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A PROPORTIONAL 3-TUPLE FUZZY LINGUISTIC REPRESENTATION MODEL FOR SCREENING NEW PRODUCT PROJECTS

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Abstract

It is critically important for companies to screen new product projects before they are launched to the market. So far, many approaches have been developed for tackling the process of screening product innovations. Due to uncertain, vague and incomplete information as well as dynamically complex process regarding to new product development (NPD), a fuzzy linguistic approach employed linguistic assessments and the fuzzy-set-based computation is reasonable for screening new products. However, such a fuzzy linguistic approach faces with various defects and limitations, such as loss of information, failing in considering the aspects related to human nature on uncertain subjective judgments etc. These defects and limitations lead to a dilemma, i.e., it's very difficult to screen new product projects reasonably and precisely. In this paper, we propose a notion of proportional 3-tuple to represent a linguistic assessment and related ignoring information, and a preference-preserving proportional 3-tuple transformation for the unification of linguistic assessments represented by proportional 3-tuples between two different linguistic term sets. On this basis, a proportional 3-tuple fuzzy linguistic representation model for screening new product projects is developed. It is shown that the proposed model is flexible to handle uncertain, vague and incomplete information related to screening new product projects. It not only allows evaluators to express their subjective judgments with different confidence levels, but is also able to deal with incomplete linguistic assessments. Ultimately, the proposed model also improves the precision and reasonability of the screening result.

Keywords: Confidence levels, ignoring information, linguistic modeling, proportional 3-tuple, screening new product projects

1. Introduction

New product development (NPD) is a dynamically complex and multistage process that ranges from idea generation through product launch (Cooper & Kleinschmidt 1986, Ozer 1999), including strategy, organization, concept generation, product and marketing plan creation and evaluation, and commercialization (Belliveau et al. 2002, Craig & Hart 1992). Under the cruel context of intense global competition, rapid change in technology, and a dynamic economic situation, it is widely recognized that effective NPD process has become one of the most causally important strategies of companies in surviving and generating long-term competitive success (Brentani 1989, Griffin 1997, Wheelwright & Clark 1995). This is rooted in the fact that new products are a major contributor to the growth and profitability of a company, and provide access to new markets.

As noted by Cooper (1981), companies typically have more new product ideas than money to develop them all. Although ideas for new products may be generated inexpensively, as NPD projects move towards commercialization, however, the costs generally increase dramatically (Calantone et al. 1999, Lin & Chen 2004a, Page 1993); even higher are the costs of the consequences of a possible failure (Cooper 2000, Schmidt & Calantone 1998, Urban & Hauser 1993). In fact, due to inevitable consequence of volatile markets, changing customer preferences, increasingly competition, lacking of sufficient information, or more often the information is imprecise, inconsistent and uncertain, NPD is a dynamically complex process with high-risk rate of failure, which often leads to substantial monetary and non-monetary losses (Brentani 1986, Cooper 1990, Deimancescu & Dwenger 1996). Cooper et al. (1983, 2004) reported that the NPD project failure rate was mostly above one-third. In such situation, screening new product projects becomes the first critical evaluation in the NPD process before a company launching a successful new product (Calantone et al. 1999, Lin & Chen 2004b). Hence, there is an increasing emphasis raised by both researchers and practitioners to dramatically enhance screening new product projects in NPD process.

Screening new product projects is a very complicated problem. One of the main reasons is that evaluators have to cater for many interrelated criteria of both quantitative and qualitative nature in a rational way simultaneously, especially under the context of uncertainty. Another main reason is related to human nature. Evaluators often lack confidence when they supply subjective judgments. This probably results from the reality that evaluations have to be conducted on the basis of both precise numbers and subjective judgments that are imprecise, vague and incomplete in nature. Such uncertainties can be incurred and lead to incomplete evaluation results due to a lack of evidence and understanding or human's inability of providing accurate judgments on the evaluation process (Chin et al. 2009).

So far, many approaches have been developed for tackling the process of screening new product projects, such as factor-weighting techniques, analytic hierarchy process, screening regression models (Rangaswamy & Lilien 1997), fuzzy-logic-based approach (Lin & Chen 2004b), 2-tuple fuzzy linguistic based evaluation model (Huynh & Nakamori 2011) and so on. Concerning incomplete and uncertain information, as well as qualitative nature of most evaluation criteria related to NPD process, a fuzzy linguistic approach employed linguistic assessments and the fuzzy-set-based computation is reasonable for screening new product projects. However, as we can see from fuzzy-logic-based approach, it faces with various defects and limitations, such as loss of information caused by the process of linguistic approximation (Carlsson & Fullér 2000). Although 2-tuple fuzzy linguistic based evaluation model solves the limitation of loss of information, it cannot deal with the screening situations in which linguistic assessments are uncertain and incomplete. Due to the facts that the uncertainty may be assigned not only to any single evaluation grade but also to their rational combinations (Yang & Sen 1994) and evaluators might not be enough confident to always supply complete subjective assessments facing with incomplete and uncertain information, it is very difficult to screen new product projects reasonably and precisely without considering these aspects.

In this paper, we propose a notion of proportional 3-tuple, which is designed for representing a linguistic assessment from the perspective of reflecting human nature on uncertain subjective judgment to deal with the problems mentioned above. In this paper, only qualitative criteria of screening new product projects will be taken into account, although quantitative criteria would also be included in a similar way. Specifically, evaluators provide subjective judgments which are represented by the so-called proportional 3-tuples towards qualitative criteria. A proportional 3-tuple consists of two consecutive linguistic terms with probabilities from a linguistic term set, and a numerical value. Two consecutive linguistic terms together with probabilities constitute the given information, while the numerical value represents the extent of ignoring information that evaluator cannot provide because of incomplete and uncertain information. In this way, evaluators can express their complete and incomplete subjective judgments with different confidence levels. This will be discussed in Section 3.1 in detail. In the sequel, we also propose a so-called preference-preserving proportional 3-tuple transformation so that we can transform a proportional 3-tuple between two different linguistic term sets without loss of information. Thus, we have an instrument to unify the criteria with inhomogeneous nature, and a requisite for developing a proportional 3-tuple fuzzy linguistic representation model for screening new product projects.

The rest of this paper is organized as follows. In section 2, we make a brief review of some preliminaries about fuzzy-logic-based approach and 2-tuple fuzzy linguistic based evaluation model. In section 3, after introducing the notion of proportional 3-tuple based on symbolic proportion and the notion of canonical characteristic values (*CCV*), we put forward a computation operator of proportional 3-tuples based on *CCV*. Then, we propose the preference-preserving proportional 3-tuple transformation. Section 4 develops a proportional 3-tuple fuzzy linguistic representation model by combining proportional 3-tuples with linguistic evaluation framework (Huynh & Nakamori 2011). Section 5 presents an example taken from previous literature (Lin & Chen 2004b) to compare the computation process and final results with previous models, and meanwhile, to illustrate the proposed model. Finally, Section 6 points out some concluding remarks of this paper.

