Selection of optimal supplier in supply chain management strategy with analytic network process and choquet integral

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\textbf{A B S T R A C T}

Selection of appropriate suppliers in supply chain management strategy (SCMS) is a challenging issue because it requires battery of evaluation criteria/attributes, which are characterized with complexity, elusiveness, and uncertainty in nature. This paper proposes a novel hierarchical evaluation framework to assist the expert group to select the optimal supplier in SCMS. The rationales for the evaluation framework are based upon (i) multi-criteria decision making (MCDM) analysis that can select the most appropriate alternative from a finite set of alternatives with reference to multiple conflicting criteria, (ii) analytic network process (ANP) technique that can simultaneously take into account the relationships of feedback and dependence of criteria, and (iii) choquet integral—a non-additive fuzzy integral that can eliminate the interactivity of expert subjective judgment problems. A case PCB manufacturing firm is studied and the results indicated that the proposed evaluation framework is simple and reasonable to identify the primary criteria influencing the SCMS, and it is effective to determine the optimal supplier even with the interactive and interdependent criteria/attributes. This hierarchical evaluation framework provides a complete picture in SCMS contexts to both researchers and practitioners.

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1. Introduction

In facing an ever-increasingly competitive and changeable environment, firms require constantly managing their organizational resources as well as tightening their industrial relationships so as to maintain competitive advantages. More specifically, firms require reorganizing their supply chain management strategy (SCMS) to harmonize with the external environments by integrating the organizational resources, information, and activities. However, SCMS may encounter multi-dimensional difficulties as it involves numerous organizational functions and resources integration among various departments. In practice, the contexts of SCMS are uncertain, unpredictable, and difficult to assess accurately with qualitative information. As a consequence, selection of appropriate suppliers in SCMS is a complicated, challenging process.

\textsuperscript{a}Davis (1993) indicated that there are three different sources of uncertainties in SCMS: (i) Supplier uncertainty, arising from on-time performance, average lateness, degree of inconsistency. (ii) Manufacturing uncertainty, arising from process performance, machine breakdown, supply chain performance, etc. (iii) Demand uncertainty, arising from forecasting errors, irregular orders, and among others. Some researchers argued that uncertainty is strate-

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strategic purchasing, and top management support are independently related. It is hard to justify the independency, and this assertion has invited many disputable arguments among the social science studies. As such, the present study will view SCMS as a complex, interactive process of many different resources with multi-dimensional, interdependent criteria/attributes. Hence, conventional multi-criteria approaches and weight average method assuming independence of attributes are not suitable for evaluating SCMS because only when information sources are non-interactively can their weighted effects be viewed as additive (Wang, Leung, & Wang, 1999). To overcome these shortcomings, non-additive set functions must be used, and choquet integral (a nonlinear integral or so-called “non-additive fuzzy integral”) with respect to non-additive set functions can be employed to replace the weighted average (Kahraman, Çevik, Ates, & Gülbay, 2007; Murofushi & Sugeno, 1989; Wang & Klier, 1992; Wang et al., 1999). By using non-additive fuzzy integral, one can eliminate experts’ subjective judgment problems involving the complex SCMS.

To date, few studies have adopted a rigorous methodology while selecting the suppliers in SCMS. Many suppliers have built up their capabilities to support some other services, such as SCM, just-in-time, service quality, etc. These suppliers normally have long-term contracts providing their customers with multiple-function services (Choi & Hartley, 1996). There are different supplier selection criteria in different status. Chan and Kumar (2007) identified some important and critical decision criteria including risk factors for the development of an efficient system for global supplier selection. Wang and Che (2007) presented a model, based on the concepts of parts change requirements, fuzzy performance indicators, and integration of different attributes, to allow the parts supplier selection of a specific commercial product to be explored. Xia and Wu (2007) proposed an integrated analytic hierarchy process (AHP), which is improved by rough sets theory and multi-objective mixed integer programming, to simultaneously determine the number of suppliers and the order quantity allocated to each supplier, under the contexts of multiple sources, multiple products, multiple criteria, and with suppliers capacity constraints. Saaty (1996) developed analytic network process (ANP), a new analysis method that simultaneously takes into account both the relationships of feedback and dependence. This paper attempts to develop a novel hierarchical evaluation framework to assess the SCMS, wherein the interdependency among various criteria/attributes can be effectively captured by a combination of ANP with choquet integral. The major advantages of combining ANP with choquet integral are that the evaluation can account for the interdependency of criteria/attributes, the nonlinear relationship among criteria/attributes, and the environmental uncertainties. Such a combination was rarely seen in literature before. This proposed hierarchical analytical approach is not only novel but sufficiently general to be applied under various settings, thus can help firms to measure and select the optimal suppliers in SCMS.

The remainder of this paper is organized as follows. Section 2 addresses the background of SCMS with relevant literature reviewed. Section 3 presents the hierarchical structure of SCMS with criteria and attributes involved in the supplier evaluation. Section 4 proposes the hierarchical analytical approach for evaluating SCMS. A PCB manufacturing case firm's SCMS is evaluated in Section 5. Managerial implications are discussed in Section 6, followed by concluding remarks.

2. Background of SCMS

A well-integrated supply chain management (SCM) involves coordinating the flows of materials and information between suppliers, manufacturers and customers, and implementing product postponement and mass customization in the supply chain. Higher level of integration with suppliers and customers in the chain is expected to result in more effective competitive advantages (Anderson & Katz, 1998; White, Pearson, & Wilson, 1999). Supply chain management strategy (SCMS) is used to explain the planning and control of materials/information flows and logistics activities, not only internally within a firm but also externally between firms (Cooper, Ellram, Gradner, & Hanks, 1997; Fisher, 1997; Seo, 2006). The key concept is that the channel is viewed as an integrated whole, with the goal of understanding the channel as an application system. Each firm in the channel affects, directly or indirectly, all the other channel members, as well as the ultimate, overall channel performance (Beamon, 1999; Carr & Pearson, 2002; Handfield & Nichols, 1999; Tan, Kannan, & Handfield, 1998).

