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A fuzzy linguistic computing approach to supplier evaluation

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ABSTRACT

Harnessing the supply base is an important but complex task for enterprises. Supplier performance evaluation is increasingly seen as a strategic issue for companies to maintain and enhance the competitive edge. However, evaluating suppliers is complicated by the fact that various criteria must be considered in the decision-making process, and is inherently a multicriteria decision-making (MCDM) problem. It also concerns the evaluation by different experts of multiple attributes, both qualitative and quantitative. To perceive and to estimate effectively the capability of suppliers are real arduous tasks for executives. This paper takes advantage of the 2-tuple linguistic computing to coping with the heterogeneity and information loss problems while the evaluation processes of subjective integration. The proposed approach based on the group decision-making scenario assists executives in adroit manipulation of the heterogeneity during integration processes and averts the information loss effectively. Finally, we demonstrate the validity and feasibility by means of a high-technology company in Taiwan.

1. Introduction

The globalization of competition in the manufacturing industry and the diversification of customers' demands as well as rapid technological developments continue to spur enterprises at a frenetic pace. The evaluation of supplier performance is undeniably regarded as the cornerstone of successful purchasing and supply management to maintain and enhance the competitive edge. Gencer and Gürpinar [1] pointed out that there are two main reasons for this. Firstly, the costs of the purchased goods and services account for more then 60% of the cost of goods sold in many firms. Secondly, over 50% of all quality defects can be traced back to purchase material. Therefore, supplier selection has been long recognized as a critical factor for the companies desiring to be successful in nowadays competition conditions.

As firms increasingly emphasize cooperative relationships with crucial suppliers, executives of buyers are using supplier evaluations to ensure that their business objectives are met consistently and at an acceptable overall performance. Moreover, more firms become interested in developing and implementing strategic partnership with their suppliers [2]. Evaluating and managing supplier performance is becoming increasingly important and challenging. An effective tool/approach is therefore required urgently to assist these firms in prequalifying their suppliers based on their overall performances, selecting the best suppliers and in developing and managing the strategic partnership.

However, evaluating suppliers is a complicated task and inherently a multiple criteria decision-making (MCDM) problem because of the fact that various criteria must be deliberated in the decision-making process. Muralidharan et al. [3]

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compared the advantages and limitations of nine previously developed methods of supplier rating, and combined multiple criteria ng and analytic hierarchy processes to construct a multicriteria group decision-making model. The attributes of quality, delivery, price, technique capability, finances, attitude, facility, flexibility and service were used for supplier evaluation, and the attributes of knowledge, skill, attitude and experience were used for individual assessments. Araz et al. [4] developed an outsourcer evaluation and management system for a textile company by use of fuzzy goal programming (FGP). The approach did not take account of group decision situation. Vonderembse and Tracey [5] investigated the extent to which supplier selection criteria and supplier involvement are used by manufacturers. It also provided support for the claim that firms employing these practices have enhanced supplier and manufacturing performance.

Guneri et al. [6] aimed to present an integrated fuzzy and linear programming approach to the supplier selection problem in supply chain management process. The proposed linear programming model was based on the coefficients of suppliers, buyer's budgeting, suppliers' quality and capacity constraints and order quantities assigned to each supplier according to the linear programming model. Chen et al. [7] applied linguistic values to assess the ratings and weights of supplier selection criteria and then proposed a hierarchy multiple criteria decision-making model based on fuzzy set theory to deal with the supplier selection problems in the supply chain system. By calculating the candidate suppliers' distances to the both fuzzy positive-ideal solution (FPIS) and fuzzy negative-ideal solution (FNIS) simultaneously, a closeness coefficient is defined to determine the ranking order of all suppliers.

In fact, during the evaluation process of self-superiority and technology capability of supplier performance, most judgments of experts however are determined in qualitative representations by past experience, vague, imprecise knowledge or subjective cognition. The contents are mainly numerical, interval and linguistic, and result in heterogeneous assessment. Integrating suchlike information turns into an important managerial topic. This paper therefore attempts to present an impersonal and systematic evaluation mechanism and the platform of supplier performance.

Evaluation techniques can be mainly classified into two groups; these are qualitative methods and quantitative methods. Qualitative methods describe the characteristics of each measure in sufficient detail to allow them to be understood. Quantitative methods use mathematical models to simulate the effect of measures on problem outcomes. These two kinds of methods, qualitative and quantitative, can be used separately or together. In addition, multicriteria decision-making methods are an important set of tools for addressing challenging business decisions because they allow the manager to better proceed in the face of uncertainty, complexity, and conflicting objectives [5,8]. In order to evaluate the performance of suppliers more appropriately, it should consider not only quantitative index but also qualitative dimensions or factors which are evaluated by multiple decision-makers or experts. The evaluation process appropriately should be regarded as a group multiple criteria decision-making problem as well [9,10].

Experts devote to judge by their experiential cognition and subjective perception in the decision-making process of supplier performance measurement. However, there exist considerable extent of uncertainty, fuzziness and heterogeneity [11]. This is not a seldom situation. In addition, it is prone to information loss happen during the integration processes, and gives rise to the evaluation result of performance level may not be consistent with the expectation of evaluators. Herrera and Martinez [12] indicated a limitation of the fuzzy linguistic approach imposed by its information representation model and the computation methods used when fusion processes are performed on linguistic values. They expressed the linguistic information by means of 2-tuples which are composed by a linguistic term and a numeric value. Together with the 2-tuple representation model they developed a computational technique for computing with words without any loss of information. In addition, they [13] developed a procedure for combining numerical and linguistic information without loss of information in the transformation processes between numerical and linguistic information, taking as base for representing the information the 2-tuple fuzzy linguistic representation model. For supporting recommender systems to evaluate and filter the great amount of information available on the Web to assist people in their search processes.

In addition, Herrera-Viedma and Peis [14] presented a fuzzy evaluation method of Standard Generalized Markup Language documents based on computing with words. Herrera-Viedma et al. [15] proposed an information retrieval system (IRS) based on fuzzy multi-granular linguistic information and a method to process the multi-granular linguistic information in which aspects of different nature are assessed with different uncertainty degrees. Herrera-Viedma et al. [16] presented different fuzzy linguistic multi-agent models for helping users in their information gathering processes on the Web. In this paper we describe a new fuzzy linguistic multi-agent model that incorporates two information filtering techniques (a content-based filtering agent and a collaborative filtering agent) in its structure.

Accordingly, developing an effortless means to estimate the performance ratings while the processes of evaluation integration and appropriately to manipulate the operation of qualitative factors and expert judgment in the supplier evaluation process could brook no delay. In this paper we propose a suitable model based on 2-tuple fuzzy linguistic information to evaluate the supplier performance. The proposed approach not only inherits the existing characters of fuzzy linguistic assessment but also overcomes the problems of information loss of other fuzzy linguistic approaches.