2. Preliminaries

In the literature, fuzzy linguistic approaches have already been employed to deal with linguistic information in screening new product projects. In this section, we briefly describe two approaches developed recently.

2.1 Fuzzy-Logic-Based Approach

Lin and Chen (2004a) proposed a fuzzy-logic-based approach to aggregate the criteria of new product projects for obtaining the fuzzy-possible-success rating (*FPSR*), which could be translated back into a linguistic term, i.e., a final suggestion for new product projects screening decision.

Formally, supposing m evaluators, $E_t = 1, 2,.., m$, conduct a new product screening decision. F_j, $j = 1, 2,\ldots, n$ are factors (include attractive and risk factors) for screening decision. $R_{tj}, j = 1,\ldots, k$, represent the fuzzy numbers approximating the linguistic effect rating given to F_j by evaluator E_t. $RPR_{tj}, j = k+1,\ldots, n$, represent the fuzzy numbers approximating the linguistic risk possibility rating given to F_j by evaluator E_t and $W_{tj}, j = 1,\ldots, n$, represent the fuzzy numbers approximating the linguistic importance weighting given to F_j by evaluator E_t. Then, the average effect rating R_j, the average risk possibility rating RPR_j and the average importance weighting W_j are computed as

$$R_j = (\frac{1}{m}) \otimes (R_{1j} \oplus R_{2j} \oplus \cdots \oplus R_{mj}), \quad j = 1,\ldots, k, \tag{1}$$

$$RPR_j = (\frac{1}{m}) \otimes (RPR_{1j} \oplus RPR_{2j} \oplus \cdots \oplus RPR_{mj}), \quad j = k+1,\ldots, n, \tag{2}$$

$$W_j = (\frac{1}{m}) \otimes (W_{1j} \oplus W_{2j} \oplus \cdots \oplus W_{mj}), \quad j = 1,\ldots, n, \tag{3}$$

where $\oplus$ and $\otimes$ stand for the extended multiplication and the extended addition over fuzzy numbers.

According to the fuzzy weighted average operator, *FPSR* is defined as

$$FPSR = \frac{\sum_{i=1}^{k} R_i \otimes W_i \oplus \sum_{i=k+1}^{n} (1 \ominus RPR_i) \otimes W_i}{\sum_{i=1}^{n} W_i}, \tag{4}$$

where $\ominus$ stands for the extended subtraction over fuzzy numbers. Then, using the fractional programming approach developed by Kao and Liu (1999), the fuzzy weighted average *FPSR* can be obtained.

Once the *FPSR* for the new product has been obtained, a linguistic approximation method based on Euclidean distance is used to match *FPSR* with linguistic success levels and its associated fuzzy numbers semantics. The linguistic success level which matches best the *FPSR* will be chosen as the final result. It is worth pointing that this approximation process often causes the loss of information in the final result.

2.2 2-Tuple Fuzzy Linguistic Representation Model

Herrera and Martínez (2000) proposed a 2-tuple fuzzy linguistic representation model for computing with words. Due to its accuracy, interpretability, simplicity, the 2-tuple linguistic representation model has been widely used in many fields and applications, where Huynh and Nakamori (2011) applied it and combined the preference-preserving 2-tuple transformation to screening new product projects.

Formally, let $S = \{s_0, s_1,\ldots, s_n\}$ be a linguistic term set, and the term s_i with $i = 0, 1,\ldots, n$, represents a possible value for a linguistic variable. The total order on S is defined as: $s_i \le s_j \Leftrightarrow i \le j$. There is a negation operator: Neg $(s_i) = s_j$ such that $j = n - i$, where $n + 1$ is the cardinality of S. In general, using a symbolic method to aggregate linguistic information, we often get a value $\beta \in [0, n]$, and $\beta \notin \{0,\ldots, n\}$. Then, an approximation function is used in order to conveniently express the index of the result in the linguistic term set S.

To avoid any approximation process which causes a loss of information in the process of computing with words, a 2-tuple (s_i, α) that expresses the equivalent information to β is obtained with the following function:

$$\Delta:[0,n]\rightarrow S\times[-0.5,0.5),$$

$$\Delta(\beta)=(s_i,\alpha),\text{with}\begin{cases}s_i & i=\text{round}(\beta),\\ \alpha=\beta-i, & \alpha\in[-0.5,0.5),\end{cases} \tag{5}$$

where round $(\cdot)$ is the usual round operation, s_i has the closest index label to β, and α is the value of the symbolic translation.

Inversely, a 2-tuple (s_i, α) $\in$ $S \times [-0.5, 0.5)$ can also be equivalently represented by a numerical value in [0, n] by means of the following transformation:

$$\Delta^{-1}:S\times[-0.5,\ 0.5)\rightarrow[0,\ n]$$

$$\Delta^{-1}(s_i,\ \alpha)=i+\alpha=\beta. \tag{6}$$

The negation operator over 2-tuples is defined by

$$\text{Neg}\,((s_i,\alpha))=\Delta(n-(\Delta^{-1}(s_i,\alpha))), \tag{7}$$

where $n + 1$ is the cardinality of S, $S = \{s_0, s_1,\ldots, s_n\}$.

Making use of 2-tuple transformations Δ and Δ^{-1}, linguistic information represented by 2-tuples can be transformed into numerical information and vice versa without loss of information. Based on this feature, Huynh and Nakamori (2011) proposed a notion of preference-preserving 2-tuple transformation, serving for the unification of linguistic information of new product criteria.

Similarly, supposing m evaluators, E_t = 1, 2,…, m, conduct a new product screening decision. F_j, j = 1, 2,…, n are criteria for screening decision, in which F_j, j = 1,…, k, are the favorable criteria, and F_j, j = k+1,…, n, are unfavorable criteria. ω_{tj} represents the linguistic importance weight given to F_j by evaluator E_t. (y_{tj}, α_{tj}), which is represented by 2-tuple, is the corresponding evaluated preference rating given to F_j by evaluator E_t after information unification by preference-preserving 2-tuple transformation. Then, the average important weights and the average preferences of criteria can be computed as

$$(\omega_j,\alpha_j^{\omega})=\Delta\left(\sum_{t=1}^{m}\frac{1}{m}\Delta^{-1}(\omega_{tj},\ 0)\right), \tag{8}$$

$$(r_j,\alpha_j)=\Delta\left(\sum_{t=1}^{m}\frac{1}{m}\Delta^{-1}(y_{tj},\ \alpha_{tj})\right), \tag{9}$$

for j = 1,…, n.

