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Evaluating new product development performance by fuzzy linguistic computing

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ABSTRACT

New product development (NPD) is indeed the cornerstone for companies to maintain and enhance the competitive edge. However, developing new products is a complex and risky decision-making process. It involves a search of the environment for opportunities, the generation of project options, and the evaluation by different experts of multiple attributes, both qualitative and quantitative. To perceive and to measure effectively the capability of NPD are real challenging tasks for business managers. This paper presents a 2-tuple fuzzy linguistic computing approach to deal with heterogeneous information and information loss problems during the processes of subjective evaluation integration. The proposed method which is based on the group decision-making scenario to assist business managers to measure the performance of NPD manipulates the heterogeneous integration processes and avoids the information loss effectively. Finally, its feasibility is demonstrated by the result of NPD performance evaluation for a high-technology company in Taiwan.

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1. Introduction

Product design has been long recognized as an opportunity for differential advantage in the market place. A number of companies successfully focus on product design as a competitive tool (Creusen & Schoormans, 2005). Nowadays, more requirements for enterprises have been put forward, such as more product variety, shorter time-to-market, lower product cost and higher quality. The globalization of competition in the manufacturing industry and the diversification of customers' demands as well as rapid technological developments continue to spur technology-based innovations at a frenetic pace. Product design innovation therefore has developed quickly and has gradually become one of mainstream production modes of manufacturing industries in the 21st century. Therefore, improving product development performance is becoming increasingly important and challenging.

New product development (NPD) is undeniably vital in determining the economic success of manufacturing companies. Firms need to create and sustain competitive advantages in order to survive in today's highly competitive business environment. One major determinant of sustaining competitive advantage is the ability of the firms to develop and launch successful new products. Differentiation through NPD is therefore one of the most effective strategies for achieving success. As competition in global markets has become intense, firms have begun to recognize the importance of NPD and innovation issues. Through innovation and the introduction of new products, new markets and growth possibilities can be created. Increasing international competition accentuates the importance of the NPD process which is secure and accurate (Ozer, 2005; Sherman, Berkowitz, & Souder, 2005). Gemser and Leenders (2001) conclude that being innovative with respect to design and design strategy can enhance competitiveness regardless of industry evolution. Timely, correct and responsive NPD has become even more critical in the highly competitive global environment. The need to respond quickly to these dynamic global market forces requires the firm to establish a specialized evaluation mechanism and platform for NPD performance.

However, the decision-making domain of NPD is highly complex and uncertain due to a demanding environment characterized by increased globalization and segmentation of markets, increased levels of product complexity, changing customer needs, and shorter product life cycles (Belecheanu, Pawar, Barson, Bredehorst, & Weber, 2003). New product introduction in today's technology-driven markets carries significant risk. New product failure rates can be as low as one of every three products or as high as the 90% of new grocery products which are withdrawn within a year of their introduction. New technology, improved communications, increased profit demands and shorter product life cycles have added to the inherent risk. Yet, without the introduction of new products, deterioration of the firm's market position is inevitable. Without new products, firms will inevitably stagnate (Yelkur & Herbig, 1996). In order to evaluate the performance of NPD more appropriately, the firms should consider not only quantitative index but also qualitative dimensions or factors which are evaluated by multiple decision-makers or experts. Thus, the evaluation of NPD performance should be regarded as a group multiple criteria decision-making problem as well.

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Experts devote themselves to judge the NPD performance measurement by their experiential cognition and subjective perception in the decision-making process. However, there exists a considerable extent of uncertainty, fuzziness and heterogeneity (Hwang & Yoon, 1981). This is not a seldom situation. In addition, it is prone to information loss happening during the integration processes, and gives rise to the evaluation result of the performance level which may not be consistent with the expectation of the evaluators. Consequently, developing an easy way to calculate the performance ratings while the processes of evaluation integration and to manipulate the operation of qualitative factors and expert judgment appropriately in the evaluation process of NPD could brook no delay. In this paper we propose a suitable model based on 2-tuple fuzzy linguistic information to evaluate the NPD 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 (Herrera-Viedma, Herrera, Martinez, Herrera, & Lopez, 2004).