The remainder of this paper is organized as follows. Section 2 describes the measurement dimensions of supplier evaluation. In Section 3 we introduce the basic definitions and notations of the fuzzy number, linguistic variable and 2-tuple fuzzy linguistic representation and operation, respectively. A supplier performance evaluation method based on 2-tuple fuzzy linguistic information is proposed in Section 4. The proposed model is then illustrated with an example for a high-technology company in Taiwan. Section 5 concludes the paper.

2. Dimensions of supplier evaluation

The purchasing activities of a company constitute a very important part in the overall operation of the company. The quality and the delivery capabilities of any manufacturing firm depend heavily on the performance of its suppliers. It deserves to be mentioned that important sources of uncertainty inherent in a supply chain are customer demand and supplier reliability. Consequently there is an emphasis on developing long-term mutually beneficial and cooperative relationships with fewer but critical suppliers in today's business environment. Many executives are hesitant to rely on untested suppliers without first taking the time to build an effective relationship to ensure specific performance objectives. When suppliers are unable to conform to the vendee's expectations, the buyer manager must determine the most appropriate action to resolve the issue. To maintain the working relationship, the manager must find a way to communicate the problem and motivate the supplier to change its results. Otherwise, the working relationship should be decisively terminated [4,5].

As more and more firms are reducing their supply base and thereby increasing their reliance on a smaller number of suppliers, performance measurement and management of the remaining core of suppliers is becoming increasingly important. Firms apply operational competitive priority measures such as quality, delivery, price, service and flexibility, as well as internal measures such as defects, schedule realization and cost. Choi and Hartley [17] evaluated suppliers based on consistency, reliability, relationship, flexibility, price, service, technological capability and finances, and also addressed 26 supplier selection criteria. Furthermore, Verma and Pullman [18] ranked the importance of the supplier attributes of quality, on-time delivery, cost, leadtime and flexibility. Additionally, Vonderembse and Tracey [5] described that supplier and manufacturing performance were determined by supplier selection criteria and supplier involvement. The proposed supplier selection criteria could be evaluated by quality, availability, reliability and performance, while supplier involvement could be evaluated by product R& D and improvement, and supplier performance could be evaluated by stoppage, delivery, damage and quality.

As such, manufacturing performance could be evaluated by cost, quality, inventory and delivery. Overall 45 criteria within three main criteria clusters are summarized by Gencer and Gürpinar [1]. The clusters include business structure, manufacturing capability and quality system, respectively. Sarkis and Talluri [2] suggested that procurement function has been attracting growing interest as a critical component of supply chain management, and multiple factors have been considered in supplier selection and evaluation, including strategic, operational, tangible and intangible measures within planning horizon, culture, technology, relationship, cost, quality, time and flexibility. Muralidharan et al. [3] illustrated attributes of quality, delivery, price, technique capability, finances, attitude, facility, flexibility and service which were used for supplier evaluation, and the attributes of knowledge, skill, attitude and experience which were used for individual assessments.

Rather than simply evaluating a series of outcome measures, many companies appear to be adopting process-based supplier evaluation methods, thus engaging more actively in understanding the supplier's process capabilities and, through supplier development programs, helping the supplier to improve. However, it is difficult and laborious to measure suppliers' performance using traditional crisp value directly as the process of supplier performance measurement is possessed of many intangible or qualitative criteria and sub-criteria. Linguistic variable representation is therefore favorable for experts to express and evaluate the ratings of suppliers under such situation. The fundamentals of 2-tuple fuzzy linguistic approach are to apply linguistic variables to represent the difference of degree and to execute processes of computing with words easier and without information loss during the integration procedure [12,16,19]. Namely, the decision-makers or experts can use linguistic variables to estimate measure items and obtain the final evaluation result with proper linguistic variable. It is an operative method to reduce the decision time and mistakes of information translation and avoid information loss through computing with words.

3. Related fuzzy concepts

Today's increasingly uncertain world yields a highly competitive environment for every business. The imprecise and vague terms will exist, because most executives find it more practical and easier to evaluate performance in linguistic terms. To deal with vagueness of human thought, Zadeh [20] first introduced the fuzzy set theory, which was oriented on the rationality of uncertainty due to imprecision or vagueness. Fuzzy sets theory is especially powerful when there is a need to take into consideration the ideas and judgments of people because of complexity and lack of proper information. Fuzzy sets provide representation of the knowledge of decision-makers in a better and more natural way. A major contribution of fuzzy set theory is its capability of representing vague knowledge. The theory also allows mathematical operators and programming to apply to the fuzzy domain. Basic definitions and concepts of fuzzy sets are briefly reviewed as follows; and further, notations below will be used throughout the paper until otherwise stated.

3.1. Fuzzy number and linguistic variable

The use of fuzzy sets theory has given very good results for modeling qualitative information. It is a technique that handles fuzziness and represents qualitative aspects as linguistic labels by means of "linguistic variables", that is, variables whose values are not numbers but words or sentences in a natural or artificial language [13]. Triangular fuzzy numbers appear as useful means of quantifying the uncertainty in decision making due to their intuitive appeal and computational-efficient representation [10,21,22]. A positive triangular fuzzy number (PTFN) $\widetilde{A}$ can be denoted as $\widetilde{A} = (a, b, c)$, where $a \leqslant b \leqslant c$ and $a > 0$, illustrated in Fig. 1. The membership function, $\mu_{\widetilde{A}}(x)$, is defined as [23]

$$\mu_{\tilde{A}}(x) = \begin{cases} (x-a)/(b-a), & a \leqslant x \leqslant b, \\ (x-c)/(b-c), & b \leqslant x \leqslant c, \\ 0, & \text{otherwise}, \end{cases} \quad (1)$$

where x takes its values on the real line. A larger $\mu_{\tilde{A}}(x)$ means a stronger degree of belongingness for x in X.

The fuzzy linguistic approach represents qualitative aspects as linguistic values by means of linguistic variables [15,20]. A linguistic variable is a variable whose value is expressed in linguistic terms. For example, "important" is a linguistic term whose values are "very low", "low", "medium", "high", "very high", etc. Linguistic values can also be represented by fuzzy numbers. It is suitable to represent the degree of subjective judgment in qualitative aspect than crisp value. The concept of linguistic variable is very useful in dealing with situations which are too complex or too ill-defined to be reasonably described in conventional quantitative expressions. Many aggregation operators have been presently developed to aggregate information.