The overall figure of merit expressing the preference regarding the NPD project is computed as

$$(r,\alpha)=\Delta\left(\frac{\sum_{j=1}^{n}\Delta^{-1}(r_j,\alpha_j)\Delta^{-1}(\omega_j,\alpha_j^{\omega})}{\sum_{j=1}^{n}\Delta^{-1}(\omega_j,\alpha_j^{\omega})}\right). \tag{10}$$

Finally, convert the overall value of preference for the NPD project represented by 2-tuple (r, α) into the corresponding 2-tuple of linguistic success levels, which will be provided to the decision makers as a guidance for their final screening decisions.

3. Proportional 3-Tuple and Computation Operator

Wang and Hao (2006) proposed a proportional 2-tuple fuzzy linguistic representation model, which interestingly provides a suitable and more flexible space in a computation stage for computing with words. This model could allow evaluators to flexibly evaluate the performances of alternatives by not only one label but with the form of proportional 2-tuples (αA, βB), where A and B are two consecutive linguistic terms, and $\alpha, \beta \in [0, 1]$, $\alpha + \beta = 1$. However, due to the premise that the summation of a pair of symbolic proportions must equal to 1, this model cannot deal with incomplete linguistic assessments. In other words, it is only applicable under the context that all the linguistic assessments are complete. As a matter of fact, the information about alternatives is not always complete, and evaluators may not give all the information that they are requested (Kim & Ahn 1997), i.e., evaluators may not always give complete linguistic assessments, especially in the case of facing with uncertain, vague and imprecise information. As such, it would be desirable that an appropriate extension of Wang and Hao's (2006) proportional 2-tuple fuzzy linguistic representation model could be developed. In this section, we recall related notions and extend them correspondingly so that they can be manipulated in the context of proportional 3-tuple.

3.1 Proportional 3-Tuple

Let $S = \{s_0, s_1,..., s_n\}$ be an ordinal term set with $s_0 < s_1 < \cdots < s_n$ ("<" represents order relation, i.e., $s_i < s_j$ iff $i < j$), $I = [0, 1]$ and

$$IS = I \times S = \{(\alpha, s_i) : \alpha \in [0,1] \text{ and } i = 0,1,...,n\}.$$

Given a pair (s_i, s_{i+1}) of two successive ordinal terms of S, any two elements (α, s_i), (β, s_{i+1}) of IS are called a symbolic proportion pair and α, β are called a pair of symbolic proportions of the pair (s_i, s_{i+1}) if $\alpha + \beta \leq 1$. A symbolic proportion pair (α, s_i), (β, s_{i+1}) will be denoted by

$$\begin{cases} (\alpha s_i, \beta s_{i+1}, 0), & \text{if } \alpha + \beta = 1, \\ (\alpha s_i, \beta s_{i+1}, \varepsilon), & \text{if } \alpha + \beta < 1, \end{cases} \tag{11}$$

where ε represents the extent of ignoring information. The set of all the symbolic proportion pairs is denoted by S^*, i.e., $S^* = \{(\alpha s_i, \beta s_{i+1}, \varepsilon) : \alpha, \beta \in [0,1], \varepsilon = 1 - \alpha - \beta,$ and $i = 0,1,...,n-1\}$. The set S^* is called the proportional 3-tuple set generated by S and the members of S^* are called proportional 3-tuples, which are designed for representing evaluators' linguistic assessments with confidence levels, and indicate the completeness of subjective judgments at the same time.

An assessment $(\alpha s_i, \beta s_{i+1}, \varepsilon)$ is called complete (respectively, incomplete) if $\alpha + \beta = 1$ (respectively, $\alpha + \beta < 1$). For example, for the criteria "marketing timing", "price superiority" and "marketing competencies" in the problem of screening new product projects (see Section 5), the following types of subjective judgments, in which the first two linguistic assessments may reflect human nature on uncertainty more easily are frequently used.

1) The *marketing timing* is evaluated to be *good* with a confidence degree of 0.6, and to be *very good* with a confidence degree of 0.3.

2) The *price superiority* is evaluated to be *poor* with a confidence degree of 0.3 and to be *fair* with a confidence degree of 0.7.

3) The *marketing competencies* are *fair* with a confidence degree of 1.

The three linguistic assessments 1) – 3) can be represented in the form of proportional 3-tuples defined by (11) as

S^* (*marketing timing*) = $(0.6s_4, 0.3s_5, 0.1)$,

S^* (*price superiority*) = $(0.3s_2, 0.7s_3, 0)$,

S^* (*marketing competencies*) = $(0s_2, 1s_3, 0)$,

where s_2, s_3, s_4 and s_5 are linguistic terms of the term set S_1 as shown in (30). Obviously, the first linguistic assessment is incomplete, while others are complete.

Remark: for $i = 1, 2, \ldots, n-1$, by abuse of notion, the term s_i can use either $(0s_{i-1}, \alpha s_i, \varepsilon)$ or $(\alpha s_i, 0s_{i+1}, \varepsilon)$ as its representation in S^*.

It is interesting if we consider whether we can use 2-tuple which is mentioned in 2-tuple fuzzy linguistic representation model (Herrera & Martínez 2000) and proportional 2-tuple which is mentioned in proportional 2-tuple fuzzy linguistic representation model (Wang & Hao 2006) to represent the three linguistic assessments. According to their definitions, the linguistic assessments 1) and 2) cannot be represented by 2-tuple because each linguistic assessment includes two linguistic terms. Similarly, the linguistic assessment 1) cannot be represented by proportional 2-tuple because it is an incomplete linguistic assessment. If the linguistic assessments cannot be represented appropriately, it is difficult for us to precisely evaluate such kind of problems. Therefore, we propose the notion of proportional 3-tuple aiming at overcoming the limitations of previous models.

3.2 Canonical Characteristic Values

In the context of screening new product projects under uncertainty, fuzzy linguistic approach is often used to capture the vagueness of related criteria where the information may be unquantifiable due to its nature. To this end, we have to choose the appropriate linguistic descriptors for the term set and their semantics. The semantics of linguistic terms, which is used to represent the linguistic information in the linguistic approach is given by fuzzy numbers that are defined in the [0, 1] interval. For each fuzzy number, we can find a set of characteristic values, which are crisp values to summarize its information. Wang and Hao (2006) enumerated several canonical characteristic values (*CCV*) to represent fuzzy numbers based semantics of linguistic term, such as Expected Value (*EV*), Center of Gravity (*COG*) and so on. Considering symmetrical triangular fuzzy numbers are used in this paper, and meanwhile, maintaining the self-sufficiency of the content for any readers, we briefly review several *CCV*.