This paper is organized as follows. In Section 2 the measurement dimensions of NPD are described. 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. In Section 4a NPD performance measurement method based on 2-tuple fuzzy linguistic information is proposed . The proposed model is then illustrated with an example for a high-technology company in Taiwan. In Section 5 conclusion is given.

2. Literature review

A contemporary NPD process usually consists of hundreds or thousands of activities, where the activities may be dependent or interdependent on one another. A rapidly changing competitive landscape and dynamic customer expectations require manufacturers to seek flexibility in product development. Unlike the manufacturing processes, product development is a creative and discovering process that tends to create something new from trial-and-error and learning from the errors made (Wang & Lin, forthcoming). The purpose of NPD is to accumulate the knowledge and capability necessary to determine an appropriate new product. Superior product design, potential for breakthrough innovation, low project and product cost, shorter lead time, better communication of cross-functional teamwork, and increased customer satisfaction and market share are among many other advantages for successful NPD. Suchlike concerns enable firms in making NPD decisions while ensuring full knowledge of the customer, the technology, and with the team's support. In view of this, a performance evaluation method or approach that is capable of systematically analyzing and accurately quantifying those subjective experiences and judgments of the NPD team is highly required.

Ozer (2005) indicated that the quality of new product evaluation decisions is affected by four major sets of factors, namely the nature of the task, the type of individuals who are involved in the decisions, the way the individuals' opinions are elicited and the way the opinions are aggregated. The main drivers of NPD include: quality and speed to market; widening customer choice and expectation; competitive priorities of responsiveness, delivery, flexibility, concern for the environment and international competitiveness. For example, Wang and Lin (forthcoming) pointed out that the introduction timing of new products is important for high-technology industries to gain premium pricing and higher sales volume. A NPD project in nature should possess four latent abilities: delivering value to the customer; being ready for change; valuing human knowledge and skills; and forming virtual partnerships (McCurry & McIvor, 2002).

NPD is thus a key factor for survival for business firms. Most of the fast-growing companies achieve above 50% of their total sales from the new products developed within 5 years (Lee, Lee, Koo, & Yan, 1996). Not only is the technology changing rapidly, but the process of the commercialization of technological change–the industrial innovation process–is also changing. Nowadays due to the increasingly competitive climate, more and more managers are forcing themselves to update on the range of factors that determine product innovation success. Takeuchi and Nonaka (1986) indicated that all profits of new products would account for 30–40% of total sales. Griffin (1997) represented a substantial anticipated increase in the profit impact of new products. Sales from establishments which were part of the business five years earlier represented 32.4% of total annual sales. Especially, high-technology industries attained a great percentage of 42.3% and this increased continuously. Even so, the average failure rate of new products also reached a great percentage of 41%. In sum, the firms are in urgent need of developing a specialized NPD performance evaluation mechanism and platform for their effective management and for enhancing business competitiveness further.

It is however difficult and laborious to measure NPD performance using traditional crisp value directly as the process of NPD performance measurement possesses many intangible or qualitative factors and items. Linguistic variable representation is therefore favorable for experts to express and evaluate the ratings of NPD under such a situation. The fundamentals of 2-tuple fuzzy linguistic approach are to apply linguistic variables to stand for the difference of degree and to carry out processes of computing with words easier and without information loss during the integration procedure (Herrera-Viedma et al., 2004). That is to say, decision participants 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. Fuzzy linguistic computing approach

Many aspects of different activities in a real world cannot be assessed in a quantitative form, but rather in a qualitative one, i.e., with vague or imprecise knowledge. Whereas characteristics of the fuzziness and vagueness are inherent in various decision-making problems, a proper decision-making approach should be capable of dealing with vagueness or ambiguity (Yager, 1995). Fuzzy set theory is a very feasible method to handle the imprecise and uncertain information in a real world. Especially, it is more suitable for subjective judgment and qualitative assessment in the evaluation processes of decision making than other classical evaluation methods applying crisp values (Lin & Chen, 2004; Wang & Chuu, 2004). Basic definitions and concepts of fuzzy sets are briefly reviewed as follows; and further, notations given below will be used throughout the paper until otherwise stated.