Usually, depending on the problem domain, an appropriate linguistic term set is chosen and used to describe the vague or imprecise knowledge. The number of elements in the term set will determine the granularity of the uncertainty. According to the uncertainty degree that an expert qualifying a phenomenon has on it, the linguistic term set chosen to provide his knowledge will have more or less terms. When different experts have different uncertainty degrees on the phenomenon, then several linguistic term sets with a different granularity of uncertainty are necessary.

3.2. 2-Tuple fuzzy linguistic term

In order to facilitate the computation and identify the diversity of each evaluation item, linguistic terms are often possessed of some characteristics like finite set, odd cardinality, semantic symmetric, ordinal level and compensative operation. The linguistic information with a pair of values is called 2-tuple that composed by a linguistic term and a number [12,13]. The main advantage of this representation is to be continuous in its domain. Therefore, it can express any counting of information in the universe of the discourse. It can be denoted by a symbol $L = (s, \alpha)$ where s represents the linguistic label of the information, and α is a numerical value representing the symbolic translation. In other words, A 2-tuple linguistic variable can be denoted as (s_i, α_i) where s_i denotes the central value of the ith linguistic term. α_i indicates the distance to the central value of the ith linguistic term. For example, a set of five terms S could be given as follows:

$$S = \{s_0 : VL, s_1 : L, s_2 : A, s_3 : H, s_4 : VH\}.$$

It means that a linguistic term set S contains five linguistic terms, "Very Low", "Low", "Average", "High", and "Very High", which are denotes s_0, s_1, s_2, s_3, and s_4, respectively. Each of the linguistic term is assigned one of five triangle fuzzy numbers whose membership functions are shown as Fig. 2. A 2-tuple linguistic variable set probably comprises three, five, seven or more terms. However, the more the set contains terms, the more arduous the experts implement. In general, a five-term set has practical applications.

3.3. Conversion between 2-tuples and numeric values

After aggregating the result of evaluation using the linguistic variable set S a numeric value β whose value belongs to interval [0,1] will be obtained. Then the symbolic translation process is applied to translate β into a 2-tuple linguistic variable. The generalized translation function (Δ) can be represented as [24]

$$\Delta : [0,1] \to S \times \left[-\frac{1}{2g}, \frac{1}{2g}\right)$$
$$\Delta(\beta) = (s_i, \alpha) \text{ with } \begin{cases} s_i, & i = round(\beta \cdot g) \\ \alpha = \beta - \frac{i}{g}, & \alpha \in \left[-\frac{1}{2g}, \frac{1}{2g}\right), \end{cases} \quad (2)$$

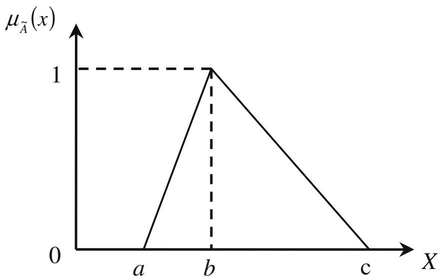

Fig. 1. Illustration of a triangular fuzzy number $\widetilde{A}$.

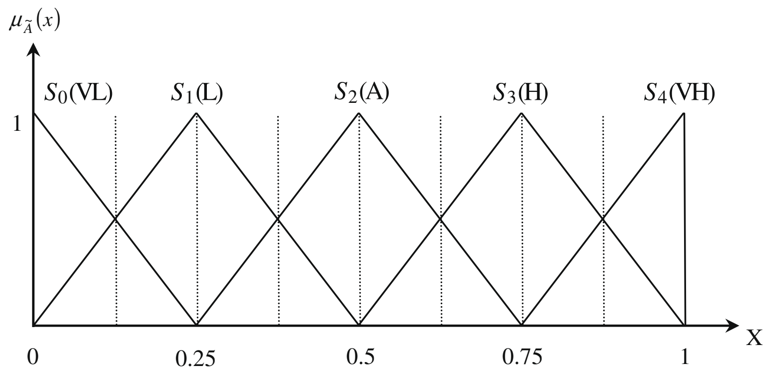

Fig. 2. Linguistic term set of five labels with its semantics.

where $\beta \in [0,1]$. A value β is translated into the closest linguistic term s_i in S with a value α through the symbolic translation. The 2-tuple fuzzy linguistic approach applies the concept of symbolic translation to represent the linguistic variable using 2-tuples (s_i, α), $s_i \in S$. The interval of value $\alpha$is derived from the number of linguistic terms. For example, if S contains five linguistic terms then $g = 5$ and $\alpha \in [-0.1, 0.1)$.

On the contrary, the 2-tuple can be converted into an equivalent numeric value $\beta (\beta \in [0,1])$ by the following formula:

$$\Delta^{-1}(s_i, \alpha) = \frac{i}{g} + \alpha = \beta. \tag{3}$$

Δ and Δ^{-1} transform numerical values into a 2-tuples and vice versa without loss of information, therefore, any numerical aggregation operator can be easily extended for dealing with linguistic 2-tuples.

3.4. Operation of 2-tuples

Suppose $L_1 = (s_1, \alpha_1)$ and $L_2 = (s_2, \alpha_2)$ stand for two 2-tuples. The primary algebraic operations are shown as follows:

$$L_1 \oplus L_2 = (s_1, \alpha_1) \oplus (s_2, \alpha_2) = (s_1 + s_2, \alpha_1 + \alpha_2),$$
$$L_1 \otimes L_2 = (s_1, \alpha_1) \otimes (s_2, \alpha_2) = (s_1 s_2, \alpha_1 \alpha_2),$$

where $\oplus$ and $\otimes$ stand for the addition and multiplication operations of parameters, respectively.

3.4.1. Arithmetic mean

Symbolic translation functions, Δ and Δ^{-1}, are applied in the process of information aggregation to guarantee the aggregation of 2-tuples linguistic variables can be a 2-tuple and without any information loss. Let $S = \{(s_1, \alpha_1), \ldots, (s_n, \alpha_n)\}$ be a 2-tuple linguistic variable set, their arithmetic mean $\bar{S}$ can be calculated as

$$\bar{S} = \Delta\left[\frac{1}{n}\sum_{i=1}^{n}\Delta^{-1}(s_i, \alpha_i)\right] = \Delta\left(\frac{1}{n}\sum_{i=1}^{n}\beta_i\right) = (s_m, \alpha_m). \tag{4}$$

3.4.2. Weighted average

When $S = \{(s_1, \alpha_1), \ldots, (s_n, \alpha_n)\}$ is a 2-tuple linguistic variable set, and $W = \{w_1, \ldots, w_n\}$ is the weight set of linguistic terms. Hence, the 2-tuple linguistic weighted average $\bar{S}^w$ can be computed as

$$\bar{S}^w = \Delta\left(\frac{\sum_{i=1}^{n}\Delta^{-1}(s_i, \alpha_i) \cdot w_i}{\sum_{i=1}^{n} w_i}\right) = \Delta\left(\frac{\sum_{i=1}^{n}\beta_i \cdot w_i}{\sum_{i=1}^{n} w_i}\right) = (s^w, \alpha^w). \tag{5}$$

