criterion set, $X = \{x_1, x_2, \ldots, x_n\}$, and the power set $P(X)$ be a class of all of the subsets of X. It can be noted that $g(\{x_i\})$ for a subset with a single element, $\{x_i\}$ is called a fuzzy density. In the following statement, we use g_i to represent $g(\{x_i\})$.

To differentiate the proposed model from other fuzzy measure models (such as λ-fuzzy measure, F-additive measure, classical probability measure), a general fuzzy measure is used to designate a fuzzy measure that is monotonic and only required to satisfy the boundary conditions. A general fuzzy measure has the fewest number of constraints and is the most general measure pattern.

C. λ-Fuzzy Measure

Since the specification for general fuzzy measures requires the values of a fuzzy measure for all subsets in X, Sugeno [30] incorporated the λ-additive axiom in order to reduce the difficulty of collecting information. In a fuzzy measure space (X, β, g), let $\lambda \in (-1, \infty)$. If

$$A \in \beta, B \in \beta$$

and

$$A \subset B = \phi$$

and

$$g_\lambda(A \cap B) = g_\lambda(A) + g_\lambda(B) + \lambda g_\lambda(A) g_\lambda(B). \tag{1}$$

Then the fuzzy measure g is λ-additive. This particular fuzzy measure is termed λ fuzzy measure because it must fulfill λ-additive. It is known as the Sugeno measure. To differentiate it from other fuzzy measures, we denote this λ-fuzzy measure by $g_\lambda(\{x_i\}) = g_i$. When $\lambda = 0$, this indicates that the measure is additive. Based on the axioms mentioned above, the λ-fuzzy measure of the finite set can be derived from fuzzy densities, as indicated in the following equation:

$$g_\lambda(\{x_1, x_2\}) = g_1 + g_2 + \lambda g_1 g_2 \tag{2}$$

where g_1, g_2 represent the fuzzy density. Furthermore

$$\begin{aligned} g_\lambda(\{x_1, x_2, \ldots, x_n\}) &= \sum_{i=1}^{n} g_1 + \lambda \sum_{i_1=1}^{n-1} \sum_{i_2=i_1+1}^{n} g_{i_1} g_{i_2} + \cdots \\ &\quad + \lambda^{n-1} g_1 g_2 \cdots g_n. \end{aligned} \tag{3}$$

When considering the influence of substitutive and multiplicative effects, people usually combine fuzzy measure and fuzzy integral to carry out integration information and evaluation. Before acquiring $g_\lambda(\{x_i\}) = g_i$, we determine c value first. Using MatLab software, we obtain c value when we have n criteria in the following equation:

$$\begin{aligned} g_\lambda(\{x_1, x_2, \ldots, x_n\}) &= c \sum_{i=1}^{n} w_i \\ &\quad + c^2 \lambda \sum_{\substack{i=1, j=1 \\ i \neq j, i \prec j}}^{n} w_i w_j \\ &\quad + c^3 \lambda^2 \sum_{\substack{i=1, j=1, z=1 \\ i \neq j \neq z, i \prec j \prec z}}^{n} w_i w_j w_z \\ &\quad + c^4 \lambda^3 \sum_{\substack{i=1, j=1, z=1, \pi=1 \\ i \neq j \neq z \neq \pi, i \prec j \prec z \prec \pi}}^{n} w_i w_j w_z w_\pi + \cdots \\ &\quad + c^n \lambda^{n-1} \prod_{i=1}^{n} w_i \end{aligned} \tag{4}$$

and

$$g_i = w_i \times c$$

and

$$\begin{aligned} &g_\lambda(\{x_1, x_2, \ldots, x_n\}) \\ &\quad = 1 \end{aligned} \tag{5}$$

where $w_i, i = 1, 2, \ldots, n$ can be obtained by the AHP method, then c and optimal λ can be estimated based on utility preference $g_i = u(x_i^*, x_{\bar{i}}^0)$ where the preferred criterion i is the best and the other criterion $\bar{i}$ (noncriterion i) is the worst.

D. Fuzzy Integral

Consider a fuzzy measure space (X, β, g). Let h be a mea-X to $[0, 1]$. Then, the definition of the fuzzy integral of h over A with respect to g is

$$\int_A h(x) dg = \sup_{\alpha \in [0,1]} [\alpha \wedge g_\lambda(A \cap H_\alpha)] \tag{6}$$

where $H_\alpha = \{x \mid h(x) \geqslant \alpha\}$. A is the domain of the fuzzy integral. Where $A = X$, then A can be eliminated.