Increased global competition pressures have been forcing firms to continuously adopt, develop and enhance customer focus, competitive priority, information technology, strategic purchasing and top management support. For these reasons, a firm must enhance its SCMS for developing the optimal suppliers more suitable than other competitive firms, and must facilitate the criteria and attributes of SCMS within its organization to strengthen its competitive advantages. The goal of integrated SCMS is to create manufacturing processes and logistics functions seamlessly across the supply chain as an effective competitive weapon that cannot be easily duplicated by competitors. Tan et al. (2002) explored the relationships between supplier management practices, customer relations practices, and organizational performance with the usage of purchasing quality and customer relations to represent SCMS. Yao, Palmer, and Dresser (2007) studied the electronically-enabled supply chains, which offer the potential for reduced costs and higher sales. They found top management support and external influences are both important determinants. Besides, perceived benefits to customers, perceived benefits to suppliers, and perceived internally focused benefits are all positively influencing electronically-enabled supply chains use. The indicators of this construct are presented to denote the presence of electronic transactions, supplier management and competitive priorities in various forms between the supply chain partners. Based on these findings, the SCMS is presented with interactive relationships among their proposed dimensions (Li et al., 2006a; Li et al., 2006b; Chou & Chang, 2008). Even if a firm merely focuses on the customer criteria, it still needs top management support and adjusts its competitive priority accordingly.

Numerous criteria and attributes must be considered when evaluating the SCMS. In this study, we emphasize the following five criteria: customer focus, competitive priority, information technology, strategic purchasing, and top management support. First of all, customer focus practices involve the establishment of links between customer needs and satisfaction and internal processes (Sousa, 2003; Stuart, 1997). Mendoza, María Pérez, and Grimán (2007) forecasted that for various reasons and with more or less clarity concerning the subject, the firms have a new trend to implement customer relationship management as a factor allowing them to survive in the new market conditions and favoring the relationship with their customers. Tan et al. (1998) considers customer relationship management as an important component of SCMS. Closer customer relationship allows an organization to differentiate its products from competitors, sustains customer loyalty, and dramatically extend the value it provides to its customers (Magretta, 1998). Closer customer relationship also requires improving the customer satisfaction (Hwang, 1998; Johnston et al., 2004). Day (2000) pointed out that committed relationships are the most sustainable advantage because of their inherent barriers to competition. The growth of mass customization and personalized service has led to an era where relationship management with customers is becoming crucial for corporate
survival. Good relationships with supply chain members, including customers, are needed for successful implementation of SCMS.

Secondly, for competitive priority, Cox and Blackstone (1998) stated that “To be most effective, the manufacturing should act in support of the overall strategic directions of the business and provide for its competitive priorities.” It guides the choice and development of competitive priorities and specifies how the operational function provides a firm with competitive priority in the marketplace or tactical goal of the operational function (Chenhall & Langfield-Smith, 1998). SCMS has to be involved in top-down operation decisions; therefore, once competitive priority is evaluated it becomes the basis for making operational decision as the goal of operational function in marketplace (Margaret, 1996).

Establishing close relationships with a limited number of suppliers, when properly and selectively used, has been directly linked to customer focus (Stanley & Wisner, 2001) and competitive priority.

Thirdly, for information technology (IT) in SCMS, Dehning, Richardson, and Zmud (2007) examined the financial benefits of newly adopted IT-based SCMS and found a positive relation between firms’ investment in IT-based SCM systems and firms’ performance. IT enhanced supply chain efficiency by providing real-time information about product availability, inventory level, shipment status, and production requirements. In particular, the common goal of these systems is to transform all the management systems into perfect information.

Fourthly, the importance of purchasing function that a company needs to optimize its entire SCM, rather than individual elements within the supply chain, suggests that purchasing is indeed strategic. For purchasing, operations and other elements of a supply chain should work together and their functional strategies should be aligned in support of the firm’s SCMS (Watts, Kim, & Hahn, 1992). Carr and Smeltzer (1999) explored how firms with strategic purchasing are able to foster long-term, cooperative relationships and communication, and achieve greater responsiveness to the needs of their suppliers. Strategic purchasing can foster greater commitment and trust to promote long-term relationships between the focal firm and its suppliers. Moreover, purchasing involvement earlier in the new product development process has provided many companies with advantages in bringing new designs to market faster, with fewer quality defects, and at lower costs (Dyer, 1996). The present study presumesthat strategic purchasing contributes to effective SCM when it fosters a long-term strategic orientation between the firm and its supplier selection.

Finally, for top management support in SCMS, Wilson and McDonald (1996) regarded it as an important factor in the successful implementation of decision support systems. SCMS may create sustained competitive advantage directly should the top management support be able to exploit unique SCM competencies. One of the major functions for top management executives is to influence the setting of organizational values and to develop suitable management styles to ensure the SCMS is on track. Although top management support of SCMS has generally been regarded as a key success parameter, yet the nature of its impact and the phenomenon it brings into being are still not very clear to us, thus it requires an in-depth analysis to enhance our understanding to draw useful implications for research and practice (Chen & Paulraj, 2004).

Optimal supplier evaluation depends on SCMS requirements, including as customer focus, competitive priority, information technology, strategic purchasing, and top management support (Hoque, 2004; Li, Ganesan, et al., 2006; Li, Ragu-Nathan, et al., 2006; Tan, 2001). Thus, the SCMS models on supplier evaluation are in essence multi-dimensional, complex, and interdependency activities (Yao et al., 2007). The SCMS models on supplier evaluation permitting intuitive judgment have garnered acceptance by various experts, including scholars and SCM professionals. To assist the expert group to select the optimal suppliers in SCMS contexts, this study proposes an effective hierarchical evaluation framework by explicitly describing the decision structure of SCMS upon which pair comparison subjective judgments of experts can base.

3. Hierarchical structure of SCMS

Generally, literature on SCM addressed the purchasing and supply perspective (Morgan & Monczka, 1996). This perspective of SCM is synonymous with supplier base integration that evolves from the traditional purchasing and SCM functions. It emphasizes that purchasing and materials management represent a basic strategic business process, rather than a narrow specialized supporting function, to overall business strategy. This is a management philosophy that extends traditional internal activities by embracing an inter-enterprise scope, bringing trading partners together with the common goal of optimization and efficiency (Carr & Pearson, 2002).