3.1. Fuzzy number

A positive triangular fuzzy number (PTFN) $\widetilde{A}$ can be denoted as $\widetilde{A} = (a, b, c)$, where $a \leqslant b \leqslant c$ and $a > 0$, which are illustrated in Fig. 1. The membership function, $\mu_{\widetilde{A}}(x)$, is defined as (Zimmermann, 1991)

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

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

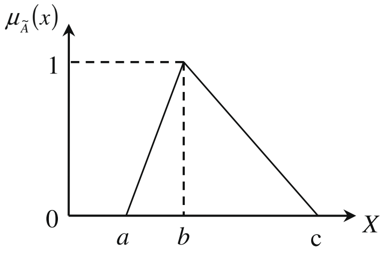

Fig. 1. Illustration of a triangular fuzzy number $\widetilde{A}$.

bers appear as useful means of quantifying the uncertainty in decision making due to their intuitive appeal and computationally efficient representation (Karsak & Tolga, 2001; Wang, 2009).

3.2. Linguistic variable

A linguistic variable is a variable whose values are expressed in linguistic terms. In other words, variable whose values are not numbers but words or sentences in a nature or artificial language. 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 in 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 developed presently to aggregate information. The fuzzy linguistic approach represents qualitative aspects as linguistic values by means of linguistic variables (Herrera-Viedma & Peis, 2003; Zadeh, 1975).

3.3. 2-Tuple fuzzy linguistic term

For identifying the diversity of each evaluation component and facilitating the computation, linguistic terms often possess some characteristics such as finite set, odd cardinality, semantic symmetric, ordinal level and compensative operation. They are capable of representing the diversity of degree instead of traditional crisp value in qualitative evaluation processes in nature (Herrera-Viedma, Cordon, Luque, Lopez, & Munoz, 2003).

The linguistic information with a pair of values is called 2-tuple that is composed of a linguistic term and a number (Herrera & Martinez, 2000a, 2000b). The main advantage of this representation is its being 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 $\alpha$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:

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

It means that a linguistic term set S contains five linguistic terms, "Very Low" "Low", "Average", "High", and "Very High", which are denoted as 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 in 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.

3.4. Transformation of 2-tuple linguistic variable

A crisp value β whose value belongs to interval $[0, 1]$ will be obtained after aggregating the result of evaluation using the linguistic variable set S (Herrera & Martinez, 2000a). 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

$$\Delta : [0, 1] \rightarrow S \times \left[-\frac{1}{2g}, \frac{1}{2g}\right)$$

$$\Delta(\beta) = (s_i, \alpha) \text{ with } \begin{cases} s_i, & i = round(\beta \cdot g) \\ \alpha = \beta - \frac{i}{g}, & \alpha \in \left[-\frac{1}{2g}, \frac{1}{2g}\right) \end{cases} \tag{2}$$

where $\beta \in$ is $[0,1]$. 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-tuple (s_i, α), $s_i \in S$. The interval of value α is derived from the number of linguistic terms. For example, if S contains five linguistic terms then ($g = 4$ and $\alpha \in$ is $[-0.125, 0.125]$.

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

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

where Δ^{-1} signifies a reverse equation for converting the 2-tuple linguistic variable into a crisp value β (see Figs. 3 and 4).