Furthermore, let $W = \{(w_1, \alpha_{w1}), \ldots, (w_n, \alpha_{wn}\}$ be the linguistic weight set of linguistic terms. Such linguistic weighted average operator is extended from weighted average operator and can be computed as

$$\bar{S}^w = \Delta\left(\frac{\sum_{i=1}^{n}\Delta^{-1}\beta_i \cdot \beta_{wi}}{\sum_{i=1}^{n}\beta_{wi}}\right) = (s^w, \alpha^w) \quad \text{with } \beta_i = \Delta^{-1}(s_i, \alpha_i) \quad \text{and } \beta_i^w = \Delta^{-1}(s_i, \alpha_i). \tag{6}$$

3.4.3. Comparison of linguistic information

According to an ordinary lexicographic order we may implement the comparison of linguistic information represented by 2-tuples. Let (s_i, α_i) and (s_j, α_j) be two 2-tuples, with each one representing a counting of information as follows [16]:

1. if $i > j$ then (s_i, α_i) is better than (s_j, α_j);
2. if $i = j$ and $\alpha_i > \alpha_j$ then (s_i, α_i) is better than (s_j, α_j);
3. if $i = j$ and $\alpha_i < \alpha_j$ then (s_i, α_i) is worse than (s_j, α_j);
4. if $i = j$ and $\alpha_i = \alpha_j$ then (s_i, α_i) is equal to (s_j, α_j), i.e. the same information.

4. The proposed approach in supplier evaluation

A 2-tuple-based evaluation model in accordance with concepts of fuzzy linguistic computing approach is proposed in this paper to measure the performance level of the supplier for a practical company. Assume that there are n criteria $C_i (i = 1, 2, \ldots, n)$ and each criterion contains several sub-criteria in an evaluation framework of the supplier performance. The algorithm procedure for the proposed evaluation approach is organized sequentially into six steps, displayed in Fig. 3 and explained as follows:

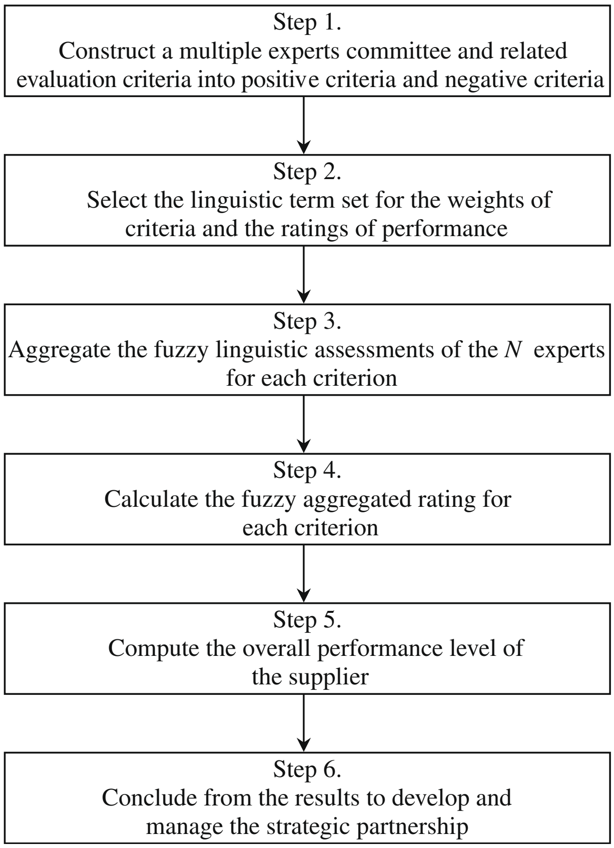

Fig. 3. Procedure of algorithm on proposing approach.

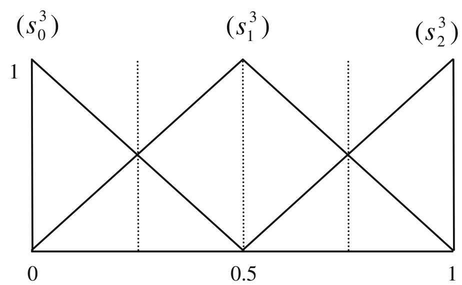

Fig. 4. Linguistic term set of three labels with its semantics.

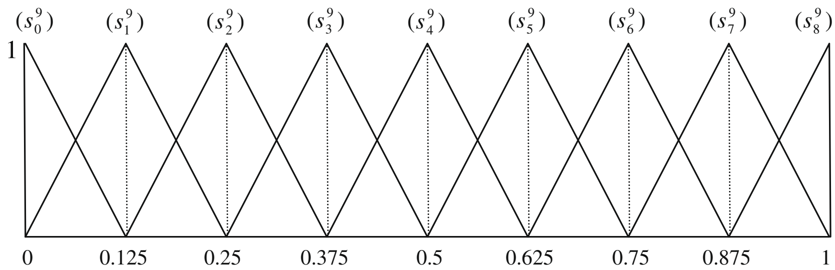

Fig. 5. Linguistic term set of nine labels with its semantics.

Table 1
Selective category of linguistic terms for experts.

Type	Number of linguistic	Linguistic variable	Illustration
A	3	Low (s_0^3), Average (s_1^3), High (s_2^3)	Shown in Fig. 4
B	5	Very low (s_0^5), Low (s_1^5), Average (s_2^5), High (s_3^5), Very high (s_4^5)	Shown in Fig. 2
C	9	Extremely low (s_0^9), Very low (s_1^9), Low (s_2^9), Fair (s_3^9), Average (s_4^9), High (s_5^9), Very high (s_6^9), Extremely high (s_7^9), Excellent (s_8^9)	Shown in Fig. 5

Step 1. Form a committee of decision-makers who are concerned and familiar with marketing, selling and the relationship of supply and demand. Identify and divide the evaluation criteria into positive criteria (the higher the rating, the greater the preference) and negative criteria (the lower the rating, the greater the preference).

Step 2. Selectable categories of linguistic terms in Table 1 for experts are prepared when they apply the linguistic importance variables to express the weight of each criterion and employ the linguistic rating variables to evaluate the performance of sub-criteria with respect to each criterion.