1) Expected Value: For a triangular fuzzy number $T\,(a, b, c)$, its expected value which is denoted by $EV\,(T)$ can be obtained by

$$EV(T) = \frac{a+b+c}{3}. \tag{12}$$

2) Center of Gravity: For a triangular fuzzy number $T\,(a, b, c)$, its center of gravity denoted by $COG\,(T)$ can be obtained by

$$COG\,(T) = \begin{cases} a, & \text{if } a = b = c, \\ (a+b+c)/3, & \text{otherwise.} \end{cases} \tag{13}$$

3) Mean Area Measure Value: For a triangular fuzzy number $T\,(a, b, c)$, its mean area measure value denoted by $MAMV\,(T)$ can be obtained by

$$MAMV\,(T) = \frac{a+2b+c}{4}. \tag{14}$$

For a symmetrical triangular fuzzy number $T\,[c-\delta, c, c+\delta]$, its expected value equals to c, i.e., $EV\,(T) = c$. Without loss of generality, $EV\,(T)$ will be used as a canonical characteristic value of T in this paper.

3.3 Computation Operator of Proportional 3-Tuple

For the reason of proportional 3-tuples unification and aggregation, related computation operator has to be defined.

Formally, let $S = \{s_0, s_1, \ldots, s_n\}$ be an ordinal term set with $s_0 < s_1 < \cdots < s_n$, and S^* is the proportional 3-tuple set generated by S. Define CCV of proportional 3-tuple $(\alpha s_i, \beta s_{i+1}, \varepsilon)$ as follows

$$\begin{aligned} & CCV(\alpha s_i, \beta s_{i+1}, \varepsilon) \\ &= \left(\alpha CCV(s_i) + \beta CCV(s_{i+1}),\ \varepsilon\right), \\ &= \left((\alpha c_i + (1-\alpha-\varepsilon)c_{i+1}),\ \varepsilon\ \right), \\ &= (h,\ \varepsilon), \end{aligned} \tag{15}$$

where h is a numerical value, and $h \in (0, 1]$. ε represents the extent of ignoring information. Formula (15) is called the corresponding canonical characteristic value function on S^* generated by CCV on S. Here, $c_i \in [0, 1]$ with $c_0 < c_1 < \cdots < c_n$ is the CCV of s_i, i= 0, 1,..., n.

Proposition 1 *let* $S = \{s_0, s_1,..., s_n\}$ *be an ordinal term set,* S^* *is the proportional 3-tuple set generated by* S, *and* (h, ε) *is the result obtained by CCV of proportional 3-tuple* $(\alpha s_i, \beta s_{i+1}, \varepsilon) \in S^*$. *Then, there is always a* CCV^{-1} *function such that from any given* (h, ε) *it returns to a proportional 3-tuple* $(\alpha s_i, \beta s_{i+1}, \varepsilon) \in S^*$ *and* $CCV(\alpha s_i, \beta s_{i+1}, \varepsilon) = (h, \varepsilon)$.

Proof. Indeed, given (h, ε), there exists i such that $h \in [c_i, c_{i+1}]$, as shown in Figure 1. If (h, ε) is the CCV of proportional 3-tuple $(\alpha s_i, \beta s_{i+1}, \varepsilon) \in S^*$ then we have

$$h = \alpha c_i + \beta c_{i+1}. \tag{16}$$

As $\beta = (1 - \alpha - \varepsilon)$, we get

$$\begin{aligned} h &= \alpha c_i + (1-\alpha-\varepsilon)c_{i+1}, \\ &= (1-\varepsilon)c_{i+1} - \alpha(c_{i+1} - c_i), \end{aligned} \tag{17}$$

and hence

$$\alpha = \frac{(1-\varepsilon)c_{i+1} - h}{c_{i+1} - c_i}. \tag{18}$$

This means that

$$CCV^{-1}(h, \varepsilon) = (\alpha s_i, \beta s_{i+1}, \varepsilon), \tag{19}$$

where α is determined by (18), and $\beta = (1 - \alpha - \varepsilon)$. This completes the proof of the Proposition 1.

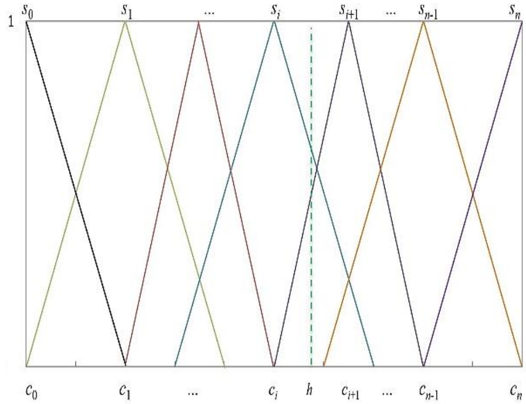

Figure 1 The representation of information h of a proportional 3-tuple

Thus, by making use of the functions of CCV and CCV^{-1} , a proportional 3-tuple can be transformed into the form of (h, ε), and vice versa.

It is worth mentioning that there is always a CCV^{-1} function to transform (h, ε) back into the original proportional 3-tuple in the same term set. However, if we use CCV^{-1} function to transform (h, ε) back into a proportional 3-tuple in a different term set, the labels and proportions of the proportional 3-tuple may be correspondingly changed. It depends on the semantics of the other term set. However, the information h and the extent of ignoring information ε don't change. Based on this feature, the notion of preference-preserving proportional 3-tuple transformation can be proposed.

3.4 Preference-Preserving Proportional 3-Tuple Transformation

Unification operation has to be carried out before multicriteria aggregation due to the inhomogeneous nature of different criteria. Therefore, it is necessary to seek out related methods for unifying the linguistic assessments represented by proportional 3-tuples from different linguistic term sets. For this reason, we define a notion of preference-preserving proportional 3-tuple transformation.

Let $S_1=\{s_0^1, s_1^1, \ldots, s_g^1\}$, $S_2=\{s_0^2, s_1^2, \ldots, s_{g'}^2\}$ be two ordinal linguistic term sets, with $s_0^1 < s_1^1 < \ldots < s_g^1$ and $s_0^2 < s_1^2 < \ldots < s_{g'}^2$. S_1^* and S_2^* are the ordinal proportional 3-tuple sets generated by S_1 and S_2 respectively. The preference order on S_1 denoted by $<s$ is either "in agreement with" or "reverse to" the preference order on S_2, denoted by $\prec s$. Suppose that we would like to transform the proportional 3-tuples in S_1^* into related proportional 3-tuples in S_2^*. Then, for the case of "in agreement with", the greater a linguistic value in S_1, by transformation, the greater a linguistic value will be in S_2. However, for the case of "reverse to", the situation is counter, i.e., the greater a linguistic value in S_1, the smaller a linguistic value will be in S_2.