3.5. Operation of 2-tuple linguistic variable

Suppose $L_1 = (s_1, \alpha_1)$ and $L_2 = (s_2, \alpha_2)$ are two 2-tuple linguistic variables. The main algebraic operations are shown as follows [8]:

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

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

3.5.1. Arithmetic mean

Symbolic translation functions, Δ and Δ^{-1}, are applied in the process of information aggregation to guarantee that the aggregation of 2-tuple linguistic variables can be a 2-tuples 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 $\overline{S}$ can be calculated as

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

3.5.2. 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, the 2-tuple linguistic weighted average $\overline{S}^w$ can be computed as

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

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

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

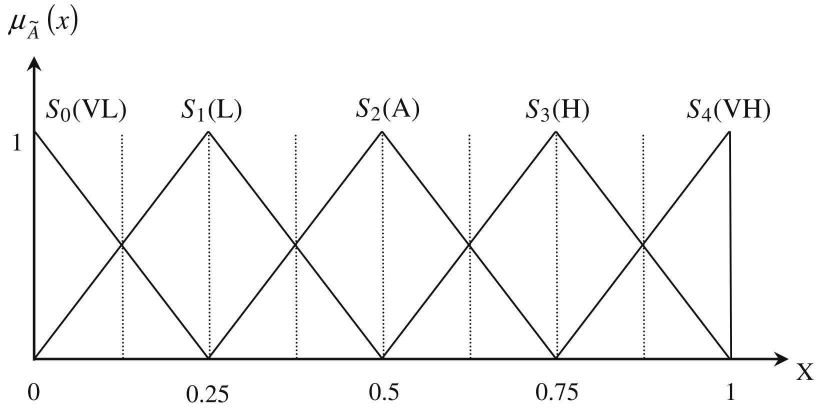

Fig. 2. Linguistic term set of five labels with its semantics.

3.5.3. Comparison of linguistic information

The comparison of linguistic information represented by 2-tuples is carried out according to an ordinary lexicographic order. Let (s_i,α_i) and (s_j,α_j) be two 2-tuple linguistic variables, with each one representing a counting of information as follows:

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.

Both comparison and aggregation operators for 2-tuple linguistic computation are descried as follows (Herrera-Viedma et al., 2004).

4. 2-Tuple fuzzy linguistic NPD performance evaluation model

Establishing an applicable NPD performance evaluation mechanism is obviously very important for firms even as the foregoing. However, in a real business environment, most of the NPD performance measurements are intangible and there is a lack of precise value to gauge their performance. Linguistic variables are appropriate for managers or experts to evaluate the level of NPD in suchlike predicaments. Therefore, linguistic variables are applied to describe the importance of all criteria and ratings of evaluation items with respect to each criterion in this paper. A 2-tuple evaluation model in accordance with concepts of fuzzy linguistic computing approach is proposed in this paper to measure the performance level of NPD for a practical company.

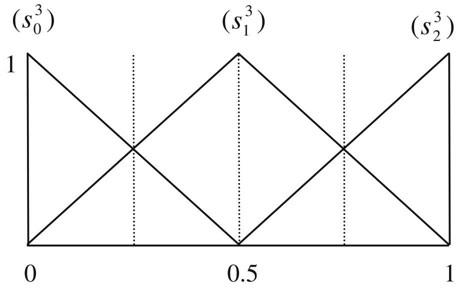

Fig. 3. Linguistic term set of three labels with its semantics.

Assume that there are n criteria C_i $(i = 1,2,\ldots,n)$ and each criterion contains several elements in an evaluation framework of NPD performance. For practical implementation, the procedure of this proposed evaluation approach is summarized as follows.

Step 1. Selective categories of linguistic terms in Table 1 are prepared for experts when they apply the linguistic importance variables to represent the weight of each criterion and employ the linguistic rating variables to evaluate the performance of elements with respect to each criterion.