Literature suggested that five rules must be obeyed when developing criteria: (i) completeness, criteria must cover all primary SCMS of the decision making problem; (ii) operational, criteria must be meaningful for the analysis; (iii) decomposable, criteria can be decomposed from a hierarchy to a lower hierarchy to simplify the evaluation process; (iv) non-redundant, criteria must not be counted twice; and (v) minimum size, the number of criteria should be kept as small as possible. As aforementioned, many criteria must be considered in evaluating the suppliers for SCMS and these criteria are normally interdependent and interactive with each other. Information of SCMS contexts can be collected by literature review as well as interviews with expert SCMS staff and related senior managers. Particularly, interviews should obtain data regarding what changes and attributes have led the firm to sustain success of SCMS. This creates typical MCDM problem with varying criteria and attributes on related activities. In addition, this study considers uncertainty as determinants for further practices of SCMS. As discussed earlier, the uncertain determinants are in the forms of supply, demand and technology. Supply uncertainty includes indicators that represent quality, timeliness and the inspection requirements of the suppliers. Demand uncertainty is measured in terms of fluctuations and variations in demand. Technology uncertainty measures the extent of technological changes evident within the industry. These constructs are operationalized based on prior research (e.g., Chen & Paulraj, 2004; Davis, 1993; Krause, 1999; Van Hoek, 1998).

Past research has offered valuable structures for SCMS, the major references for this study are from Lado, Boyd, and Wright (1992), Palmer and Griffith (1998), Carr and Pearson (1999), Tan et al. (2002), Chen and Paulraj (2004), Johnston et al. (2004), Li, Ganesan, et al. (2006) and Li, Ragu-Nathan, et al. (2006). An in-depth discussion and literature review have led this study to decide five criteria with eighteen attributes and to select four suppliers. The five criteria used are customer focus (Hwang, 1998; Johnston et al., 2004; Mendoza et al., 2007; Sousa, 2003), competitive priority (Chenhall & Langfield-Smith, 1998; Cox & Blackstone, 1998; Dreyer & Gronhaug, 2004; Kathuria, 2000; Margaret, 1996), strategic purchasing (Carr & Smeltzer, 1999; Cousins, 1999; Dyer, 1996; Watts et al., 1992), top management support (Chen & Paulraj, 2004; Krause, 1999; Wilson & McDonald, 1996), and information technology (King, 1996; Carr and Pearson, 1999; Dehning et al., 2007; Yao et al., 2007). Our SCMS model will integrate the most relevant activities, components, and characteristics found in SCMS literature, which are put forward as criteria. The criteria and their associated attributes are discussed as follows.

First, the customer focus (C1) is the goal of businesses, which is to “create and maintain customers” (Levitt, 1985). The attributes for customer focus construct contain the responses to customers evolving needs and wants (A11), evaluation of customer complains...
(A12), products satisfying customer expectation (A13) and satisfying customer needs—the central purpose of business plan (A14) (Hwang, 1998; Johnston et al., 2004; Mendoza et al., 2007; Sousa, 2003).

Secondly, the competitive priority (C2) is a common success theme of operations strategy, which picks up the manufacturers’ choices of emphasis among key capabilities. The attributes in this construct contain offering products with lowest price (A21), greater emphasis on innovation (A22), launching new product quickly (A23), and quality performance (A24) (Chenhall & Langfield-Smith, 1998; Margaret, 1996; Stanley & Wisner, 2001).

Thirdly, the strategic purchasing (C3) is critical to facilitate close interactions with a limited number of suppliers and making effective use of the firm’s supply base (Cousins, 1999). Three attributes in this construct are considered: purchasing function with a formally written long-range plan (A31), purchasing focus on longer term issues that involve risk and uncertainty (A32), and purchasing performance measured (A33) (Carr & Smeltzer, 1999; Dyer, 1996; Watts et al., 1992).

Fourthly, all the SCMS activities are involved with the top management support (C4), which is a sustained competitive advantage directly, should it be able to exploit unique SCM competencies (Lado et al., 1992). This construct emphasizes such attributes as purchasing function strategic role (A41), supporting the competitive priority with company mission (A42), supporting the need for inter-organizational information system (A43), and accounting for customer needs a vital part of corporate strategy (A44) (Chen & Paulraj, 2004; Krause & Ellram, 1997; Wilson & McDonald, 1996).

Lastly, the information integration needs the information technology (C5) to be applied in SCMS. The complete integration into SCMS with electronic commerce component also aids in the evolution of SCMS. Sharing information with supply chain partners through electronic data interchange (EDI), for instance, is also a critical component of SCMS (King, 1996). The attributes in this construct include a direct link of computers to computers with key suppliers (A51), inter-organizational coordination achieved by electronic links (A52), and using IT-enabled transaction processing (A53) (Carr and Pearson, 1999; Dehning et al., 2007; Yao et al., 2007).

Fig. 1 presents the hierarchical structure of evaluation framework for SCMS, a MCDM analysis combining ANP with choquet integral to select the optimal suppliers for case PCB manufacturing firm. Basically, MCDM analysis is to assist the evaluators in selecting one or few most appropriate alternatives from a finite set of alternatives with reference to multiple, usually conflicting, criteria (Yeh, Deng, & Pan, 1999); ANP is to simultaneously account for the relationships of feedback and dependence (Saaty, 1996); while choquet integral (non-additive fuzzy integral) is to eliminate the interactivity of expert subjective judgment problems (Kahraman et al., 2007; Murofushi & Sugeno, 1989; Wang & Klir, 1992; Wang et al., 1999).
4. Methodologies

To determine the overall performance of SCMS, evaluation criteria are multiple and frequently structured into multi-level hierarchies. Decision-making is the process of defining the decision objectives, gathering relevant information, and selecting the optimal alternatives. Hence, the first phase is to define the decision objectives—here is to select the suppliers in SCMS under uncertainty. After defining the decision objectives, it is required to generate and establish evaluation objectives in current business scenario, which is similar to a chain of the determinants—criteria (purposes), attributes (evaluation factors) and alternatives (decisions). As discussed in the previous section, five criteria of SCMS are to be considered: customer focus, competitive priority, strategic purchasing, top management support and information technology. Moreover, the criteria cluster has to interact with supply, demand, and technology determinants in order to precisely find the best supplier among the four suppliers of case firm. Overall performance of the case firm (Suppliers A, B, C, and D) can be obtained by (i) assigning weights to five criteria (Client, Supplier, C2, C3, C4, and C5) and their associated Aj attributes (Cij, i = 1, 2, 3, 4, 5; j = 1, 2, …., Aj) and (ii) assessing the performance rating of each aspect and its associated criteria. We will first introduce the ANP technique and then discuss the choquet integral approach, followed by the proposed application procedures.