In the following equations, we introduce the fuzzy integral calculation. For the sake of simplification, consider a fuzzy measure $g(X, P(X))$ where X is a finite set. Let h: $X \rightarrow [0, 1]$, and assume without loss of generality that the function $h(x_j)$ is monotonically decreasing with respect to j, i.e., $h(x_1) \geqslant h(x_2) \geqslant \cdots \geqslant h(x_n)$. To assure this, the elements in X can be renumbered. Then

$$\int_A h(x) dg = \vee_{i=1}^{n} [f(x_i) \wedge g_\lambda(x_i)] \tag{7}$$

where $X_i := \{x_1, x_2 \ldots, x_i\}, i = 1, 2, \ldots, n$.

In practice, h can be the performance of a particular criterion for the alternatives, while g represents the grade of subjective importance of each criterion. The fuzzy integral of h

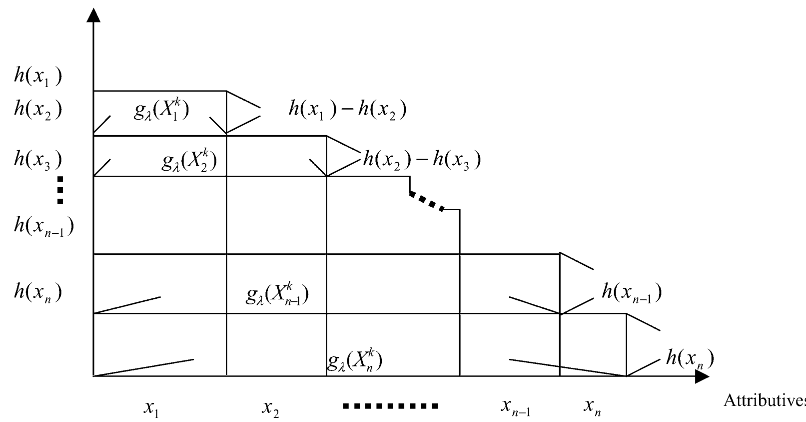

Fig. 2. The basic concept of the Choquet integral equation.

with respect to g gives the overall assessment of the alternatives. Furthermore, we can use the same fuzzy measure but with Chouqet's integral instead of the fuzzy integral, yielding (c)

$$\int hdg = h(x_n)g_\lambda(X_n) + [h(x_{n-1}) - h(x_n)] \times g_\lambda(X_{n-1}) + \cdots + [h(x_1) - h(x_2)]g_\lambda(X_1). \quad (8)$$

The fact that the fuzzy integral model does not need to assume the independence of each criterion, means it can be used in nonlinear situations. Even if, in an objective sense any two criteria are independent, they are not necessarily considered to be independent from the decision maker's subjective viewpoint. This explains why a fuzzy integral with synthetic assessment is more appropriate. Furthermore, even if one criterion is physically independent from another, the assessment of the alternatives by the subjects is according to the difference between the ideal and actual criterion values. Because the ideal values of each person are different and extremely difficult to measure, it is best to use the subjective assessment. In realistic assessment problems, the number of criteria will influence the complexity of calculation of the assessment problems. Choquet's integral can be used to measure the relations between each criterion in the same group.

E. Fuzzy Integral Multicriteria Assessment Method

This research employs the fuzzy integral to combine assessments, mainly because this model does not need to assume independence among the criteria and can be applied to nonlinear conditions. Even if some criteria are objectively independent from others, an evaluator might possibly think it was not quite independent, so the fuzzy integral is more appropriate for assessment.

A traditional multicriteria combining assessment method adopts the additive concept as the basis for determining whether criteria are independent from one another or not. In other words, using a multicriteria combining assessment to assess a system is an operation of simple additive weight (SAW) that sums up the importance of individual criteria and their effective values. Very often, each individual criterion is not completely independent from the others, which does not comply with the characteristics of this additive-type. Therefore, a partitioning type of fuzzy integral must be applied to the relating criteria to regroup it into a new assessment criteria hierarchy system. The fuzzy integral proposed by Sugeno [31] is then applied to combine the effective values of those related criteria and develop a new combining performance value. A brief explanation of the fuzzy integral follows.

First, assume under general conditions, $h(x_1^k) \geqslant \cdots \geqslant h(x_i^k) \geqslant \cdots \geqslant h(x_n^k)$, where $h(x_i^k)$ is the normalized performance value of the kth alternatives for the ith criterion, the fuzzy integral of the fuzzy measures $g(')$ of $h(')$ on X can be defined using the following Choquet integral equation:

$$\int^k hdg = h\left(x_n^k\right) g_\lambda\left(X_n^k\right) + \left[h\left(x_{n-1}^k\right) - h\left(x_n^k\right)\right] g_\lambda\left(X_{n-1}^k\right) + \cdots + \left[h\left(x_1^k\right) - h\left(x_2^k\right)\right] g_\lambda\left(X_1^k\right) \quad (9)$$

where

$$g_\lambda(X_1^k) = g_\lambda\left(\{x_1^k\}\right), g_\lambda\left(X_2^k\right) = g_\lambda\left(\{x_1^k, x_2^k\}\right)$$
$$g_\lambda\left(X_n^k\right) = g_\lambda\left(\{x_1^k, x_2^k \cdots x_n^k\}\right).$$