Step 2. Aggregation of the fuzzy linguistic evaluations generated by N experts for each criterion is as follows:

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

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

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

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

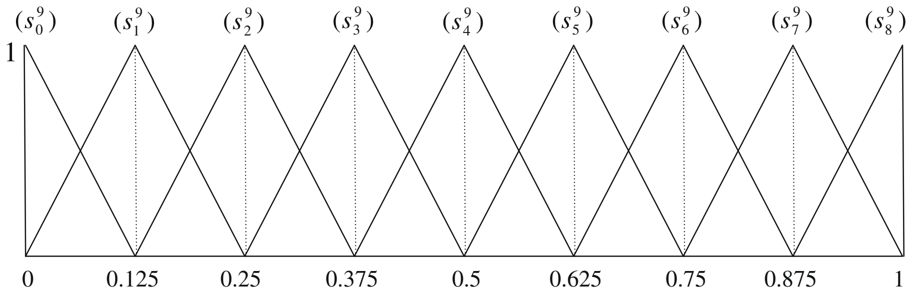

Fig. 4. Linguistic term set of nine labels with its semantics.

Table 1
Selective category of linguistic terms for experts.

Type	Number of linguistic	Linguistic variable	Illustration
A	3	Poor (s_0^3), average (s_1^3), good (s_2^3)	Shown in Fig. 3
B	5	Very poor (s_0^5), very poor (s_1^5), poor (s_2^5), average (s_3^5), good (s_4^5)	Shown in Fig. 2
C	7	Extremely poor (s_0^7), very poor (s_1^7), poor (s_2^7), average (s_3^7), good (s_4^7), very good (s_5^7), extremely good (s_6^7)	Shown in Fig. 4

Step 3. Applying Eq. (6) to obtain the fuzzy aggregated rating of $C_i(\bar{S}_i)$;

$$\bar{S}_i^w = \Delta\left(\frac{\sum_{j=1}^{l_i} \Delta^{-1}\beta_{ij} \cdot \beta_{ij}^w}{\sum_{j=1}^{l_i} \beta_{ij}^w}\right) = (s_i^w, \alpha_i^w)$$

with $\beta_{ij} = \Delta^{-1}(r_{ij}, \alpha_{ij})$ and $\beta_{ij}^w = \Delta^{-1}(w_{ij}, \alpha_{ij}^w)$

Step 4. By computing the overall performance level (OPL) of NPD, the linguistic term s_T, can be applied to represent the control and management performance level of NPD as well as being the improvement index directly,

$$OPL = \Delta\left(\frac{\sum_{i=1}^{n} \beta_i \cdot \beta_{w_i}}{\sum_{i=1}^{n} \beta_{w_i}}\right) = (s_T, \alpha_T)$$

with $\beta_i = \Delta^{-1}(r_i, \alpha_i)$ and $\beta_{w_i} = \Delta^{-1}(w_i, \alpha_{w_i})$

5. Exemplification

A real electronic manufacturing company founded in 1997 in the Neihu District of Taipei, Taiwan is selected to verify the proposed NPD performance evaluation approach. It is a fabulous IC components company with high-caliber professionals specialized in designing and manufacturing, and supplies leading edge, high-performance memory products and memory-intensive logic products to numerous high-growth and performance- demanding markets. It has been in operation for eleven years, employs approximately 100 employees, as well as its annual sales are approximately \$7 million. 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 firm continues to serve these diverse market segments by utilizing and adapting its innovative design methodologies, advanced CMOS process technologies, and loyal manufacturing relationships to provide state-of-the-art, and cost-effective products that meet diverse application needs.

After preliminary sifting the related information carefully and the above-mentioned literature on NPD, an expert committee of four decision-makers, D_1, D_2, D_3 and D_4 had been formed to conduct the evaluation of NPD performance for the company. At the outset, they make their individual opinion in accordance with their knowledge, expertise, as well as experience to infer the overall performance level of NPD for the case company. The inferences are ”Good”, “Good”, “Average” and “Good”, respectively. In addition, four types of concerned criteria and their corresponding elements drew forth advanced measurement, and are shown in Fig. 5.

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

Step 1. The four decision-makers choose one kind of linguistic variables from the selective categories, say a five-term linguistic variable, to determine the importance of each criterion and the performance of each element with respect to each criterion. The rating outcome is shown in Tables 2 and 3.