Step 3. Aggregate the fuzzy linguistic assessments of the N experts for each criterion as follows:

$$\overline{S}_{ij} = \Delta\left(\frac{1}{N}\sum_{n=1}^{N}\Delta^{-1}(s_{ijn},\alpha_{ijn})\right) = \Delta\left(\frac{1}{N}\sum_{N=1}^{N}\beta_{ijn}\right) = (s_{ij},\alpha_{ij}), \tag{7}$$

$$\overline{W}_{ij} = \Delta\left(\frac{1}{N}\sum_{n=1}^{N}\Delta^{-1}\left(s_{ijn}^{w},\alpha_{ijn}^{w}\right)\right) = \Delta\left(\frac{1}{N}\sum_{n=1}^{N}\beta_{ijn}^{w}\right) = \left(s_{ij}^{w},\alpha_{ij}^{w}\right), \tag{8}$$

$$\overline{W}_{i} = \Delta\left(\frac{1}{N}\sum_{n=1}^{N}\Delta^{-1}(s_{in}^{w},\alpha_{in}^{w})\right) = \Delta\left(\frac{1}{N}\sum_{n=1}^{N}\beta_{in}^{w}\right) = (s_{i}^{w},\alpha_{i}^{w}), \tag{9}$$

where, s_{ijn} is the fuzzy rating of sub-criteria j with respect to C_i of the nth expert, s_{ijn}^w is the fuzzy importance of sub-criteria j with respect to C_i of the nth expert;

Step 4. Compute the fuzzy aggregated rating of $C_i(\overline{S}_i)$ through Eq. (6);

$$\overline{S}_i^w = \Delta\left(\frac{\sum_{j=1}^{l_i}\Delta^{-1}\beta_{ij}\cdot\beta_{ij}^{w}}{\sum_{j=1}^{l_i}\beta_{ij}^{w}}\right) = (s_i^w,\alpha_i^w) \quad \text{with } \beta_{ij} = \Delta^{-1}(r_{ij},\alpha_{ij}) \quad \text{and } \beta_{ij}^{w} = \Delta^{-1}\left(w_{ij},\alpha_{ij}^{w}\right). \tag{10}$$

Step 5. Compute the overall performance level (OPL) of the supplier, the linguistic term s_T, can be applied to represent the control and management performance level of suppliers as well as being the improvement index directly.

$$OPL = \Delta\left(\frac{\sum_{i=1}^{n}\beta_i\cdot\beta_{w_i}}{\sum_{i=1}^{n}\beta_{w_i}}\right) = (s_T,\alpha_T) \quad \text{with } \beta_i = \Delta^{-1}(r_i,\alpha_i) \quad \text{and } \beta_{w_i} = \Delta^{-1}(w_i,\alpha_{w_i}). \tag{11}$$

Step 6. Conclude from the results to develop and manage the strategic partnership through supplier development programs.

5. Application of proposed method

A real high-tech electronic manufacturer in the Neihu District of Taipei, Taiwan has been in operation for twelve years, employs approximately 100 employees, as well as its annual sales are approximately $7 million. It is a fabulous IC components company with high-caliber professionals specialized in designing, manufacturing, and supplies leading edge, high performance memory products and memory-intensive logic products to numerous high growth and performance-demanding markets. The major product categories are computing (PCs, disk drives, printers, graphics, multimedia, etc.), communications (telecommunications, data communications, cellular phones, switches hubs network interface, modems, etc.) and consumers (VCD, DVD, Set Top Box, Digital Camera, Video games, etc.), respectively.

The manufacturer is subject to the globalization competition where the demands of frequent innovation and higher quality lead to competitive leverages for the new product development. They must be extremely responsive to meet the changing requirements of customers. Consequently, developing the strategic relationships with innovative suppliers is a vital objective in supply management. Executives believe that the objective can be achieved by the assistance of an effective supplier evaluation mechanism. The proposed approach can help the firm to effectively deal with the troublesome problem. In general, the following questions are expected to be answered:

- Which suppliers should be selected as strategic partners? (It means perfect suppliers).
- Which suppliers must be supported via supplier development programs? (It means promising suppliers).
- Which suppliers to consider for competitive partnerships for some products? (It means moderate suppliers).
- Which suppliers no longer should be considered for the partnership in any level? (It means bad suppliers).

A central tenet of the supplier evaluation literature is that certain task-related performance attributes will be more important than others. Based on the profound discussions with executives and experts the main concerns for measuring the suppliers' performance can be concluded as follows:

C 1: Supplier's product quality

Companies in today's highly competitive marketplace are responsible to deliver goods with a salient advantage in order to drive consumer acceptance. Since the performance and functionality of the input secured from a vendor can impact the perception that the downstream customer possesses about the business customer's goods, a supplier's product quality should have great bearing on the business customer's perception regarding the vendor's operational performance. The derived sub-criteria are as follows:

C_{11}: Product performance (reliability and accuracy).
C_{12}: Level of technology.

C 2: Supplier's delivery/order fulfillment capability

Delivery, which refers to both the supplier's logistical capabilities as well as the critical activities and processes that it performs from the time that the input is (re) ordered until it arrives at the business customer's facility (i.e., order fulfillment), can also influence a business customer's costs, velocity to market, and/or how its value proposition is perceived by the end user [8]. Inaccurate, missed, and/or delayed deliveries can disrupt a business customer's operational efficiency. Furthermore, the supplier's order fulfillment capability can also affect costs and velocity to the market. Companies based on velocity to market have tangibly demonstrated the benefits that can strengthen from attending better to their supplier's order fulfillment capability. The obtained sub-criteria are as follows:

C_{21}: Condition of products on arrival.
C_{22}: On-time delivery performance.
C_{23}: Accuracy in filling orders.
C_{24}: Order cycle time.
C_{25}: Ability to fill emergency orders.
C_{26}: Accuracy in billing and credit.

C 3: Price/cost reduction performance

In fact, this criterion has declined in its relative importance and is demonstrated no longer the critical factor driving purchasing activities as it found that only one fourth of all firms include price as part of their suppliers evaluation systems. However, price may be the most important criterion in industries in which the inputs secured are primarily commodities (e.g., the paint industry). After cautious deliberation with the on-the-spot staff, this criterion is still included in our measurement mechanism for its inherent property in organizational buying decisions. The derived sub-criteria are as follows:

C_{31}: Price of products and services.
C_{32}: Financial strength.
C_{33}: Cost harness capability.

C 4: Supplier's postsales service

The criterion service is actually concluded as possessing the least influence with regard to the other criteria. We expect as the proposed approach omni-bearing focuses on assessing the evaluation criteria to be used by firms. Any postsales assistance required is to be considered an undesirable result of deviations from previously agreed upon tolerances. The obtained sub-criteria are as follows:

C_{41}: Postsales assistance and support.
C_{42}: Ability and willingness to assist with the design process.
C_{43}: Ease of communication.