To express the fuzzy measures of each individual criterion group, $g_\lambda(x_n^k)$ can be expressed as follows:

$$\begin{aligned} g_\lambda\left(X_n^k\right) &= g_\lambda\left(\{x_1^k, x_2^k, \ldots, x_n^k\}\right) \\ &= \sum_{i=1}^n g_\lambda\left(\{x_i^k\}\right) \\ &\quad + \lambda \sum_{j>i}^n \sum_{i=1}^n g_\lambda\left(\{x_i^k\}\right) g_\lambda\left(\{x_j^k\}\right) + \cdots \\ &\quad + \lambda^{n-1} g_\lambda\left(\{x_1^k\}\right) g_\lambda\left(\{x_2^k\}\right) \cdots g_\lambda\left(\{x_n^k\}\right) \\ &\Rightarrow g_\lambda\left(\{x_1^k, x_2^k, \ldots, x_n^k\}\right) \\ &= \frac{1}{\lambda}\left[\Pi_{i=1}^n\left(1 + \lambda g_\lambda\left(\{x_i^k\}\right)\right) - 1\right] \\ &\qquad \text{for } -1 < \lambda < \infty \quad (10) \end{aligned}$$

where λ is the parameter showing the relationship among the related criteria (if $\lambda = 0$, (9) is an additive form; if $\lambda \neq 0$, (9) is a nonadditive form.). The basic concept of this Choquet integral equation is illustrated in Fig. 2. The fuzzy integral defined by Equation $(c) \int fdg$ is called the Choquet integral.

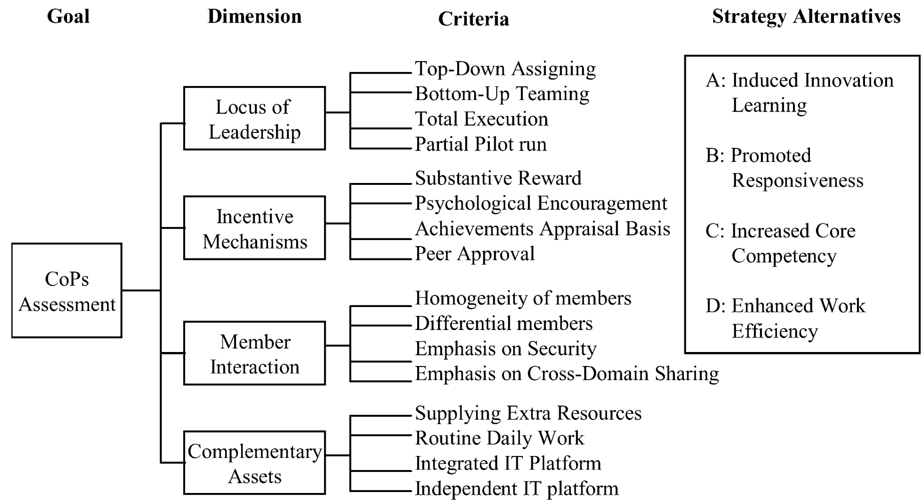

Fig. 3. The hierarchy system of CoPs performance alternatives.

IV. Constructing A Multigoal and Multicriteria Assessment Model

To solve interindependent problems in CoPs, we attempted to construct a multigoal and multicriteria assessment model based on fuzzy MCDM theory. This section includes the research model, hierarchy weights, questionnaire design, respondents' selections, and performance preferences for CoPs.

A. Forming a Research Model

An evaluation model was constructed based on literature comments and expert brainstorming. The method and concept of planning assistance through technical evaluation of relevance number (PATTERN) (NASA PATTERN, 1965 [41]; [2], [14]–[16], [23], [32]) was used.

The aim of this section is to build a multicriteria and multilevel evaluation model for four CoPs alternatives. The three steps in building models are: 1) describing the situation in scenario writing; 2) establishing a multicriteria hierarchy and relevance tree structure; 3) evaluating the criteria weights and strategy alternatives.

The construction of an evaluation model involved expert brainstorming and discussions. It enabled us to develop the foundations of our questionnaire and construction of dimensions and criteria considered relevant by the experts. These are explained as follows.

1) The **Locus of Leadership** dimension contains four criteria: top-down assigning, bottom-up teaming, total execution, and partial pilot run;
2) The **Incentive Mechanisms** dimension contains: substantive reward, psychological encouragement, achievement appraisal basis, and peer approval;
3) The **Member Interaction** contains: homogeneity of members, differential members, emphasis on security, and emphasis on cross-domain sharing;
4) The **Complementary assets** dimension contains: supplying extra resources, routine daily work, integrated it platform, and independent it platform.