Further, for a proportional 3-tuple, we believe the extent of ignoring information ε doesn't change after transformation. In other words, once an evaluator makes a subjective judgment towards a basic attribute, the extent of ignoring information is constant, even though the transformation process has been carried out between two different linguistic term sets. One reasonable explanation is that the subjective judgment including given information and ignoring information provided by an evaluator has already been an established fact. The established fact cannot change. The changing parts are labels and associated probabilities due to using different linguistic term sets with different semantics. But the given information h and the extent of ignoring information ε are constant. This prerequisite gives us a guarantee so that we can put forward the preference-preserving proportional 3-tuple transformation. With these considerations, the preference-preserving proportional 3-tuple transformation can be defined. Supposing we would like to transform a proportional 3-tuple in S_1^* into the corresponding proportional 3-tuple in S_2^*, i.e.,

$$\Lambda: S_1^* \to S_2^*$$
$$(\alpha s_i^1, \beta s_{i+1}^1, \varepsilon) \mapsto \Lambda\left((\alpha s_i^1, \beta s_{i+1}^1, \varepsilon)\right) = \left(\theta s_j^2, (1-\theta-\varepsilon)s_{j+1}^2, \varepsilon\right), \quad (20)$$

with $i\in[0, g-1]$, $j\in[0, g'-1]$, $0<\alpha+\beta\le 1-\varepsilon$, $0\le\theta\le 1-\varepsilon$.

According to formula (15), CCV of proportional 3-tuple $(\alpha s_i^1, \beta s_{i+1}^1, \varepsilon)$ in S_1^* is

$$\begin{aligned} &CCV(\alpha s_i^1, \beta s_{i+1}^1, \varepsilon) \\ &= \left(\alpha CCV(s_i^1) + \beta CCV(s_{i+1}^1), \varepsilon\right) \\ &= (\alpha c_i^1 + \beta c_{i+1}^1, \varepsilon) \\ &= (h, \varepsilon). \end{aligned} \quad (21)$$

1) In the case that $<s$ is in agreement with $\prec s$, i.e., $<s \equiv \prec s$. Define

$$CCV\left(\theta s_j^2, (1-\theta-\varepsilon)s_{j+1}^2\right) = h, \quad (22)$$

i.e., CCV of the two proportional 3-tuples both equal to h. Then,

$$h = \theta c_j^2 + (1-\theta-\varepsilon)c_{j+1}^2,$$
$$\theta = \frac{(1-\varepsilon)c_{j+1}^2 - h}{c_{j+1}^2 - c_j^2}. \quad (23)$$

Because ε does not change after transformation, $h \in [0, 1]$, and $0\le\theta\le 1-\varepsilon$, we can obtain one and only one θ.

2) In the case that $<s$ is reverse to $\prec s$,

i.e., $<s^{-1} \equiv \prec s$. Define a new ordinal linguistic term set $S_t = \{s_0^t, s_1^t, ..., s_g^t\}$, which has the same semantics with S_1, and reversed ranking order of linguistic terms with S_1, i.e., $s_0^t = s_g^1$, $s_1^t = s_{g-1}^1, ..., s_g^t = s_0^1$. The linguistic term set S_t is called transition set. The preference order on S_t is denoted by $<s_t$, such that $<s^{-1} \equiv <s_t \equiv \prec s$. S_t^* is the ordinal proportional 3-tuple set generated by S_t. Now, the proportional 3-tuple $(\alpha s_i^1, \beta s_{i+1}^1, \varepsilon)$ in S_1^* can be easily represented by a proportional 3-tuple $(\beta s_{g-i-1}^t, \alpha s_{g-i}^t, \varepsilon)$ in S_t^*. Because of the preference order $<s_t \equiv \prec s$, we can easily transform the proportional 3-tuple $(\beta s_{g\text{-}i-1}^t, \alpha s_{g-i}^t, \varepsilon)$ in S_t^* into the corresponding proportional 3-tuple in S_2^* by formula (15), (22) and (23). Such that, the proportional 3-tuple can be transformed between different linguistic term sets without loss of information, and the preference-preserving proportional 3-tuple transformation can be used as a tool for unification of proportional 3-tuples between different linguistic term sets.

4. Proportional 3-Tuple Fuzzy Linguistic Representation Model

Huynh and Nakamori (2011) proposed a screening evaluation procedure based on 2-tuple linguistic representation, which demonstrated the effectiveness for managers to make their decisions regarding to screening NPD projects under uncertainty. Considering its convenience and advantage, we combine this evaluation framework with proportional 3-tuples, and then propose a proportional 3-tuple fuzzy linguistic representation model. Specifically, the procedure of proportional 3-tuple fuzzy linguistic representation model is described as follows:

1) Proportional 3-tuples transformation and unification: This step aims at transforming original linguistic information of a NPD project assessed by evaluators towards a set of criteria into a unified representation by means of proportional 3-tuples. It includes converting original linguistic assessments of merit/risk ratings and weights. After converting evaluators' linguistic assessments into related proportional 3-tuples, unification operation should be carried out in order to pave the way for multicriteria aggregation. In the problem of screening new product projects, because the preference order is counter between merit rating set (represented by S_1 in (30)) and risk rating set (represented by S_2 in (31)), the proportional 3-tuples in S_1^* and S_2^* should be unified. The ordinal proportional 3-tuple set S_t^* generated by the linguistic term set S_t as shown in (34) is chosen as a transition set used for transforming the proportional 3-tuples in S_2^*, and the ordinal proportional 3-tuple set S_P^* generated by the preference set S_p as shown in (35) is chosen as a unification set of proportional 3-tuples. Then, the unification process can be denoted by

$$\Lambda : S_1^* \to S_p^*;\ \ \Lambda : S_2^* \to S_t^* \to S_p^*,$$

where Λ is preference-preserving proportional 3-tuple transformation.

2) Aggregating the average important weights and the average preferences of criteria: Since this paper employs multi-experts to supply their linguistic assessments represented by means of proportional 3-tuples, the average mechanism for proportional 3-tuples has to be defined. For No. d criterion, the computation and aggregation of the average weight and the average preference represented by proportional 3-tuples are defined as follows.

For the weights $(\mu_p\omega_{p,j}, \rho_p\omega_{p,j+1}, \varepsilon_p^{'})_d$, the average weight $(\mu\omega_j, \rho\omega_{j+1}, \varepsilon^{'})_d$ is given by

$$\begin{aligned}(\mu\omega_j, \rho\omega_{j+1})_d &= CCV^{-1}\left(\sum_{p=1}^{q}\frac{CCV(\mu_p\omega_{p,j}, \rho_p\omega_{p,j+1})_d}{q}\right),\\ &= CCV^{-1}\left(\sum_{p=1}^{q}\frac{\left(\mu_p CCV(\omega_{p,j}) + \rho_p CCV(\omega_{p,j+1})\right)_d}{q}\right),\end{aligned} \quad (24)$$

$$\varepsilon_d^{'} = \sum_{p=1}^{q}\frac{(\varepsilon_p^{'})_d}{q}, \quad (25)$$

where p represents the evaluator, $p \in [1, q]$, d is the No. d criterion, and ω is the weight of criterion.