4.1. ANP

Analytic hierarchy process (AHP) was first proposed by Saaty (1980a) and Saaty (1980b). It has been widely applied in areas such as MCDM and has become a popular application for performance evaluation. AHP must satisfy the characteristic of independence among the criteria before it can proceed to decision making. However, given the problems encountered in reality, a dependent and feedback relationship usually be generated among the evaluation criteria and such an interdependent relationship usually becomes more complex with the change in scope and depth of the decision-making problems. Therefore, Saaty (1996) developed a new analysis method—analytic network process (ANP) that simultaneously takes into account both the relationships of feedback and dependence, and developed the ANP. Tseng, Lin, Chiu, and Liao (2008) applied ANP to selecting of competitive priority in cleaner production implementation. The merits of AHP in group decision-making are as follows (Dyer & Forman, 1992): (i) both tangibles and intangibles, individual values, and shared values can be included in the decision process; (ii) discussion in a group can be focused on objectives rather than on alternatives; (iii) the discussion can be structured so that every factor relevant to the decision is considered; and (iv) in a structured analysis, the discussion continues until relevant information from each individual member in the group is considered and a consensus is achieved.

In addition to these merits of AHP, the ANP provides a more generalized model in decision-making without making assumptions about the independency of the higher-level elements from lower-level ones and also of the elements within their own level. A two-way arrow among different levels of attributes may graphically represent the interdependencies in an ANP model. If interdependencies are present within the same level of analysis, a looped arc may be used to represent such interdependencies.

1. Saaty randomly generated reciprocal matrix using scale 1/9, 1/8, 1/7, …., 1/2, 1, 2, …., 9, 8, 7, …., 1 and 9. The scales are described as 1: equal importance, 3: moderate importance, 5: strong importance, 7: very strong or demonstrated importance, and 9: extreme importance. Even numbered values will fall in between importance levels. Reciprocal values (e.g. 1/3, 1/5, etc.) mean less importance, strongly less importance, etc. Only the upper triangle of the matrix needs to be completed. The lower triangle of the pairwise comparison matrix is composed of reciprocal values.

2. Assuming there are n number of criteria, denoted as (C1, …., Cn), its pairwise comparison matrix would be A = (ajij), in which ajij represents the relative significance of Ci to Cj. Then, by using the row vector average normalization proposed by Saaty (1996), the approximate weight Wi of Ci is calculated as follows:

\[
\text{Wi} = \frac{\sum_{j=1}^{n} a_{ij} / \sum_{j=1}^{n} a_{ij}}{n}, \quad \forall i, j = 1, 2, \ldots, n
\]

3. The consistency test of ANP is designed to ensure the consistency of judgments by decision makers throughout the decision making process. When inconsistencies exist in the pairwise comparison matrix A, Saaty (1980a) and Saaty (1980b) proved that for consistent reciprocal matrix, the \( \lambda_{\text{max}} \) is equal to the number of comparisons, or \( \lambda_{\text{max}} = n \). Then Saaty gave a measure of consistency, called consistency index (CI), as deviation or degree of consistency using the following formula:

\[
\text{CI} = \frac{\lambda_{\text{max}} - n}{n - 1}
\]

4. Limiting the weight supermatrix for the weights.

ANP uses supermatrix to deal with the relationship of feedback and independence among the criteria. If no interdependent relationship exists among the criteria, the pairwise comparison value would be 0. In contrast, if an interdependent and feedback relationship exists among the criteria, then such value would no longer be 0 and an unweighted supermatrix M will be obtained. If the matrix does not conform to the principle of column stochastic, the decision maker can provide the weights to adjust it into a supermatrix that conforms to the principle of column stochastic, and it will become a weighted supermatrix M. We then get the limited weighted supermatrix \( M^\ast \) based on Eq. (4) and allow for gradual convergence of the interdependent relationship to obtain the accurate relative weights among the criteria.

\[
M^\ast = \lim_{k \to \infty} M^k.
\]

4.2. Choquet integral

The choquet integral (a non-additive fuzzy integral), is a numeric-based approach which has been used for both pattern recognition and image segmentation (Grabisch & Nicolas, 1994; Keller, Gader, Tahani, Chiang, & Mohamed, 1994). Adoption of a fuzzy integral in membership aggregation, rather than a traditional aggregation operator, leads to an important distinction as
to how processes of fuzzy integration are utilized. The success of a choquet integral depends on an appropriate representation of fuzzy measures, which captures the importance of individual criterion or their combination (Chiang, 2000; Klir, Wang, & Harmanec, 1997). This holistic utilization of fuzzy integral is an important component in many related works to provide information integration capability. For instance, Chiang (2000) demonstrated a good classification result using the proposed aggregator to integrate the memberships of several clusters in a complex, unconstrained, handwritten digit recognition domain. Chen and Tzeng (2001) presented a good traffic assignment scheme based on the conventional optimization technique cannot be applied to solving λ-fuzzy measures. The basic properties and definitions of the choquet integral with respect to fuzzy measures applied in this study are introduced as follows.

Sugeno (1974) introduced monotonic and non-additive fuzzy integrals to express the grades of importance for attributes, which is useful to model the preference structure. Fuzzy measure can be explicates as the subjective importance of a criterion during the evaluation process. Sugeno and Terano (1977) incorporated the λ-additive axiom to reduce the difficulty of collecting information. In fuzzy measure space $(X, \beta, g)$, let $\lambda \in (-\infty, \infty)$. If $A \in \beta, B \subseteq \beta, A \wedge B = \phi$, then the fuzzy measure $g$ is $\lambda$-additive. This particular fuzzy measure is termed as $\lambda$-fuzzy measure because it has to satisfy $\lambda$-additively, named Sugeno measure.