The goal is to evaluate the effectiveness of the strategy alternatives of CoPs. Four dimensions were created to assess the 16 criteria. Fig. 3 shows the appraisal hierarchy system.

B. Measuring the Hierarchical Weight of Related Systems

The evaluation of the related hierarchical system and weight comes from a pair wise comparison using AHP method; each criterion's importance within the hierarchy is determined by its weight (Saaty, 1977, 1980) [37], [38]. Where there are evaluations criteria/objectives, decision makers must carry out a pair wise comparison. In the process of comparison, a certain degree of inconsistency is allowed. Saaty used AHP to depict a scale and came up with the main Eigenvector of the pair wise comparison matrix. The same scale was used to find different relative weights of different standards.

Given here is a mathematical formula to compare a normalized set with n criteria, according to its relative importance (weights). Suppose the normalization for comparison is $c_1, c_2, \ldots, c_n$, and the weight of each is $w_1, w_2, \ldots, w_n$ and assuming $\boldsymbol{w} = (w_1, w_2, \ldots, w_n)^t$, then the pair wise comparison can be represented by the following formula of the matrix $\boldsymbol{A}'$:

$$(\boldsymbol{A} - \boldsymbol{\lambda}_{\max}\boldsymbol{I})\boldsymbol{w} = 0. \qquad (11)$$

Formula (11) shows how $\boldsymbol{A}$ is a pair wise comparison matrix sorted in order by instinct and judgment. To come up with the priority Eigenvector, we must satisfy the Eigenvector of every $\boldsymbol{w}$ of $\boldsymbol{A}w = \lambda_{\max}\boldsymbol{w}$, where $\lambda_{\max}$ is the maximum eigenvalue of $\boldsymbol{A}$. The sorting judgment of the order of the pair wise comparison is observed and examined for consistency because an $n \times n$ matrix $\boldsymbol{A}$ includes n independent features λ_j; moreover, $j = 1, 2, \ldots, n$, also ranks aspects in order according to dimension, (as in the concept of main component analysis), $\sum_{j=1}^{n} \lambda_j$ is the Diagonal Element of matrix $\boldsymbol{A}$ and equal $\sum_{j=1}^{n} \lambda_j = \mathrm{tr}(\boldsymbol{A}) = n$ is the total. The diagonal factor line of matrix $\boldsymbol{A}$ is 1, so the total of the diagonal line factor of matrix $\boldsymbol{A}$ is n; therefore, only one $\lambda_j = 0$ $(\lambda_j \neq \lambda_{\max})$ can be obtained from the middle of $C.I. = (\lambda_{\max} - n)/(n-1), (C.I.)$. The latter deviation value indicates consistency.

TABLE V
WEIGHTED DIMENSIONS AND CRITERIA OF RETRIEVED QUESTIONNAIRES

Weight / Dimension/Criteria	Weight of Each dimension	Weight of Inter dimension	Weight of cross dimension (Ranking)
Locus of Leadership	0.215		
Top-Down Assigning		**0.348 (1)**	0.075 (4)
Bottom-Up Teaming		0.174 (4)	0.037 (15)
Total Execution		0.204 (3)	0.044 (13)
Partial Pilot run		0.274 (2)	0.059 (9)
Incentive Mechanisms	0.264		
Substantive Reward		0.280 (2)	0.074 (5)
Psychological Encouragement		0.158 (4)	0.042 (14)
Achievements Appraisal Basis		**0.361 (1)**	0.095 (2)
Peer Approval		0.201 (3)	0.053 (11)
Member Interaction	**0.287**		
Homogeneity of members		0.190 (4)	0.055 (10)
Differential members		0.236 (2)	0.068 (6)
Emphasis on Security		0.233 (3)	0.067 (7)
Emphasis on Cross-Domain Sharing		**0.341 (1)**	**0.098 (1)**
Complementary assets	0.234		
Supplying Extra Resources		0.285 (2)	0.067 (7)
Routine Daily Work		0.191 (3)	0.045 (12)
Integrated IT Platform		**0.367 (1)**	0.086 (3)
Independent IT platform		0.157 (4)	0.037 (15)

For example: $C.I. = (\lambda_{\max} - n)/(n-1), (C.I.)$ is close to the consistency index, so it is deemed consistent. Generally speaking, only the value that is smaller than 0.1 can satisfy the requirements. In this problem, the respondent making the strategic analysis must take the four dimensions into consideration as shown in Fig. 3.