After preliminary sifting the related information carefully and the above-mentioned literature on supplier evaluation, an expert committee of four decision-makers, D_1, D_2, D_3 and D_4 (an assistant manager of customer service and three senior managers from manufacturing group, advanced technology center and global sales group) has been formed to conduct the evaluation of suppliers performance for the company. At the outset, they make their individual opinion in accordance with own knowledge, expertise, as well as experience to infer the overall performance level of suppliers for the case company. There are five levels (perfect, promising, moderate, unlikely and imperfect) to differentiate the supplier's overall performance. The inferences are ''Promising'', ''Perfect'', ''Moderate'' and ''Promising'', respectively, namely $(s_3,0)$, $(s_4,0)$, $(s_2,0)$ and $(s_3,0)$ by using the linguistic variables. In addition, four types of concerned criteria and their corresponding sub-criteria drew forth advanced measurement, and are shown in Fig. 6.

According to the above-mentioned procedure, the proposed method is currently applied to evaluate the supplier performance of the specific company and the computational procedure is summarized as follows:

Step 1. Four decision-makers from specialized sections organize the evaluation committee and subsequently conclude the required evaluation criteria.

Step 2. Every decision-maker chooses one kind of linguistic variables from the selectable categories (Table 1), say, a five-term linguistic variable, to determine the importance of each criterion and the performance of each sub-criterion with respect to each criterion. Afterward the rating outcome is shown in Tables 2 and 3.

Step 3. The 2-tuple fuzzy linguistic aggregation method is employed to compute fuzzy evaluation and weighting value of each sub-criterion by Eqs. (7) and (8). For example, fuzzy rating and weighting value of sub-criteria ''Product performance (reliability and accuracy)'' with respect to criterion ''Product quality'' are computed as

$$\overline{S}_{11} = \Delta\left[\frac{1}{4}\left(\Delta^{-1}(s_3,0)+\Delta^{-1}(s_4,0)+\Delta^{-1}(s_2,0)+\Delta^{-1}(s_4,0)\right)\right] = \Delta\left[\frac{1}{4}(0.75+1+0.5+1)\right] = \Delta(0.8125) = (s_3,0.0625),$$
$$\overline{W}_{11} = \Delta\left[\frac{1}{4}\left(\Delta^{-1}(s_2,0)+\Delta^{-1}(s_4,0)+\Delta^{-1}(s_2,0)+\Delta^{-1}(s_2,0)\right)\right] = \Delta\left[\frac{1}{4}(0.5+1+0.5+0.5)\right] = \Delta(0.625) = (s_2,0.125).$$

And then the computational results are shown in Table 4.

Step 4. The aggregated weighting value of each criterion by Eq. (9) can be calculated as follows, ''Delivery/order fulfillment capability'' for example.

$$\overline{W}_1 = \Delta\left[\frac{1}{4}\left(\Delta^{-1}(s_3,0)+\Delta^{-1}(s_4,0)+\Delta^{-1}(s_4,0)+\Delta^{-1}(s_4,0)\right)\right] = \Delta\left[\frac{1}{4}(0.75+1+1+1)\right] = \Delta(0.9375) = (s_4,-0.0625).$$

By Eq. (10) the weighted rating can be calculated as, ''Postsales service'' for example.

$$\overline{S}_4^w = \Delta\left[\frac{\Delta^{-1}(s_3,0.125)\cdot\Delta^{-1}(s_3,0)+\Delta^{-1}(s_3,0)\cdot\Delta^{-1}(s_3,-0.0625)+\Delta^{-1}(s_3,0.125)\cdot\Delta^{-1}(s_3,-0.0625)}{\Delta^{-1}(s_3,0)+\Delta^{-1}(s_3,-0.0625)+\Delta^{-1}(s_3,-0.0625)}\right]$$
$$= \Delta\left[\frac{0.875\cdot0.75+0.75\cdot0.6875+0.875\cdot0.6875}{0.75+0.6875+0.6875}\right] = \Delta(0.83456) = (s_3,0.08456).$$

And then foregoing outcomes are shown on the right-hand side of Table 4.

Step 5. According to values of the weighted rating and aggregated weighting of each criterion the overall performance level (OPL) of suppliers by Eq. (11) can be computed as follows:

$$OPL = \Delta\frac{\left(\Delta^{-1}(s_4,-0.0625)\times\Delta^{-1}(s_3,0.0625)+\Delta^{-1}(s_4,-0.0625)\times\Delta^{-1}(s_3,0.0221)+\Delta^{-1}(s_4,-0.125)\times\Delta^{-1}(s_3,0.079)+\Delta^{-1}(s_3,0.125)\times\Delta^{-1}(s_3,0.0846)\right)}{\left[\Delta^{-1}(s_4,-0.0625)+\Delta^{-1}(s_4,-0.0625)+\Delta^{-1}(s_4,-0.125)+\Delta^{-1}(s_3,0.125)\right]}$$
$$= \Delta\left(\frac{0.8125\times0.9375+0.7722\times0.9375+0.829\times0.875+0.8346\times0.875}{0.9375+0.9375+0.875+0.875}\right) = \Delta(0.8114) = (s_3,0.0614).$$

Compared with linguistic term set S, the obtained overall performance level (OPL) of suppliers is 2-tuple fuzzy linguistic information. If $i = j$ and $\alpha_i > \alpha_j$ then (s_i,α_i) is better than (s_j,α_j). The transformed value $(s_3,0.0614)$ represents slightly better than ''Promising'', $(s_3,0)$. Analyzing the results, such outcome intuitively makes sense that the final evaluation by the proposed approach is consistent with the overall performance measurement by four experts. Furthermore, according to the foregoing four questions that are expected to be answered, the initial inferences estimated by four experts, ''Promising'', "Perfect", ''Moderate'' and ''Promising'', can be perceived through the computation of their opinions. The mean estimation of experts by Eq. (4) is computed as

$$\overline{OPL} = \Delta[1/4(\Delta^{-1}(S_3,0)+\Delta^{-1}(S_4,0)+\Delta^{-1}(S_2,0)+\Delta^{-1}(S_3,0))] = \Delta[1/4(0.75+1+0.5+0.75)] = \Delta(0.75) = (S_3,0).$$