Step 2. The 2-tuple fuzzy linguistic aggregation method is employed to compute fuzzy evaluation and weighting value of each element. For example, fuzzy rating and weighting value of element ”Quality and speed to market” with respect to criterion “market-related” are computed as

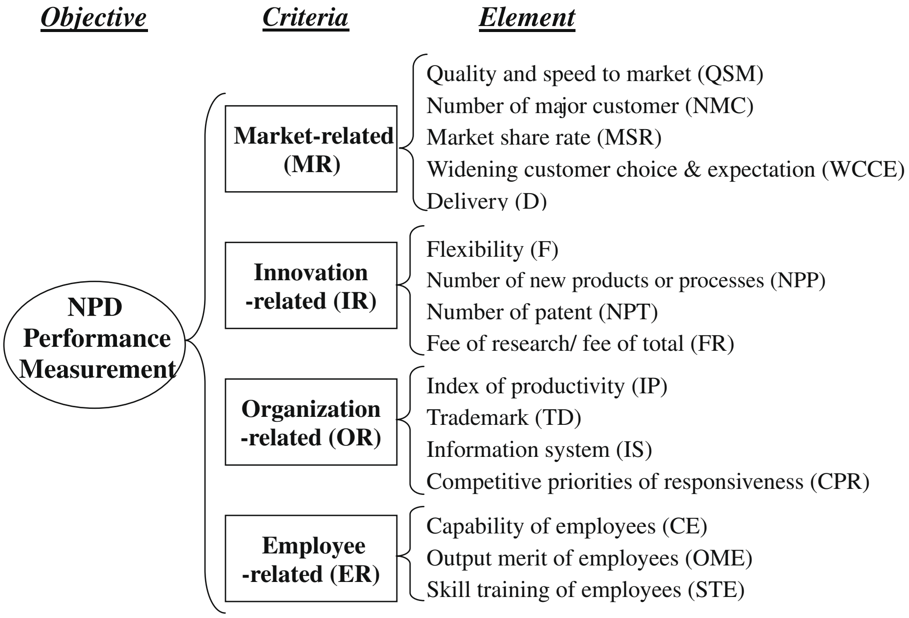

Fig. 5. Hierarchy of the illustrated example.

Table 2
Linguistic evaluations of each decision-maker for each criterion and elements.

Criteria		Decision-makers			
		D_1	D_2	D_3	D_4
Market-related (MR)					
Element	Quality and speed to market (QSM)	G	VG	A	VG
	Number of major customer (NMC)	VG	A	VG	G
	Market share rate (MSR)	G	VG	G	G
	Widening customer choice and expectation (WCCE)	VG	G	A	VG
	Delivery (D)	A	A	VG	VG
Innovation-related (IR)					
Element	Flexibility (F)	VG	A	VG	A
	Number of new products or processes (NPP)	VG	G	A	G
	Number of patent (NPT)	A	G	VG	G
	Fee of research/fee of total (FR)	G	VG	VG	A
Organization-related (OR)					
Element	Competitive priorities of responsiveness (CPR)	VG	VG	A	VG
	Trademark (TD)	G	VG	G	G
	Information system (IS)	VG	A	VG	G
	Index of productivity (IP)	A	G	VG	VG
Employee-related (ER)					
Element	Capability of employees (CE)	VG	G	G	VG
	Output merit of employees (OME)	A	VG	A	VG
	Skill training of employees (STE)	G	VG	VG	G

Table 3
Linguistic evaluations of importance of each criterion and corresponding elements.