C. Designing Questionnaires

The observed evaluation system and criterion in the hierarchy of each dimension in Fig. 3 were used as a template for the questionnaire. First, we sought to discover the respondents' recognition of the relative importance (weight) of the main four dimensions of **Locus of Leadership, Incentive Mechanisms, Member Interaction** and **Complementary Assets**. Second, we used the template to find out the interviewee's recognition of the relative importance (weights) of the evaluation criterion below each dimension. Following this procedure, respondents could easily understand the questions and the relationship between each evaluation criterion. The result reflects the true relationship of each opinion in relation to the relative importance of the evaluation criterion in the questionnaire.

D. Targeting Questionnaire Respondents

The target groups of the questionnaire covered 14 industries and 75 experts with empirical experiences of CoPs. The industries include electronics research and services; optical-electronics; computer and communications research; chemicals; materials research; energy and resources; mechanical industry; measurement standards; environmental; health and safety technology; industrial economics information services; technology transfer and services; and information technology services.

E. Assessing Fuzzy Preference Tendencies

This research uses triangle fuzzy theory to value the effectiveness of the four strategy alternatives with 16 criteria. These particular experts chose a fuzzy value region in their questionnaire to show their priority setting. Using center of area solutions we then transfer fuzzy linguistic expressions (very important, important, ordinary, unimportant, and very unimportant) to best nonfuzzy performance (BNP). These BNPs represent the respondent's comments on the quantity criteria value regarding the four kinds of strategy alternatives and 16 criteria. These effective values form this respondent's effective matrix, and U respondents represent the first respondent's effectiveness matrix.

F. Ranking of Strategy Alternatives

In the ranking of effective values between criteria A and B, there are three conditions.

If $\lambda > 0$, then $g_\lambda(A \cup B) > g_\lambda(A) + g_\lambda(B)$, which represents the multiplicative effect occurring between A and B.

If $\lambda = 0$, then $g_\lambda(A \cup B) = g_\lambda(A) + g_\lambda(B)$, which represents the additive effect occurring between A and B.

If $\lambda < 0$, then $g_\lambda(A \cup B) < g_\lambda(A) + g_\lambda(B)$, which represents the substitutive effect occurring between A and B.

Considering the substitutive and multiplicative effects between criteria, we combine the fuzzy measures and fuzzy integrals to integrate available information and strategic priorities.

V. AN EMPIRICAL CASE FOR ANALYSIS AND DISCUSSION

After collecting 62 questionnaires, and deleting five that were invalid, we adopted 57 effective questionnaires with a return-ratio of approximately 76%. Utilizing the fuzzy multigoals model to measure the weight and average effective value, the analysis and explanation of the results are as follows.

A. Retrieving Questionnaires and Acquiring the Average Weight

The cross-dimension weights were derived from Table V. $\bar{W} = (0.075, 0.037, 0.044, 0.059, 0.074, 0.042, 0.095, 0.053,$

TABLE VI
SENSITIVITY SCORES OF FOUR-ALTERNATIVE VALUES

λ	(-1.0)	(-0.50)	0.00	**0.50**	**1.00**	**3.00**	**5.00**	10.00	20.00	40.00	100.00	150.00	200.00	(SAW)
A	68.79	70.03	70.23	**70.22**	**70.17**	**69.86**	**69.59**	69.11	68.53	67.91	67.10	66.77	66.54	71.36
B	66.74	70.58	70.84	**70.85**	**70.80**	**70.50**	**70.22**	69.71	69.09	68.41	67.53	67.16	66.90	70.16
C	70.31	71.15	71.64	**71.77**	**71.78**	**71.59**	**71.34**	70.84	70.18	69.45	68.45	68.02	67.73	73.52
D	72.89	71.93	71.73	**71.51**	**71.31**	**70.69**	**70.27**	69.60	68.87	68.14	67.23	66.86	66.62	73.38

TABLE VII
RANKING OF FOUR STRATEGY ALTERNATIVES

Ranking		Alternatives
SAW	Alternative $C \succ D \succ A \succ B$	*A*: Induced Innovation
λ=-1	Alternative $D \succ C \succ A \succ B$	*B*: Promoted responsiveness
λ=-0.5	Alternative $D \succ C \succ B \succ A$	*C*: Increased core competency
λ=0	Alternative $D \succ C \succ B \succ A$	*D*: Enhanced work efficiency
0 <λ< 10	Alternative $C \succ D \succ B \succ A$	