Assume that $X = \{x_1, x_2, x_3, \ldots, x_n\}$ and $P(X)$ is the power set of $X$, the set function $g$: $P(X) \rightarrow [0, 1]$ is called a fuzzy measure, which is non-additive and preserves the following properties:

1. $g(\phi) = 0$;
2. $g(X) = 1$;
3. if $A \subseteq B$ then $g(A) \leq g(B)$ (monotonicity);
4. In $P(X)$, if $A_1 \subseteq A_2 \subseteq A_3 \subseteq \ldots$ and $U^n_{i=1}A_i \in P(X)$, then $\lim_{n \to \infty} g(A_i) = g(U^n_{i=1}A_i)$ (continuity from below);
5. In $P(X)$, if $A_1 \supseteq A_2 \supseteq A_3 \supseteq \ldots$ and $\bigcap^n_{i=1}A_i \in P(X)$, then $\lim_{n \to \infty} g(A_i) = g(\bigcap^n_{i=1}A_i)$ (continuity from above).

In addition, λ-fuzzy measure has the following additional properties:

$$g(A \cup B) = g(A) + g(B) + \lambda g(A)g(B)$$

where $\lambda \geq 0$ for all $A, B \in P(X)$ and $A \cap B = \phi$. If $X$ is a finite set, then $U^n_{i=1}A_i = X$. The $\lambda$-fuzzy measure $g$ satisfies the following:

$$g(X) = g \left( \bigcap_{i=1}^{n} A_i \right) = \frac{1}{\lambda} \left( 1 - \prod_{i=1}^{n} (1 + \lambda g(A_i)) - 1 \right)$$

if $\lambda \neq 0$,

$$g(X) = \sum_{i=1}^{n} g(A_i)$$

if $\lambda = 0$, where $A_i \cap A_j = \phi$ for all $i, j = 1, 2, 3, \ldots, n$ and $i \neq j$. In Eq. (1), $\lambda \neq 0$ indicates that the $\lambda$-fuzzy measure $g$ is non-additive; otherwise, the $\lambda$-fuzzy measure $g$ is additive and there is no interaction between $A_i$ and $A_j$ for $i \neq j$. The interaction means there is information fusion between criteria (Klir et al., 1997). $\lambda > 0$ implies that $g(A \cup B) = g(A) + g(B)$ and the set $\{A, B\}$ has multiplicative effect; whereas $\lambda < 0$ indicates the substitutive effect of the set $\{A, B\}$ (Chen & Tzeng, 2001). In fuzzy measure space $(X, \beta, g)$, let $h$ be a measurable function from $X$ to $[0, 1]$, the definition of the fuzzy integral of $h$ over $A$ with respect to $g$ is

$$\int_{A} h(x) dg = \sup_{\phi \subseteq [0,1]} \{x \wedge g(A \cup F_x) \}$$

where $F_x = \{x|h(x) > x\}$ (Wang & Klir, 1992). $A$ is a domain of fuzzy integral. When $A = X$, the fuzzy integral can be denoted by $\int h dg$. Consider a fuzzy measure $g$ of $(X, P(X))$ and $X$ is a finite set here. Let $h$: $X \rightarrow [0, 1]$ and assume without loss of generality that the function $h(x_i)$ is monotonically decreasing with respect to $i$, for instance $h(x_1) \geq h(x_2) \geq \cdots \geq h(x_n)$. To assure that the elements in $X$ be renumbered, we get the following equation:

$$\int_{A} h(x) dg = \sup_{\phi \subseteq [0,1]} \{x \wedge g(A \cup F_x) \}$$

where $H = \{x_1, x_2, \ldots, x_n\}$, $i = 1, 2, \ldots, n$. In practice, $h$ can be regarded as the performance on a particular attribute for the criteria; $g$ presents the grade of subjective importance of each attribute. The fuzzy integral of $h(x)$ with respect to $g$ gives the overall assessment of the attribute. To simply the calculation, the same fuzzy measure of choquet integral is expressed as follow:

$$c \int h dg = h(x_0)g(H_0) + [h(x_n) - h(x_0)]g(H_{n-1}) + \cdots + [h(x_1) - h(x_2)]g(H_1)$$

where $0 \leq h(x_1) \leq h(x_2) \leq \cdots \leq h(x_n) \leq 1, h(x_0) = 0$ and $H_i = x_{(i)}$, $i = 1, 2, \ldots, n$. In literature, the fuzzy integral defined by $\int h dg$ is called “choquet integral.” The basic concept can be illustrated in Fig. 2. The fuzzy integral measurement model needs not assume independence among alternatives; it can, therefore, be used in nonlinear situations.

4.3. Proposed procedures

The expert group should follow the following five-step procedures to evaluate the favorable supplier in SCMS with uncertainties.

Step 1: building up a network framework. As the subjective preference of every decision maker is different and the judgments made will not be completely identical, Saaty (1996) suggested an integration of decision makers’ preferences with the geometric mean by establishing a pairwise comparison matrix for each component, which needs to conform to the characteristic of positive reciprocal matrix.

Step 2: calculating the relative weight for criteria and attributes. This study calculates the relative weights of the criteria with dependent relationships. The pairwise comparison matrices for evaluation criteria are established. Then the maximum eigenvalues and the corresponding eigenvectors of the pairwise comparison matrices are calculated to generate the supermatrix.

Step 3: limiting the weighted supermatrix for the weigh. The unweighted supermatrix contains the priorities derived from the
pairwise comparisons of the elements. In an unweighted supermatrix, its columns may not be column stochastic. To obtain a stochastic matrix (i.e., each column sums to one), multiply the blocks of the unweighted supermatrix by the corresponding cluster priority. The supermatrix must satisfy the principle of column stochastic, which means every column should add up to 1. Based on the rule of ANP (Saaty, 1996), the decision makers believe that if the column stochastic is not conform, then the matrix weights of the shadow area are 0.5 and the remaining matrix weights would add up to 0.5.

Step 4: calculating the weights of all attributes. After obtaining the relative weights of all criteria, integrating the evaluation by multiplying the score of each criterion with the relative attributes weight. Eventually, the attributes weight of hierarchical structure can be generated based on the scores.

Step 5: calculating the final weights of each supplier. Using Eqs. (5)–(9) to solve the proposed SCMS model with non-additive fuzzy integral needs not assume mutual independence of criteria. It can be applied to nonlinear cases. Even if any two criteria are objectively and mutually independent, they are not considered independent of subjective evaluators.