Criteria		Decision-makers			
		D_1	D_2	D_3	D_4
Market-related (MR)		VI	VI	VI	I
Element	Quality and speed to market (QSM)	VI	VI	VI	I
	Number of major customer (NMC)	A	VI	A	A
	Market share rate (MSR)	I	I	A	A
	Widening customer choice and expectation (WCCE)	I	I	VI	I
	Delivery (D)	VI	VI	VI	VI
Innovation-related (IR)		I	I	VI	I
Element	Flexibility (F)	I	VI	VI	VI
	Number of new products or processes (NPP)	I	A	VI	VI
	Number of patent (NPT)	A	I	A	I
	Fee of research/fee of total (FR)	VI	VI	VI	I
Organization-related (OR)		VI	I	VI	I
Element	Competitive priorities of responsiveness (CPR)	VI	I	I	VI
	Trademark (TD)	A	I	A	A
	Information system (IS)	VI	VI	I	VI
	Index of productivity (IP)	VI	A	VI	I
Employee-related (ER)		I	A	I	I
Element	Capability of employees (CE)	I	VI	VI	I
	Output merit of employees (OME)	I	I	I	I
	Skill training of employees (STE)	A	VI	A	I

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

And the computational results are shown in Table 4.

Step 3. The aggregated weighting value of each criterion can be calculated as follows, "market-related" for example.

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

The weighted rating can be calculated as, "market-related" for example.

$$\begin{aligned}\bar{S}_4^w &= \Delta\left[\frac{\Delta^{-1}(s_3,0.125)\cdot\Delta^{-1}(s_3,0)+\Delta^{-1}(s_3,0)\cdot\Delta^{-1}(s_3,-0.0625)+\Delta^{-1}(s_3,0.125)\cdot\Delta^{-1}(s_3,-0.0625)}{\Delta^{-1}(s_3,0)+\Delta^{-1}(s_3,-0.0625)+\Delta^{-1}(s_3,-0.0625)}\right]\\ &= \Delta\left[\frac{0.875\cdot 0.75+0.75\cdot 0.6875+0.875\cdot 0.6875}{0.75+0.6875+0.6875}\right] = \Delta(0.8456) = (s_3,0.0846)\end{aligned}$$

Table 4
Aggregation results.

Criteria	Mean rating	Mean weighting	Weighted rating	Aggregated weighting
Market-related (MR)				
Quality and speed to market (QSM)	$(s_3, 0.0625)$	$(s_2, 0.125)$	$(s_3, 0.0494)$	$(s_4, -0.0625)$
Number of major customer (NMC)	$(s_3, 0.0625)$	$(s_2, 0.125)$		
Market share rate (MSR)	$(s_3, 0.0625)$	$(s_3, 0.0625)$		
Widening customer choice and expectation (WCCE)	$(s_3, 0.0625)$	$(s_4, 0)$		
Delivery (D)	$(s_3, 0)$	$(s_3, 0.0625)$		
Innovation-related (IR)				
Flexibility (F)	$(s_3, 0)$	$(s_3, 0.0625)$	$(s_3, 0.015)$	$(s_4, -0.0625)$
Number of new products or processes (NPP)	$(s_3, 0)$	$(s_2, 0.125)$		
Number of patent (NPT)	$(s_3, 0)$	$(s_4, -0.0625)$		
Fee of research/fee of total (FR)	$(s_3, 0.0625)$	$(s_3, 0)$		
Organization-related (OR)				
Competitive priorities of responsiveness (CPR)	$(s_3, 0.125)$	$(s_2, 0.0625)$	$(s_3, 0.074)$	$(s_4, 0)$
Trademark (TD)	$(s_3, 0.0625)$	$(s_4, -0.0625)$		
Information system (IS)	$(s_3, 0.0625)$	$(s_3, 0.0625)$		
Index of productivity (IP)	$(s_3, 0.0625)$	$(s_3, 0)$		
Employee-related (ER)				
Capability of employees (CE)	$(s_3, 0.125)$	$(s_3, 0)$	$(s_3, 0.0846)$	$(s_3, 0.125)$
Output merit of employees (OME)	$(s_3, 0)$	$(s_3, -0.0625)$		
Skill training of employees (STE)	$(s_3, 0.125)$	$(s_3, -0.0625)$		