In terms of preferences $\left(\alpha_P s_{p,i}, \beta_p s_{p,i+1}, \varepsilon_p\right)_d$, the average preference $\left(\alpha s_i, \beta s_{i+1}, \varepsilon\right)_d$ is given by

$$\begin{aligned}(\alpha s_i, \beta s_{i+1})_d &= CCV^{-1}\left(\sum_{p=1}^{q}\frac{CCV(\alpha_p s_{p,i}, \beta_p s_{p,i+1})_d}{q}\right),\\ &= CCV^{-1}\left(\sum_{p=1}^{q}\frac{\left(\alpha_p CCV(s_{p,i}) + \beta_p CCV(s_{p,i+1})\right)_d}{q}\right),\end{aligned} \quad (26)$$

$$\varepsilon_d = \sum_{p=1}^{q}\frac{(\varepsilon_p)_d}{q}. \quad (27)$$

3) Computing the overall figure of merit: After obtaining the average preferences and average weights, the overall figure of merit (λr_t, ηr_{t+1}, ε) typically expressing the preference regarding the NPD project under consideration is given by

$$(\lambda r_t, \eta r_{t+1}) = CCV^{-1}\left(\frac{\sum_{d=1}^{k} CCV(\alpha s_i, \beta s_{i+1})_d \cdot CCV(\mu\omega_j, \rho\omega_{j+1})_d}{\sum_{d=1}^{k} CCV(\mu\omega_j, \rho\omega_{j+1})_d}\right), \quad (28)$$

and the extent of ignoring information can be obtained approximately by

$$\varepsilon = \frac{\sum_{d=1}^{k}\frac{\varepsilon_d + \varepsilon_d^{'}}{2}}{k}, \quad (29)$$

where r represents the overall figure of merit and $d \in [1, k]$.

4) Proportional 3-tuple linguistic conversion: After obtaining the overall figure of merit (λr_t, ηr_{t+1}, ε) in S_P^*, convert it into the corresponding proportional 3-tuple in linguistic success levels of the set S_4^* by using preference-preserve proportional 3-tuple transformation, i.e., $\Lambda : S_p^* \to S_4^*$. Thus, we arrive at the final result, which will be provided to the decision makers as a reference for their final screening decisions.

Table 1 The evaluation criteria of new product project

Criteria	
Competitive marketing advantages (C_1)	Marketing timing (C_{11})
	Price superiority (C_{12})
	Marketing competencies (C_{13})
	Marketing attractiveness (C_{14})
Superiority (C_2)	Functional competency (C_{21})
	Featured differentia (C_{22})
Technological suitability (C_3)	Design quality (C_{31})
	Material specialization (C_{32})
	Manufacturing compatibility (C_{33})
	Supply benefit (C_{34})
Risk (C_4)	Market competitiveness (C_{41})
	Technological uncertainty (C_{42})
	Monetary risk (C_{43})

5. An Illustrative Application Example

In this section, we consider an example taken from previous literature (Lin & Chen 2004b) so as to illustrate the practical application of proportional 3-tuple fuzzy linguistic representation model for screening new product projects.

The problem is that a company named TV plans to launch a new product, called TV center-HX, in order to compete in the 21st century. Because the limitations imposed by both nature and the timing of NPD, there is ambiguity and uncertainty about technology and the competitive environment. The TV company wants to make an evaluation whether it is appropriate to launch this new product. For further detailed information related to this case, please refer to (Lin & Chen 2004b).

5.1 Selecting Evaluation Criteria

Previous researchers have identified criteria for assessing and screening new product projects, which provide a gauge for companies to assess design approaches and, in turn, select the most suitable design (Astebro 2004, Holtta & Otto 2005). By reference to previous literatures, 13 criteria have been selected and categorized into four groups including the factors of competitive marketing advantages, superiority, technological suitability, and the unfavorable factor of risk, as shown in Table 1.

5.2 Selecting Linguistic Term Sets and Associated Semantics

It's essential and imperative to define linguistic term sets and associated semantics to supply evaluators with an instrument, by which they can naturally express their assessments against different criteria. One of main approaches is to directly define a finite linguistic term set associated with a fuzzy set representation of its linguistic terms distributing on a scale on which a total order is defined (Huynh & Nakamori 2011). This is the approach that Lin & Chen (2004b) used in order to satisfy the particular requirements of TV center-HX. Specifically, the linguistic term sets and associated fuzzy set semantics are defined as follows.

1) The first term set is used to linguistically evaluate the merit ratings of favorable criteria:

$$S_1 = \left\{ \begin{array}{l} s_0^1(\text{Worst}), s_1^1(\text{Very Poor}), s_2^1(\text{Poor}), \\ s_3^1(\text{Fair}), s_4^1(\text{Good}), s_5^1(\text{Very Good}), \\ s_6^1(\text{Best}) \end{array} \right\}, \quad (30)$$

and the associated fuzzy set semantics is shown in Figure 2.

2) The second term set, which has the reversed preference order compared with other term sets, is used to linguistically evaluate the risk ratings of unfavorable criteria:

$$S_2 = \begin{Bmatrix} s_0^2(\text{Low}), s_1^2(\text{FairlyLow}), s_2^2(\text{Medium}), \\ s_3^2(\text{FairlyHigh}), s_4^2(\text{High}), s_5^2(\text{VeryHigh}), \\ s_6^2(\text{ExtremelyHigh}) \end{Bmatrix}, \quad (31)$$

and the associated fuzzy set semantics is shown in Figure 3.

3) The third term set is used to linguistically evaluate the importance of different criteria:

$$S_3 = \begin{Bmatrix} s_0^3(\text{VeryLow}), s_1^3(\text{Low}), s_2^3(\text{FairlyLow}), \\ s_3^3(\text{FairlyHigh}), s_4^3(\text{High}), s_5^3(\text{VeryHigh}) \end{Bmatrix}, \quad (32)$$

and the associated fuzzy set semantics is shown in Figure 4.

4) The fourth term set is used to linguistically express the success levels of the new product project:

$$S_4 = \begin{Bmatrix} s_0^4(\text{VeryLow}), s_1^4(\text{Low}), s_2^4(\text{FairlyLow}), \\ s_3^4(\text{FairlyHigh}), s_4^4(\text{High}), s_5^4(\text{VeryHigh}) \end{Bmatrix}, \quad (33)$$

and the associated fuzzy set semantics is also shown in Figure 4.

5.3 Assessing Merit/Risk Ratings and Weights of Criteria

Once the criteria have been carefully chosen, linguistic variables and associated membership functions have been elaborately defined, four evaluators denoted by $p = \{E_1, E_2, E_3, E_4\}$ need to give linguistic assessments of merit/risk ratings and weights towards criteria. In this paper, we first use the original data as in (Lin & Chen 2004b) in order to compare the final result with previous models. Then, the original linguistic assessments which are represented by proportional 3-tuples are shown in Table 2 and Table 3.