5. Empirical evaluation of case firm

This section aims to operationalize the proposed hierarchical evaluation framework to evaluate an optimal alternative supplier for the case firm. There are some reasons. First, the case firm has to constantly improve its manufacturing processes while facing challenges as to how they manage the SCMS in the competitive and changeable environment. Second, the case firm has to keep reforming the SCMS in the industrial sector to cope with market competition and customer requirements. The expert opinions are obtained from the expert group, composed of five professors and six senior management staff, with extensive experience consulting in this study.

5.1. Case firm

Under the prosperous and booming electronic consumption products and network markets, Taiwan plants of COM Co. Ltd. were built for IC substrates and entering IC packing field to meet the customer demand in related products in 1998. Today, COM is the largest professional PCB manufacturer in Taiwan; it is also ranked as number six worldwide. To offer the best services for electronic manufacturers, COM has been constantly developing new generation technology, enhancing competitiveness, fully satisfying the market and customer demands, and building up closer relationships with its suppliers and customers. COM, insisting on the principle of “Highest Quality, Customer First,” has continually spent a lot of effort on improving processes, developing the SCMS and setting up full quality system to meet customer requirements. Due to the quick replacement of electronic products and rapid exploration of new technologies, the R&D for COM is leading its competitors so as to meet product demands from customers and explore new products in markets. COM’s operational principles are focused on prompting technology development, developing closer relationships with upper- and down-stream of industry, and committing the customer-demand satisfaction. The SCMS is relatively important for COM to sustain in facing an ever-increasingly competitive and changeable environment.

The expert group with eleven members strived to recommend the SCMS criteria and attributes, which are expected to remain long-term competition in intensively competitive markets. The group members reviewed the SCMS criteria and attributes because SCMS is one of the most prioritized issues of the management team. They have the same need to find a suitable supplier in SCMS for COM; namely, to evaluate and select the most proper supplier in SCMS, and to make this selection more logically and persuasively. For better handling of this MCDM problem, the eleven experts’ management group should adopt possible solutions and criteria and attributes of SCMS which cover the five criteria mentioned above.

5.2. The results

The objective of this empirical study is to demonstrate how ANP and choquet integral can be used to determine the best supplier selection prior to SCMS criteria and attributes. The expert group followed the five-step procedures.

Step 1: building up a network framework. An expert committee for group knowledge is formed. Relevant information from the case firm is collected to evaluate the advantages and disadvantages and to monitor the results to ensure the objectives can be achieved. The relevant information consists of five criteria and eighteen attributes, most of which are determined from extensive literature review.

Step 2: calculating the relative weight for criteria and attributes. In the formation of a pairwise comparison matrix, group decision-making is used to avoid the biased attitude of the decision maker towards a particular supplier. A series of pairwise comparisons are made to the importance of determinants in achieving objectives. Table 1 shows the pairwise comparison of criteria under determinant (U1) along with the eigenvector (local priority vector), also known as e-vector. Decomposing $\lambda$ by Eqs. (1)–(3), one obtains $\lambda_1 = -7.778$, $\lambda_2 = -3.395$, $\lambda_3 = -0.981$, $\lambda_4 = 0.386$, and $\lambda_5 = 8.245$. The evaluation matrices are also reported. The $w_\text{max}$ is equal to 8.245. The consistency of the pairwise judgment of each comparison matrix is also checked by consistency index and consistency ratio, both should be less than 0.1. Table 1 presents CI = 0.035 and CR = 0.024, therefore the results are acceptable and consistent. This computational results for e-vector are U1(0.53, 0.22, 0.70, 0.41, 0.11) and the normalized results are U1(0.27, 0.11, 0.35, 0.21, 0.06). Repeat all the process of pair comparisons, the normalized results under determinants U2 and U3 are, respectively, U2 (0.26, 0.01, 0.16, 0.24, 0.32) and U3 (0.08, 0.22, 0.11, 0.14, 0.45). These computational results are for the composition of unweighted supermatrix as shown in Table 3.

Table 1

<table>
<thead>
<tr>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>e-Vector Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2 5/6</td>
<td>5 1/2</td>
<td>1 3/8</td>
<td>3</td>
<td>0.53 0.27</td>
</tr>
<tr>
<td>C2</td>
<td>2 5/6</td>
<td>1</td>
<td>2 3/5</td>
<td>3 4/5</td>
<td>2</td>
</tr>
<tr>
<td>C3</td>
<td>5 1/2</td>
<td>2 3/5</td>
<td>1</td>
<td>4 2/7</td>
<td>4 4/5</td>
</tr>
<tr>
<td>C4</td>
<td>1 3/8</td>
<td>3 4/5</td>
<td>4 2/7</td>
<td>1</td>
<td>3 1/3</td>
</tr>
<tr>
<td>C5</td>
<td>3</td>
<td>4 2/7</td>
<td>3 1/3</td>
<td>1</td>
<td>0.11 0.06</td>
</tr>
</tbody>
</table>

$w_\text{max} = 8.245; CI = 0.035; CR = 0.024$

Table 2

<table>
<thead>
<tr>
<th>C1</th>
<th>U1</th>
<th>U2</th>
<th>U3</th>
<th>e-Vector Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3 4/7</td>
<td>4 1/2</td>
<td>0.76</td>
<td>0.47</td>
</tr>
<tr>
<td>U2</td>
<td>3 4/7</td>
<td>1</td>
<td>2 1/3</td>
<td>0.29</td>
</tr>
<tr>
<td>U3</td>
<td>4 1/2</td>
<td>2 1/3</td>
<td>1</td>
<td>0.58</td>
</tr>
</tbody>
</table>

$w_\text{max} = 0.007; CI = 0.007; CR = 0.005$
The unweighted supermatrix for interdependency among determinants and SCMS strategy.