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

Step 4. According to the values of the weighted rating and aggregated weighting of each criterion the overall performance level (*OPL*) of NPD is computed as follows as

$$
\begin{aligned}
OPL &= \Delta \frac{\left(\Delta^{-1}(s_3, 0.0494) \cdot \Delta^{-1}(s_4, -0.0625) + \Delta^{-1}(s_3, 0.015) \cdot \Delta^{-1}(s_4, -0.0625) + \Delta^{-1}(s_3, 0.074) \cdot \Delta^{-1}(s_4, 0) + \Delta^{-1}(s_3, 0.0846) \cdot \Delta^{-1}(s_3, 0.125)\right)}{\left[\Delta^{-1}(s_4, -0.0625) + \Delta^{-1}(s_4, -0.0625) + \Delta^{-1}(s_4, 0) + \Delta^{-1}(s_3, 0.125)\right]} \\
&= \Delta\left(\frac{0.7994 \cdot 0.9375 + 0.765 \cdot 0.9375 + 0.824 \cdot 1 + 0.8346 \cdot 0.875}{0.9375 + 0.9375 + 1 + 0.875}\right) \\
&= \Delta(0.8056) = (s_3, 0.0556)
\end{aligned}
$$

In contrast with linguistic term set *S*, the obtained overall performance level (*OPL*) of NPD is 2-tuple fuzzy linguistic information. The transformed value $(s_3, 0.0846)$ represents slightly better than “Good”. Such outcome intuitively makes sense in that the final evaluation by the proposed approach is consistent with the overall performance measurement by the four experts. Furthermore, the initial inferences estimated by the four experts, “Good”, “Good”, “Average” and “Good”, can be perceived through the computation of their opinions. The mean measurement is computed as

$$
\begin{aligned}
\overline{OPL} &= \Delta\left[\frac{1}{4}\left(\Delta^{-1}(s_3, 0) + \Delta^{-1}(s_3, 0) + \Delta^{-1}(s_2, 0) + \Delta^{-1}(s_3, 0)\right)\right] \\
&= \Delta\left[\frac{1}{4}(0.75 + 0.75 + 0.5 + 0.75)\right] = \Delta(0.6563) \\
&= (s_3, -0.0938)
\end{aligned}
$$

The β values, 0.8056 and 0.6563, caused a difference moderately between the proposed method and expert opinions. In regard to the difference, the experts in the beginning roughed in the performance of NPD by using the linguistic variables, $((s_3, 0)$, $(s_3, 0)$, $(s_2, 0)$ and $(s_3, 0))$. Only if they described their own opinion with linguistic variables in depth, it takes much stock in the aggregated results which will be approximated to the proposed approach. For example, their description may be between ”Average” and “Good” $(s_2, 0.125)$, or much better than ”Good” $(s_4, -0.05)$, and so on. Consequently, the proposed approach shows the exceptional competence to deal with the interaction among criteria and their related elements, and to effectively obtain the appropriate overall performance evaluation level of NPD which is consistent with the measurement by experts.

6. Conclusions

Differentiation through NPD is one of the most effective strategies for achieving success. Obviously NPD is a key factor for survival for business firms in drastic conditions. With all the strategy concern, NPD evaluation model should be an applicable mechanism for companies to explore the core vantage and guide the company in the face of the challenge in the future; likewise, it would be advantageous for managers to effectively carry on and enhance current NPD mode in the light of diverse performance levels of criterion and related considerations. This paper presents a fuzzy linguistic computing approach to deal with heterogeneous information, and information loss problems that are to be averted. The proposed approach ministers to the managers in comprehending the performance of NPD. Especially it takes advantage of 2-tuple fuzzy representation of linguistic variables to express the qualitative evaluation of measured criteria of experts' subjective opinions. Also, 2-tuple fuzzy operation method effectively assists in dealing with the aggregation of rating and weighting among criteria. Particularly the proposed method supplies companies with a flexible manner to perceive the present situation of NPD and to handle the performance evaluation decisions of NPD in a practical business environment.

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