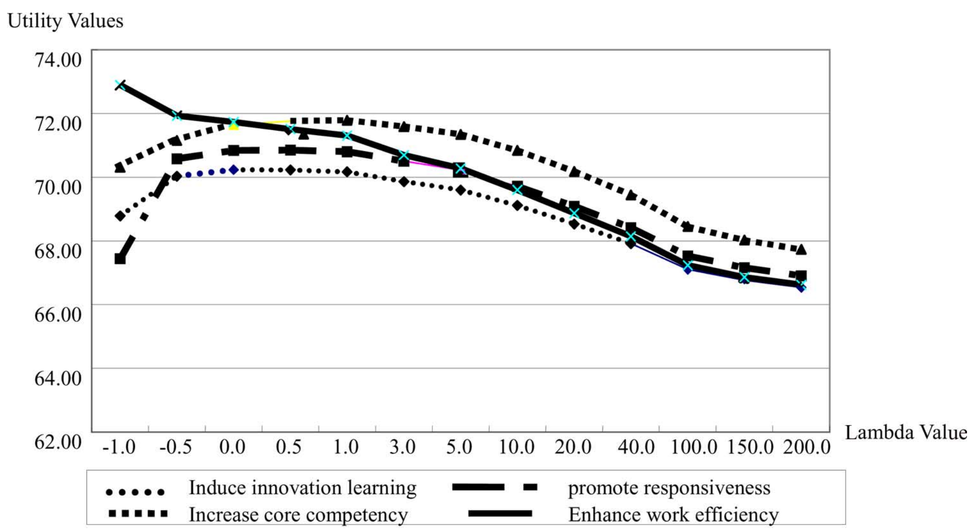

Fig. 4. Effective values of strategy alternatives on CoPs.

$0.055, 0.068, 0.067, 0.098, 0.067, 0.045, 0.086, 0.037)$. *Ui* was multiplied with the respondents' utility scores to derive four kinds of alternatives. The averages of all the respondents' utility scores for the four alternatives are shown in the SAW column in Tables VI and VII.

B. *Sensitivity Analysis of* λ *Value to Strategy Alternatives*

The area of the λ value is $-1 \leqslant \lambda \leqslant \infty$. The research sets the λ value from -1 to 200 (Table VI and Fig. 4) to acquire different effective values and varying ranking. When $\lambda < 0$, the effective value of strategy D scores the highest, however, it lacks consistent ranking; when $0 < \lambda < 10$, the ranking is consistent as strategy $\mathrm{C} \succ \mathrm{D} \succ \mathrm{B} \succ \mathrm{A}$; when $\lambda > 10$, there is no consistency among the rankings.

C. *Final Value of Strategy Alternatives by Fuzzy Integral*

Based on the analysis in Table VI, we discover that when $\lambda < 0$, there are substitutive effects between the four strategy alternatives; when $0 < \lambda < 10$, there are multiplicative effects and the ranking is the same. **Increased Core Competency** is the most highly emphasized; However, when $\lambda > 10$, the ranking changes. According to empirical experience, the criteria of this research have multiplicative effects, so we adopt the final value and ranking of $0 < \lambda < 10$ (see Table VII).

According to our targeted subject and the empirical experience indicating the multiplicative effects of the criteria, we adopt the result of using $0 < \lambda < 10$. Among the four alternatives, the effective value of **Increased Core Competency** is the highest, followed by that of **Enhanced Work Efficiency, Promoted Responsiveness**, and **Induced Innovation** respectively.

Generally speaking, we use SAW to select alternatives when the criteria are independent. Since the criteria are not independent within the context of this research, we are unable to assess the viability of various alternatives by using SAW. However, we can properly evaluate strategy alternatives by using fuzzy integral.

D. Obtaining Preferences for the Performance of CoPs

Increased Core Competency and **Enhanced Work Efficiency** seem to be the most effective performances of CoPs according to the survey results. Though not playing a critical role, **Promoted Responsiveness** meets short-term work requirements instead of long-term ones. **Induced Innovation**, a popular issue in the knowledge-based economy, remains a long-term target despite its lowest score. The survey outcomes conform to the experts' interview responses regardless of whether the relations among criteria are independent or not. In particular, it is desirable to focus on the demand of core competency so as to meet external challenges and elevate the organization's intellectual and profit-making capabilities while maintaining sustainable competitive advantage. By adequate integrations and theoretical calculations, this research aims to provide organizations with reusable decision-making alternatives to solve otherwise irresolvable scenarios.

E. Results and Discussions

In this section, we describe the results and discuss the assessment hierarchy model, weights or relative importance assigned to dimensions and criteria, perception of CoPs assessment, and final ranking of fuzzy integral. We also discuss research limitations and future work.

1) Assessment Hierarchy Model: This research has outlined a multicriteria model for CoPs strategy alternatives (see Fig. 3), and sorts the priority setting according to the survey responses. Instead of qualitatively assessing the issue of CoPs, this research provides a practical quantitative model and approach for research institutes and enterprises to conduct their own CoPs research in the knowledge-based economy. Before distributing the research questionnaires, we conducted a pretest with experts to both help us modify our questions to ensure accessibility, and to help us choose important dimensions and criteria. Through the experts' review of and input into the survey design, this research identifies four dimensions and 16 critical criteria in the CoPs research area. We utilized pair wise comparison in the first level to establish the relative importance of the four strategic constructions and, repeated this in the second level for criteria-weighting, and finally concluded various AHP weights.