<table>
<thead>
<tr>
<th>Determinants</th>
<th>SCM strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>U1</td>
<td>U2</td>
</tr>
<tr>
<td>U1</td>
<td>0.00</td>
</tr>
<tr>
<td>U2</td>
<td>0.00</td>
</tr>
<tr>
<td>U3</td>
<td>0.00</td>
</tr>
<tr>
<td>SCMS</td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>0.27 (Table 1)</td>
</tr>
<tr>
<td>C2</td>
<td>0.11</td>
</tr>
<tr>
<td>C3</td>
<td>0.35</td>
</tr>
<tr>
<td>C4</td>
<td>0.21</td>
</tr>
<tr>
<td>C5</td>
<td>0.06</td>
</tr>
</tbody>
</table>

And consistent. The computational results for e-vector are C1 (0.76, 0.29, 0.58) and the normalized results are C1 (0.47, 0.18, 0.36). Repeated all the process of pair comparisons, the normalized results for the remaining criteria are C2 (0.45, 0.26, 0.29), C3 (0.47, 0.15, 0.38), C4 (0.47, 0.11, 0.41) and C5 (0.47, 0.16, 0.36), respectively. Again, these computational results are for the composition of unweighted supermatrix as shown in Table 3.

Step 3: limiting the weighted supermatrix for the weigh. The outcomes of the process in Table 3 form the unweighted supermatrix, which is for interdependency among determinants and SCMS. Its columns contain the priorities derived from pairwise comparisons resulted from Tables 1 and 2. In an unweighted supermatrix, its columns may not be column stochastic. To obtain a stochastic matrix, i.e., each column sums to one, one can multiply the blocks of the unweighted supermatrix by the corresponding cluster priority. Raise the supermatrix to a large power to capture first-, second-, and third-degree influences. If the differences between corresponding elements of a column are less than a very small number, for successive powers of the supermatrix using Eq. (4), the process has converged. To derive the overall priorities of elements, we need to multiply submatrices numerous times, in turn, until the columns stabilize and become identical in each block of submatrices. Because our model involves inner dependences between determinants and criteria, it requires adjusting the unweighted supermatrix to make it column stochastic. Then, the weighted supermatrix (Table 4) can be raised to limiting powers to calculate the priority weights.

The supermatrix is made to converge to obtain a long-term stable set of weights, shown in Table 4. For convergence to occur, the supermatrix needs to be column stochastic. In other words, the sum of each column of the supermatrix needs to be one. The converged supermatrix presents the results of the relative importance measures for determinants and SCMS.

The elements of the supermatrix have been imported from the pairwise comparison matrices of interdependencies, shown in Table 5. As there are still five such pairwise comparison matrices, one for each interdependent attribute in the criteria, therefore, there will be non-zero columns in this supermatrix. Each of the non-zero values in a column is the relative importance weight associated with the interdependent pairwise comparison matrices. The supermatrix is made to converge to obtain a stable set of weights. The converged supermatrix is shown in Table 6.

Step 4: calculating the weights of all attributes. The local priority weights of criteria can be obtained from the integration of determinants and criteria, and the priority weights of attribute are from the converged supermatrix. The integration weight results are through normalization process. The resulted global priority weights are shown in Table 7.

Step 5: calculating the final weights of each supplier. The choquet integral provides with functionality and reliability for determining best alternatives by solving $\lambda$-fuzzy measure, where the $\lambda$ values are limited to [0, 1]. The choquet integral $\int_M^h d g$ in Eqs. (1), (3)–(9) is employed to obtain the aggregated value for each criteria based on attributes. The aggregated values of $h d g$ for the four alternatives are then used for case firm to select its suppliers in SCMS and determinants. The ranking order of aggregated value when $\lambda \approx 1$ for these four alternative suppliers is that supplier B (8.648) is suitable for its present requirements. Note that there is
The proposed hierarchical evaluation framework has been effectively applied to select the optimal supplier in SCMS for the case PCB manufacturing firm. Especially, it has provided managers and researchers with better understanding of the differences in SCMS activity needs and specific management interventions by examining the eighteen attributes. These attributes serve as a bridging mechanism, which is very helpful in SCMS. It can also provide other PCB manufacturing firms with a mechanism to monitor and establish measurement platform of SCMS.

In order to examine if the evaluation of suppliers is effective in SCMS, this study further conducted a post-survey discussion with the SCM expert group. The discussion results are summarized as follows. First, it is a common understanding that the purposes of SCMS often emphasize the expectation of improving performance. The expert group chose an optimal supplier with determinants of supply uncertainty containing quality, timeliness, and inspection requirements of the suppliers, which are most concerned by the case firm.

Secondly, the expert group chose the satisfying customer needs over other PCB manufacturing firms with a mechanism to monitor and establish measurement platform of SCMS.

6. Managerial implications

The final results are shown in Table 8.

6. Managerial implications

Table 6
Supermatrix of attributes in interdependency relationships after convergence.

<table>
<thead>
<tr>
<th>Attributes</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
</tr>
</thead>
<tbody>
<tr>
<td>A11</td>
<td>0.30</td>
<td>0.23</td>
<td>0.24</td>
<td>0.24</td>
<td>0.44</td>
</tr>
<tr>
<td>A12</td>
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<td>0.23</td>
<td>0.24</td>
<td>0.24</td>
<td>0.44</td>
</tr>
<tr>
<td>A13</td>
<td>0.30</td>
<td>0.23</td>
<td>0.24</td>
<td>0.24</td>
<td>0.44</td>
</tr>
<tr>
<td>A14</td>
<td>0.30</td>
<td>0.23</td>
<td>0.24</td>
<td>0.24</td>
<td>0.44</td>
</tr>
<tr>
<td>A21</td>
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<td>0.00</td>
<td>0.00</td>
<td>0.35</td>
</tr>
<tr>
<td>A22</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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</tr>
<tr>
<td>A23</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.35</td>
</tr>
<tr>
<td>A24</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.35</td>
</tr>
<tr>
<td>A31</td>
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<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.35</td>
</tr>
<tr>
<td>A32</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.35</td>
</tr>
<tr>
<td>A33</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.35</td>
</tr>
<tr>
<td>A41</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>A42</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
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<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>A52</td>
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<td>0.00</td>
</tr>
<tr>
<td>A53</td>
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<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Table 7
Integrated the priority weights of criteria and attributes for Choquet integral.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Attributes</th>
<th>Incumbent</th>
<th>Local</th>
<th>Global</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>A11 0.30</td>
<td>0.06</td>
<td>0.30</td>
<td>0.06</td>
</tr>
<tr>
<td>C2</td>
<td>A21 0.35</td>
<td>0.05</td>
<td>0.35</td>
<td>0.05</td>
</tr>
<tr>
<td>C3</td>
<td>A31 0.45</td>
<td>0.11</td>
<td>0.45</td>
<td>0.09</td>
</tr>
<tr>
<td>C4</td>
<td>A41 0.33</td>
<td>0.06</td>
<td>0.33</td>
<td>0.07</td>
</tr>
<tr>
<td>C5</td>
<td>A51 0.44</td>
<td>0.11</td>
<td>0.44</td>
<td>0.09</td>
</tr>
</tbody>
</table>

Table 8
Choquet integral computation of overall weight index for alternatives.