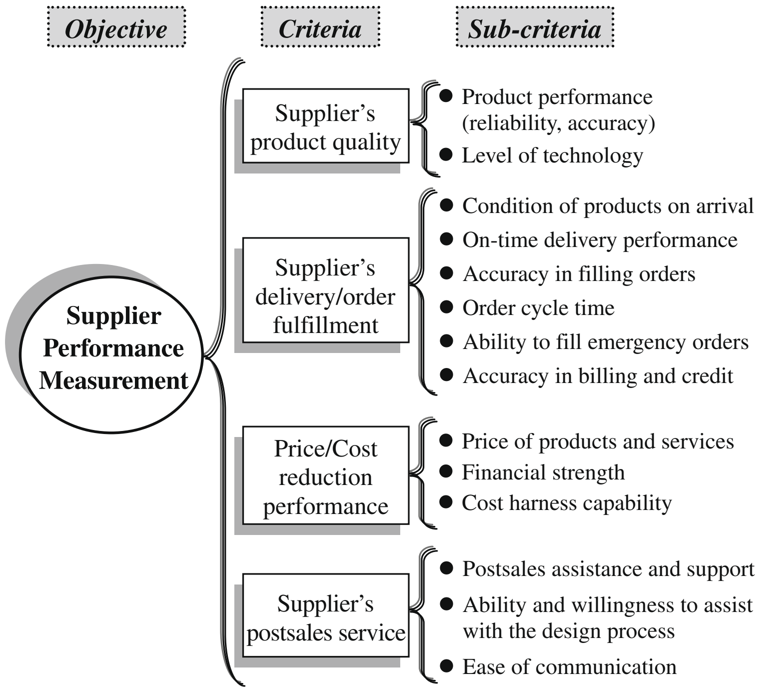

Fig. 6. Hierarchical structure of decision problem for the case company.

Table 2
Linguistic evaluations of each decision maker for each sub-criteria.

Criteria	Decision-makers			
	D_1	D_2	D_3	D_4
Product quality (PQ)				
C_{11}: Product performance (reliability, and accuracy)	H	VH	A	VH
C_{12}: Level of technology	VH	A	VH	H
Delivery/order fulfillment capability (DOFC)				
C_{21}: Condition of products on arrival	VH	A	VH	A
C_{22}: On-time delivery performance	VH	H	A	H
C_{23}: Accuracy in filling orders	A	H	VH	H
C_{24}: Order cycle time	H	VH	VH	A
C_{25}: Ability to fill emergency orders	VH	H	A	VH
C_{26}: Accuracy in billing and credit	A	A	VH	VH
Price/cost reduction performance (PCRP)				
C_{31}: Price of products and services	VH	VH	A	VH
C_{32}: Financial strength	VH	A	VH	H
C_{33}: Cost harness capability	A	H	VH	VH
Postsales service (PS)				
C_{41}: Postsales assistance and support	VH	H	H	VH
C_{42}: Ability and willingness to assist with the design process	A	VH	A	VH
C_{43}: Ease of communication	H	VH	VH	H

Analyzing 0.8114 and 0.75 of the β values, this slight difference emerged between expert opinions and the proposed method. The experts in the beginning roughed in the performance of suppliers by using the linguistic variables, $((s_3,0)$, $(s_4,0)$, $(s_2,0)$ and $(s_3,0))$ regarding the difference. Only if they described their own opinion with linguistic variables in depth, it takes much stock in the aggregated results will be approximated to the proposed approach. For example, their description may be between "Promising" and "Perfect" $((s_3,0.125))$, or much better than "Moderate" $((s_3,-0.05))$, and so on. Thus, the proposed approach shows the exceptional competence to deal with the interaction among criteria and their related sub-criteria, and to effectively obtain the appropriate overall performance evaluation level of suppliers which is consistent with the measurement by experts.

It can be seen that the evaluated supplier is superior on both criteria, "Price/Cost reduction performance" and "Postsales service" $((s_3,0.079)$ and $(s_3,0.0846))$. However, it is slightly weak in the "Delivery/order fulfillment capability" $((s_3,0.0222))$.

Table 3
Linguistic evaluations of importance of each criterion and corresponding sub-criteria.

Criteria	Decision-makers			
	D_1	D_2	D_3	D_4
Product quality (PQ)	VI	VI	VI	I
C_{11}: Product performance (reliability, and accuracy)	A	VI	A	A
C_{12}: Level of technology	I	I	A	A
Delivery/order fulfillment capability (DOFC)	I	VI	VI	VI
C_{21}: Condition of products on arrival	I	A	VI	VI
C_{22}: On-time delivery performance	A	I	A	I
C_{23}: Accuracy in filling orders	VI	VI	VI	I
C_{24}: Order cycle time	I	VI	I	A
C_{25}: Ability to fill emergency orders	VI	VI	VI	VI
C_{26}: Accuracy in billing and credit	I	VI	I	I
Price/cost reduction performance (PCRP)	VI	I	I	VI
C_{31}: Price of products and services	A	I	A	A
C_{32}: Financial strength	VI	A	VI	I
C_{33}: Cost harness capability	A	I	I	VI
Postsales service (PS)	I	VI	VI	I
C_{41}: Postsales assistance and support	I	I	I	I
C_{42}: Ability and willingness to assist with the design process	A	VI	A	I
C_{43}: Ease of communication	I	A	VI	A

Table 4
Aggregation results.

Criteria	Mean rating	Mean weighting	Weighted rating	Aggregated weighting
Product quality (PQ)				
C_{11}: Product performance (reliability, and accuracy)	$(S_3, 0.0625)$	$(S_2, 0.125)$	$(S_3, 0.0625)$	$(S_4, -0.0625)$
C_{12}: Level of technology	$(S_3, 0.0625)$	$(S_2, 0.125)$		
Delivery/order fulfillment capability (DOFC)				
C_{21}: Condition of products on arrival	$(S_3, 0)$	$(S_3, 0.0625)$	$(S_3, 0.0222)$	$(S_4, -0.0625)$
C_{22}: On-time delivery performance	$(S_3, 0)$	$(S_2, 0.125)$		
C_{23}: Accuracy in filling orders	$(S_3, 0)$	$(S_4, -0.0625)$		
C_{24}: Order cycle time	$(S_3, 0.0625)$	$(S_3, 0)$		
C_{25}: Ability to fill emergency orders	$(S_3, 0.0625)$	$(S_4, 0)$		
C_{26}: Accuracy in billing and credit	$(S_3, 0)$	$(S_3, 0.0625)$		
Price/cost reduction performance (PCRP)				
C_{31}: Price of products and services	$(S_3, 0.125)$	$(S_2, 0.0625)$	$(S_3, 0.079)$	$(S_4, -0.125)$
C_{32}: Financial strength	$(S_3, 0.0625)$	$(S_3, 0.0625)$		
C_{33}: Cost harness capability	$(S_3, 0.0625)$	$(S_3, 0)$		
Postsales service (PS)				
C_{41}: Postsales assistance and support	$(S_3, 0.125)$	$(S_3, 0)$	$(S_3, 0.0846)$	$(S_4, -0.125)$
C_{42}: Ability and willingness to assist with the design process	$(S_3, 0)$	$(S_3, -0.0625)$		
C_{43}: Ease of communication	$(S_3, 0.125)$	$(S_3, -0.0625)$		
Overall performance level (*OPL*)			$(S_3, 0.0614)$	

Furthermore, the main shortcoming of this supplier is ''Condition of products on arrival'', ''On-time delivery performance'', ''Accuracy in filling orders'', ''Accuracy in billing and credit'' and ''Ability and willingness to assist with the design process''. Consequently, this supplier must identify ways to improve the performance on these criteria. Manufacturer must assist this supplier by implementing supplier development programs on ''Delivery/order fulfillment capability'' and ''Postsales service'' simultaneously. On the other hand, the supplier should initiate its own training and development programs designed to improve performance on weak criteria.