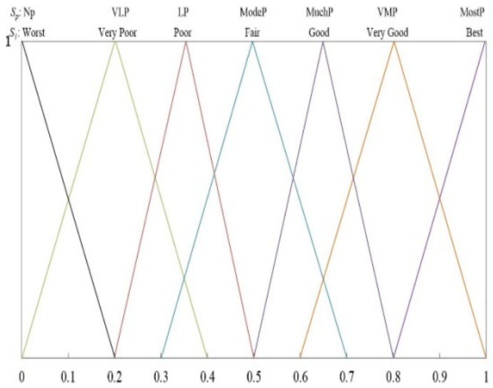

Figure 2 Linguistic merit rating values and associated fuzzy number semantic

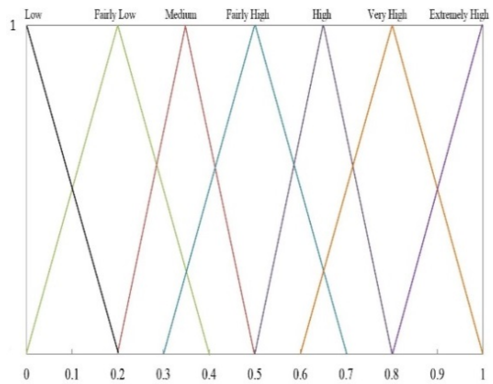

Figure 3 Linguistic risk rating values and their associated fuzzy number semantics

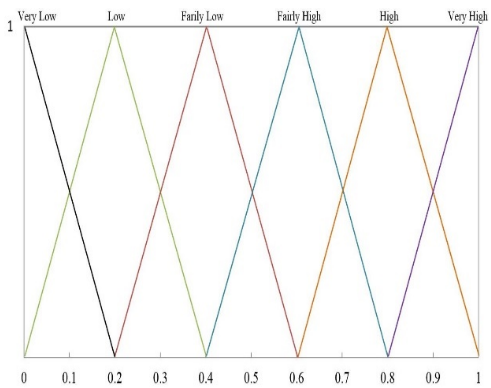

Figure 4 Linguistic weights (success levels) and associated fuzzy number semantics

Table 2 Linguistic assessments of merit/risk ratings of criteria represented by proportional 3-tuples

Criteria	Evaluators			
	E_1	E_2	E_3	E_4
C_{11}	$(1s_4, 0s_5, 0)$	$(0s_5, 1s_6, 0)$	$(0s_5, 1s_6, 0)$	$(0s_4, 1s_5, 0)$
C_{12}	$(0s_2, 1s_3, 0)$	$(0s_3, 1s_4, 0)$	$(1s_2, 0s_3, 0)$	$(0s_2, 1s_3, 0)$
C_{13}	$(0s_2, 1s_3, 0)$	$(1s_2, 0s_3, 0)$	$(1s_2, 0s_3, 0)$	$(0s_2, 1s_3, 0)$
C_{14}	$(1s_5, 0s_6, 0)$	$(1s_5, 0s_6, 0)$	$(0s_5, 1s_6, 0)$	$(0s_5, 1s_6, 0)$
C_{21}	$(0s_5, 1s_6, 0)$	$(0s_5, 1s_6, 0)$	$(1s_5, 0s_6, 0)$	$(0s_5, 1s_6, 0)$
C_{22}	$(1s_5, 0s_6, 0)$	$(1s_5, 0s_6, 0)$	$(0s_5, 1s_6, 0)$	$(1s_5, 0s_6, 0)$
C_{31}	$(1s_5, 0s_6, 0)$	$(1s_5, 0s_6, 0)$	$(1s_5, 0s_6, 0)$	$(0s_5, 1s_6, 0)$
C_{32}	$(1s_4, 0s_5, 0)$	$(0s_4, 1s_5, 0)$	$(1s_4, 0s_5, 0)$	$(0s_4, 1s_5, 0)$
C_{33}	$(0s_5, 1s_6, 0)$	$(1s_5, 0s_6, 0)$	$(1s_5, 0s_6, 0)$	$(1s_4, 0s_5, 0)$
C_{34}	$(1s_3, 0s_4, 0)$	$(0s_3, 1s_4, 0)$	$(1s_3, 0s_4, 0)$	$(0s_3, 1s_4, 0)$
C_{41}	$(1s_4, 0s_5, 0)$	$(0s_4, 1s_5, 0)$	$(1s_4, 0s_5, 0)$	$(0s_4, 1s_5, 0)$
C_{42}	$(1s_4, 0s_5, 0)$	$(0s_4, 1s_5, 0)$	$(0s_3, 1s_4, 0)$	$(0s_3, 1s_4, 0)$
C_{43}	$(1s_2, 0s_3, 0)$	$(0s_3, 1s_4, 0)$	$(0s_2, 1s_3, 0)$	$(1s_2, 0s_3, 0)$

Table 3 Linguistic assessments of weights of criteria represented by proportional 3-tuples

Criteria	Evaluators				Average
	E_1	E_2	E_3	E_4	$\overline{E}$
C_{11}	$(0s_4, 1s_5, 0)$	$(1s_4, 0s_5, 0)$	$(0s_4, 1s_5, 0)$	$(0s_4, 1s_5, 0)$	$(0.25s_4, 0.75s_5, 0)$
C_{12}	$(1s_2, 0s_3, 0)$	$(0s_3, 1s_4, 0)$	$(0s_3, 1s_4, 0)$	$(1s_3, 0s_4, 0)$	$(0.75s_3, 0.25s_4, 0)$
C_{13}	$(0s_4, 1s_5, 0)$	$(0s_4, 1s_5, 0)$	$(1s_4, 0s_5, 0)$	$(1s_4, 0s_5, 0)$	$(0.5s_4, 0.5s_5, 0)$
C_{14}	$(1s_4, 0s_5, 0)$	$(0s_4, 1s_5, 0)$	$(0s_4, 1s_5, 0)$	$(0s_4, 1s_5, 0)$	$(0.25s_4, 0.75s_5, 0)$
C_{21}	$(0s_4, 1s_5, 0)$	$(1s_4, 0s_5, 0)$	$(0s_4, 1s_5, 0)$	$(1s_4, 0s_5, 0)$	$(0.5s_4, 0.5s_5, 0)$
C_{22}	$(0s_2, 1s_3, 0)$	$(1s_2, 0s_3, 0)$	$(0s_2, 1s_3, 0)$	$(0s_2, 1s_3, 0)$	$(0.25s_2, 0.75s_3, 0)$
C_{31}	$(1s_4, 0s_5, 0)$	$(1s_4, 0s_5, 0)$	$(0s_4, 1s_5, 0)$	$(0s_4, 1s_5, 0)$	$(0.5s_4, 0.5s_5, 0)$
C_{32}	$(0s_3, 1s_4, 0)$	$(1s_3, 0s_4, 0)$	$(1s_3, 0s_4, 0)$	$(1s_2, 0s_3, 0)$	$(1s_3, 0s_4, 0)$
C_{33}	$(0s_3, 1s_4, 0)$	$(1s_3, 0s_4, 0)$	$(1s_2, 0s_3, 0)$	$(0s_2, 1s_3, 0)$	$(0s_2, 1s_3, 0)$
C_{34}	$(1s_3, 0s_4, 0)$	$(0s_3, 1s_4, 0)$	$(1s_3, 0s_4, 0)$	$(1s_3, 0s_4, 0)$	$(0.75s_3, 0.25s_4, 0)$
C_{41}	$(0s_4, 1s_5, 0)$	$(1s_4, 0s_5, 0)$	$(0s_4, 1s_5, 0)$	$(0s_4, 1s_5, 0)$	$(0.25s_4, 0.75s_5, 0)$
C_{42}	$(1s_4, 0s_5, 0)$	$(1s_4, 0s_5, 0)$	$(0s_4, 1s_5, 0)$	$(1s_4, 0s_5, 0)$	$(0.75s_4, 0.25s_5, 0)$
C_{43}	$(1s_3, 0s_4, 0)$	$(0s_3, 1s_4, 0)$	$(0s_2, 1s_3, 0)$	$(1s_2, 0s_3, 0)$	$(1s_3, 0s_4, 0)$