2) Weights Assigned to Dimensions and Criteria: By employing fuzzy logic, the decision-making methodology eliminates the issue of criteria independent assumptions. This research utilized fuzzy AHP to acquire the final weights for the four dimensions affecting CoPs. The minimal difference among the four dimensions implies that they are equally important. Nevertheless, the dimension weighting of **Member Interaction** was the highest, which indicates people interface is key to knowledge sharing and emphasizes the human aspect of CoPs. This result again supports the idea that the essence of a community is its members and that they organize themselves and participate because they get value from their participation. **Incentive Mechanisms** was weighted the second. The result supports the idea that when you reward people for certain behavior, for example, sharing knowledge, they will want to do it more. Therefore, developing meaningful rewards is essential to sustaining community goals and achieving a knowledge-centered organization. Among the 16 criteria, **Emphasis on Cross-Domain Sharing** in relative importance to other criteria indicates that CoPs practitioners hope to break through boundaries in new thinking and work patterns while enlarging cross field synergy by way of mutual exchange and integration.

TABLE VIII
RELIABILITY ANALYSIS

Four Dimensions of Questionnaire	Cronbachα
Locus of Leadership	0.7476
Incentive Mechanisms	0.7250
Member Interaction	0.6928
Complementary assets	0.7443

3) Perception of the Assessment of CoPs: Apart from functional divergence, many organizations consist of different divisions with distinct projects targeting correspondent industries and customers. This mix usually causes different acknowledgements and choices of strategies inside CoPs. When first implementing CoPs, such disagreements may even be major obstacles in their functioning. In addition, differences in strategic preferences bring about not only different outcomes but also different operational modes and preferred performances.

4) Final Ranking of the Fuzzy Integral: In the possible rankings we surveyed, we found that when $0 < \lambda < 10$, four alternatives have the same ranking with nonadditive multiplying value. As for utility value, **Increased Core Competency** is the highest, which may provide obvious benefits as a starting point when **Induced Innovation** becomes the greatest benefit in the future. According to the interdependent attributes of CoPs and consistency of ranking, this research considers those criteria that have multiplicative effects. Hence, we adopt the results of using $0 < \lambda < 10$. After analyzing the survey results, this research provides insight into preferences for the strategy alternatives created by CoPs. The results show that there are gaps between the effective value (scores 56.0–80.2) and ideal value (score 100) of CoPs and provide directions by which to improve the CoPs' performances. The criteria with high weights but low effective values should be improved first, for example, the bold numbers as shown in Table IX in the Appendix. Three major assessment criteria, **Emphasis on Cross-Field Sharing, Achievements Appraisal Basis**, and **Integrated IT Platform**, are suggested directions to improve the effectiveness of CoPs. After investigation by experts again, the effective values of these improvements became higher than the original effective values. To continue implementing KM moving toward higher organizational targets, such as organizational learning and innovation initiatives, organizations must place more emphasis on the management of CoPs.

5) Research Limitations and Further Work: This paper provides a methodology and model to help organizations employing CoPs to understand the critical criteria in managing a successful CoP. This methodology and model enable KM managers to quantify the intangible CoPs issues so that they can allocate their resources in appropriately in different areas. However, this paper does not address the next layer of CoPs issues for each specific industry. For example, depending on the nature of science and technology, some industries may require more global interaction or empirical study for CoPs. It would

TABLE IX
CRITERIA WITH HIGH WEIGHT BUT LOW PERFORMENCE VALUE

Weight/Effective Value Dimension/Criteria	Weight of cross dimension	**Induced Innovation**	**Promoted Responsive-ness**	**Increased Core Competency**	**Enhanced Work Efficiency**
Locus of Leadership					
Top-Down Assigning	0.075	**65.6**	70.3	79.0	77.0
Bottom-Up Teaming	0.037	78.8	71.7	71.5	69.8
Total Execution	0.044	63.9	72.3	72.1	73.5
Partial Pilot run	0.059	74.5	67.7	74.6	70.8
Incentive Mechanisms					
Substantive Reward	0.074	69.7	69.3	74.6	77.2
Psychological Encouragement	0.042	77.6	71.8	72.1	73.7
Achievements Appraisal Basis	0.095	**70.4**	73.5	76.9	78.8
Peer approval	0.053	77.7	71.6	73.1	80.2
Member Interaction					
Homogeneity of members	0.055	58.1	67.2	72.2	75.0
Differential members	0.068	81.4	68.2	70.2	66.5
Emphasis on Security	0.067	56.0	56.9	67.0	63.4
Emphasis on Cross-Domain Sharing	0.098	83.3	74.9	75.2	**70.2**
Complementary assets					
Supplying Extra Resources	0.067	73.7	**71.5**	74.6	74.3
Routine Daily Work	0.045	59.3	65.5	67.1	69.5
Integrated IT Platform	0.086	76.1	77.0	77.0	80.4
Independent IT platform	0.037	65.6	65.7	68.9	65.0

be a natural next step for the authors to select an industry to conduct an in-depth CoPs study, and determine the differences between this high-level generic study and specific CoPs in sole industries and technology. In addition, future study would also include international R&D organization participants so that the study can reflect the global trend of the CoPs.