6. Conclusions

Enterprises count on suppliers for a plethora of inputs. Suchlike suppliers can result in a tremendous impact on the firm's bottom line as significant resources are typically devoted to organizational procurement. Moreover, these suppliers can influence the perceptions that downstream consumers hold about the organization's products as well as the velocity with which products reach the market. Thus, it has become widely accepted that world-class procurement practices can provide a basis for securing a competitive advantage. With all the strategy concern, evaluating strategic suppliers should be an applicable mechanism for companies to collaborate for gaining the core vantage and guide the company in the face of the challenge in the future; likewise, it would advantage managers to effectively carry on and enhance current supplier's capabilities in the light of diverse performance level of criteria and related facets. Up to date, the criteria for assessing supplier performance in the supplier selection process have been widened. The main aim of this paper is to present a new methodology for evaluating and managing suppliers for the strategic partnership. The proposed 2-tuple fuzzy linguistic computing approach is capable of dealing with heterogeneous information and preventing information loss problems. In an attempt to harness the predicament, the proposed approach ministers to the managers in comprehending the performance of suppliers. As such, it takes advantage of 2-tuple fuzzy representation of linguistic variables to express the qualitative evaluation of measured criteria of experts' subjective opinions. Furthermore, 2-tuple fuzzy operation method effectively assists in dealing with the aggregation of rating and weighting among criteria. Particularly the proposed method provides companies with a flexible manner to experience the present situation of suppliers and to deal with the performance evaluation of suppliers in practical business environments.

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References

[1] C. Gencer, D. Gürpinar, Analytic network process in supplier selection: a case study in an electronic firm, Appl. Math. Model. 31 (2007) 2475–2486.
[2] J. Sarkis, S. Talluri, A model for strategic supplier selection, J. Supply Chain Manage. 38 (1) (2002) 18–28.
[3] C. Muralidharan, N. Anantharaman, S.G. Deshmukh, A multi-criteria group decision-making model for supplier rating, J. Supply Chain Manage. 38 (4) (2002) 22–33.
[4] C. Araz, P.M. Ozfirat, I. Ozkarahan, An integrated multicriteria decision-making methodology for outsourcing management, Comput. Oper. Res. 34 (2007) 3738–3756.
[5] M.A. Vonderembse, M. Tracey, The impact of supplier selection criteria and supplier involvement on manufacturing performance, J. Supply Chain Manage. 35 (3) (1999) 33–39.
[6] A.F. Guneri, A. Yucel, G. Ayyildiz, An integrated fuzzy-lp approach for a supplier selection problem in supply chain management, Expert Syst. Appl. 36 (5) (2009) 9223–9228.
[7] C.T. Chen, C.T. Lin, S.F. Huang, A fuzzy approach for supplier evaluation and selection in supply chain management, Int. J. Prod. Econ. 102 (2) (2006) 289–301.
[8] N. Bharadwaj, Investigating the decision criteria used in electronic components procurement, Ind. Market. Manage. 33 (2004) 317–323.
[9] R.C. Wang, S.J. Chuu, Group decision-making using a fuzzy linguistic approach for evaluating the flexibility in a manufacturing system, Eur. J. Oper. Res. 154 (3) (2004) 563–572.
[10] W.P. Wang, Toward developing agility evaluation of mass customization systems using 2-tuple linguistic computing, Expert Syst. Appl. 36 (2) (2009) 3439–3447.
[11] C.L. Hwang, K. Yoon, Multiple Attributes Decision Making Methods and Applications, Springer-Verlag, 1981.
[12] F. Herrera, L. Martinez, A 2-tuple fuzzy linguistic representation model for computing with words, IEEE Trans. Fuzzy Syst. 8 (6) (2000) 746–752.
[13] F. Herrera, L. Martinez, An approach for combining linguistic and numerical information based on 2-tuple fuzzy representation model in decision-making, Int. J. Uncertain. Fuzz. Knowl. -Based Syst. 8 (5) (2000) 539–562.
[14] E. Herrera-Viedma, E. Peis, Evaluating the informative quality of documents in SGML format from judgments by means of fuzzy linguistic techniques based on computing with words, Inform. Process. Manage. 39 (2) (2003) 233–249.
[15] E. Herrera-Viedma, O. Cordon, M. Luque, A.G. Lopez, A.M. Munoz, A model of fuzzy linguistic IRS based on multi-granular linguistic information, Int. J. Approx. Reason. 34 (2–3) (2003) 221–239.
[16] E. Herrera-Viedma, F. Herrera, L. Martinez, J.C. Herrera, A.G. Lopez, Incorporating filtering techniques in a fuzzy linguistic multi-agent model for information gathering on the web, Fuzzy Sets Syst. 148 (1) (2004) 61–83.
[17] T.Y. Choi, J.L. Hartley, An exploration of supplier selection practices across the supply chain, J. Oper. Manage. 14 (4) (1996) 333–343.
[18] R. Verma, M.E. Pullman, An analysis of the supplier selection process, Omega 26 (6) (1998) 739–750.
[19] C.T. Lin, Y.T. Chen, Bid/no-bid decision-making – a fuzzy linguistic approach, Int. J. Project Manage. 22 (7) (2004) 585–593.
[20] L.A. Zadeh, The concept of a linguistic variable and its application to approximate reasoning, Inform. Sci. 8 (pt. I) (1975) 199–249 (pt. II) 301–357.
[21] E.E. Karsak, E. Tolga, Fuzzy multi-criteria decision-making procedure for evaluating advanced manufacturing system investments, Int. J. Prod. Econ. 69 (1) (2001) 49–64.
[22] R.R. Yager, An approach to ordinal decision making, Int. J. Approx. Reason. 12 (3–4) (1995) 237–261.
[23] H.J. Zimmermann, Fuzzy Set Theory and its Applications, second ed., Kluwer Academic Publishers, 1991.
[24] C.T. Chen, W.S. Tai, Measuring the intellectual capital performance based on 2-tuple fuzzy linguistic information, in: Proceedings of the 10th Annual Meeting of Asia Pacific Region of Decision Sciences Institute, APDSI, Taiwan, 2005.