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Global priority</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
</tr>
</thead>
<tbody>
<tr>
<td>A11</td>
<td>0.06</td>
<td>8.552 (1.00)</td>
<td>8.684 (1.00)</td>
<td>8.216 (1.00)</td>
<td>8.315 (1.00)</td>
</tr>
<tr>
<td>A12</td>
<td>0.05</td>
<td>8.549 (0.00)</td>
<td>8.682 (0.00)</td>
<td>8.213 (0.00)</td>
<td>8.312 (0.00)</td>
</tr>
<tr>
<td>A13</td>
<td>0.05</td>
<td>1.075</td>
<td>0.095</td>
<td>0.108</td>
<td>0.108</td>
</tr>
<tr>
<td>A14</td>
<td>0.05</td>
<td>0.235</td>
<td>0.210</td>
<td>0.200</td>
<td>0.200</td>
</tr>
<tr>
<td>A21</td>
<td>0.07</td>
<td>0.272</td>
<td>0.298</td>
<td>0.237</td>
<td>0.266</td>
</tr>
<tr>
<td>A22</td>
<td>0.06</td>
<td>0.348</td>
<td>0.374</td>
<td>0.271</td>
<td>0.322</td>
</tr>
<tr>
<td>A23</td>
<td>0.04</td>
<td>0.436</td>
<td>0.410</td>
<td>0.361</td>
<td>0.371</td>
</tr>
<tr>
<td>A24</td>
<td>0.03</td>
<td>0.472</td>
<td>0.469</td>
<td>0.437</td>
<td>0.407</td>
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<tr>
<td>A31</td>
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<tr>
<td>A32</td>
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<td>0.577</td>
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<td>0.537</td>
<td>0.571</td>
</tr>
<tr>
<td>A33</td>
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<td>0.670</td>
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<td>0.720</td>
<td>0.766</td>
<td>0.800</td>
<td>0.793</td>
</tr>
<tr>
<td>A43</td>
<td>0.05</td>
<td>0.767</td>
<td>0.800</td>
<td>0.842</td>
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<tr>
<td>A44</td>
<td>0.03</td>
<td>0.800</td>
<td>0.866</td>
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<td>0.870</td>
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<tr>
<td>A51</td>
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<td>0.866</td>
<td>0.971</td>
<td>0.940</td>
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</tr>
<tr>
<td>A52</td>
<td>0.04</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
</tbody>
</table>

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is sensible because satisfied IT is important in central point of SCMS activities, which should aim primarily to take good care of their IT ability.

Thirdly, many works on SCM suggested that a sound SCMS should be a broader consideration in many criteria, which should integrate all attributes as the ideal form of SCMS, rather than an attribute along. However, the expert group remarked on the merits of the proposed solutions. Unlike a traditional hierarchical model based on the linear and piecemeal approach, the Modified Feedback System model of the proposed evaluation framework is novel since it is based on a complex interrelationship and intertwining among criteria and attributes. It is favorable to use ANP to handle the problem of inner dependences since it can provide more valuable information for decision-making (Wu, 2008; Tseng et al., 2008).

In broader sense, the proposed hierarchical evaluation framework in SCMS can also be used as an analytical monitoring tool to further developing or constructing an overall supplier evaluation. For the practice of management, SCMS is sufficient for organizational managers to better understand the relevant criteria and attributes. Moreover, the managers are able to capture a fairly complete picture of SCMS while assessing the relative performance of the components developed, validated, and operationalized by this approach.

7. Conclusions

This study has contributed to, in particular, the SCM literature by: (i) proposing a research framework that relates determinants to SCMS under uncertainty, (ii) developing valid and reliable measures for the dimensions based on expert’s qualitative opinion, and (iii) developing a SCMS hierarchical analytical structure to evaluate the optimal supplier using ANP and fuzzy integral. In practical SCMS problems, vast amounts of criteria and attributes are typically interactive and interdependent and with elusive qualitative information. This study developed an effective evaluation framework to select the most appropriate supplier in SCMS. The proposed framework incorporated a hierarchical MCDM structure, ANP and choquet integral, wherein MCDM is to select the most appropriate alternative from a finite set of alternatives with reference to multiple conflicting criteria, ANP is to simultaneously consider the relationships of feedback and dependence of criteria, and choquet integral is to eliminate the interactivity of expert subjective judgment problems. The proposed evaluation framework has been validated with its effectiveness and simplicity in selecting the optimal supplier in SCMS for the case firm. The ANP is a relatively new MCDM method which can deal with many interactions systematically, particularly the SCMS evaluation problems. Moreover, the ANP can be used not only as a way to handle the inner dependences within a set of criteria/attributes, but also as a way of producing more valuable information for decision-making. The whole supply chain members can apply the proposed framework to evaluate and determine firms’ optimal suppliers in uncertainty.

Some directions for future study are proposed here. Development of a richer, multi-hierarchical structure that incorporates other criteria/attributes with quantitative measurement, not only the qualitative measurement in this study, deserves further exploration. To prevent the information bias, future study might involve the fuzzy set theory in when, especially, qualitative measures are involving imprecision, constraints, and possible actions that are not precisely in description (Bellman & Zadeh, 1970). Furthermore, the uncertain environment is highly affected by subjective judgments, which is vague and imprecise in nature (Al-Najjar & Alsyouf, 2003). Modeling the imprecise and uncertain problems with proper mathematical tools, such as fuzzy logic (Zadeh, 1975), also deserves attempting to account for the vagueness in the SCMS evaluation process.

References