VI. CONCLUSION

CoPs are key strategy elements for evolving a knowledge-based enterprise. CoPs offer a collaborative structure that facilitates the creation and transfer of knowledge. Although many authors assert that CoPs create organizational value, there has been relatively little systematic study on the linkage between criteria and strategy alternatives, since many organizations find the measurement systems have difficulty tracking the benefits associated with the execution of CoPs. This research attempts to explore one way to assess CoPs key criteria and preferred alternatives.

In the real world, most criteria have inter-dependent or interactive characteristics so they cannot be evaluated by conventional additive measures. To better evaluate human subjective judgments like CoPs, there must be better methods to distinguish the preferences by applying fuzzy integral model instead of traditional SAW, in which it is not necessary to assume additivity and independence. This research also gives examples of CoPs with the hierarchical structure of the Choquet integral model.

This research has established a multiobjective and multicriteria model of a preferred CoPs strategy to increase effectiveness, conducted a survey, interviewed experts and practitioners in related fields regarding CoPs, and used pair wise comparisons to draw up first-tier priorities. In our assessment hierarchy model, we first examined critical elements offered by experts and practitioners, and analyzed relations between organizational value and CoPs activities in four dimensions and 16 criteria. We identified four specific strategy alternatives associated with CoPs and linked to the above dimensions and criteria. Finally, we concluded with the results and discussions on the criteria weights and rankings of alternatives.

We suggest the criteria with high weights but low values should be improved first (see Table IX in the Appendix). This research intends to help in understanding the critical dimensions and criteria which facilitate successful deployment of a strategy for CoPs, and then develop strategies to exploit knowledge that lead to measurable business results.

The contribution of this paper can be summarized as following: 1) Through the experts' review and input on the survey design, this paper identifies critical criteria in the CoPs research area. 2) By employing fuzzy logic, the decision-making methodology eliminates the issue of criteria independent assumption. 3) After analyzing the survey results, this paper provides insight into the importance and ranking of criteria in CoPs management. 4) Instead of qualitative assessment of the CoPs issue, this paper provides a practical quantitative model and approach for research institutes and enterprises to conduct their own CoPs research in the knowledge based economy.

APPENDIX

1) **Reliability Test**: This refers to the examination results of stability and consistency.
   a) Stability: An identical testing tool is used on identical members twice and then calculates the correlation coefficient twice.
   b) Consistency: namely internal homogeneity; this refers to certain items when measuring criteria in the same dimension, and should be consistent between items; two popular approaches are as follows: Split-half Reliability and Cronbach α.

   Due to the difficulty of using the stability method to measure the test, the commonly used method is consistency, while Cronbach α is the most popular approach. Therefore this research also uses this approach. There are four dimensions of the questionnaire construction. After the SPSS software analysis results, all reliability test coefficients were above 0.69, higher than the average standard of 0.5. Obviously this research demonstrated consistent results. The reliable results are shown in Table VIII in the Appendix.

2) **Validity Test**: This refers to the accuracy of the target solution and is generally divided into three categories.
   a) Content Validity: This refers to the degree to which the research subject is covered, and to whether the questions of the questionnaire clearly express problems.
   b) Criterion-related Validity: This refers to the interrelation between the measurement and validity standard, which can predict future performance and current estimation. Concurrent validity is obtained while the test is being carried out; predictive validity is obtained after the test.
   c) Constructive Validity: This refers to the topic or content which must be based in theory in order to build measurement items and target the problems.

Our evaluation model's construction is based on literature comments and expert brainstorming and takes fuzzy logic and application scope into consideration fully. We have established four dimensions and 16 criteria and interviewed five experts to confirm the sufficiency. Experts assisted in the pretest and modifications were made before the questionnaire was used. We think all the questions of the questionnaire express the measurements clearly, and we have confirmed the Content Validity. We use AHP hierarchy for theory construction, and constructive validity.

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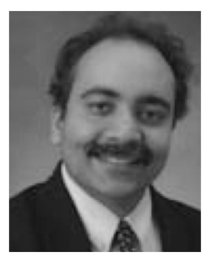

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