Table 4 Linguistic assessments of risk ratings of criteria represented by proportional 3-tuples in transition linguistic term set

Criteria	Evaluators			
	E_1	E_2	E_3	E_4
C_{41}	$(0s_1, 1s_2, 0)$	$(1s_1, 0s_2, 0)$	$(0s_1, 1s_2, 0)$	$(1s_1, 0s_2, 0)$
C_{42}	$(0s_1, 1s_2, 0)$	$(1s_1, 0s_2, 0)$	$(1s_2, 0s_3, 0)$	$(1s_2, 0s_3, 0)$
C_{43}	$(0s_3, 1s_4, 0)$	$(1s_2, 0s_3, 0)$	$(1s_3, 0s_4, 0)$	$(0s_3, 1s_4, 0)$

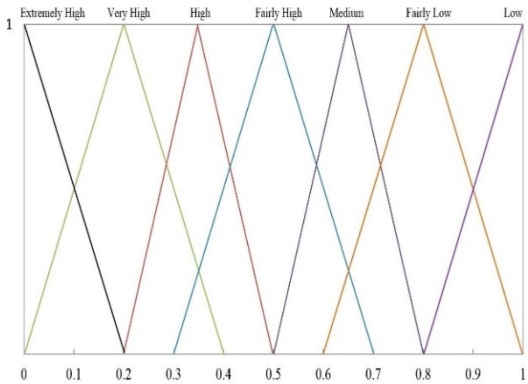

Figure 5 Transition linguistic term set and associated fuzzy number semantics

5.4 The Unification of Proportional 3-Tuples

As mentioned in preceding part, due to the inhomogeneous nature of different measurement used for different criteria, the linguistic assessments of merit and risk ratings must be unified in the evaluation process. The seven-term set S_t as shown in (34) is selected as transition set for proportional 3-tuples in S_2^*, and its associated fuzzy set semantics is shown in Figure 5. Thus, we can easily transform the proportional 3-tuples of criteria C_{41}, C_{42} and C_{43} in S_2^* into corresponding proportional 3-tuples in S_t^*, as shown in Table 4.

The seven-term set S_p of linguistic preferences as shown in (35) is selected for unifying information, and its associated fuzzy set semantics is also shown in Figure 2. Because the preference orders on S_1, S_t and S_p are the same, the overall unified information of proportional 3-tuples can be obtained by formula (15), (22) and (23), and finally is showed in Table 5. It is worth noting that the final result of unified information doesn't depend on the granularity of S_p.

$$S_t = \left\{ \begin{array}{l} s_0^t(\text{Extremely High}),\ s_1^t(\text{Very High}), \\ s_2^t(\text{High}),\ s_3^t(\text{Fairly High}),\ s_4^t(\text{Medium}), \\ s_5^t(\text{Fairly Low}),\ s_6^t(\text{Low})\}. \end{array} \right\}, \quad (34)$$

$$S_p = \left\{ \begin{array}{l} s_0^p(\text{No Preference}),\ s_1^p(\text{Very Little Preference}), \\ s_2^p(\text{Little Preference}), s_3^p(\text{Moderate Preference}), \\ s_4^p(\text{Much Preference}),\ s_5^p(\text{Very Much Preference}), \\ s_6^p(\text{Most Preference}). \end{array} \right\}. \quad (35)$$

5.5 The Evaluation Result

After information unification, the average important weights and the average preferences as well as the average extent of ignoring information of criteria represented by proportional 3-tuples can be obtained via (24) and (26), (25) and (27) respectively, as shown in the last columns of Table 3 and Table 5. Then, the overall value of preference reflecting the overall figure of merit regarding the new product development project can be obtained by (28) and (29), i.e.,

$$(0.945\, s_4^p,\ 0.055 s_5^p,\ 0) = (94.5\%\ \text{Much Preference},\ 5.5\%\ \text{Very Much Preference},\ 0)$$

which is then converted into the corresponding proportional 3-tuple of linguistic success levels in S_4^*, i.e.,

$$\Lambda(0.945\, s_4^p,\ 0.055 s_5^p,\ 0) = (0.709 s_3^4, 0.291 s_4^4, 0) = (70.9\%\ \text{Fairly High},\ 29.1\%\ \text{High},\ 0).$$

This is the final result. This proportional 3-tuple indicates that the possible success level of TV center-HX project is 70.9% fairly high and 29.1% high, which gives the decision makers a reference whether it is suitable to launch this new product project or not.

Table 5 Linguistic preferences of criteria represented by proportional 3-tuples

Criteria	Evaluators				Average
	E_1	E_2	E_3	E_4	$\overline{E}$
C_{11}	$(1s_4, 0s_5, 0)$	$(0s_5, 1s_6, 0)$	$(0s_5, 1s_6, 0)$	$(0s_4, 1s_5, 0)$	$(0.6875s_5, 0.3125s_6, 0)$
C_{12}	$(0s_2, 1s_3, 0)$	$(0s_3, 1s_4, 0)$	$(1s_2, 0s_3, 0)$	$(0s_2, 1s_3, 0)$	$(0s_2, 1s_3, 0)$
C_{13}	$(0s_2, 1s_3, 0)$	$(1s_2, 0\ s_3, 0)$	$(1s_2, 0s_3, 0)$	$(0s_2, 1s_3, 0)$	$(0.5s_2, 0.5s_3, 0)$
C_{14}	$(1s_5, 0s_6, 0)$	$(1s_5, 0s_6, 0)$	$(0s_5, 1s_6, 0)$	$(0s_5, 1s_6, 0)$	$(0.5s_5, 0.5s_6, 0)$
C_{21}	$(0s_5, 1s_6, 0)$	$(0s_5, 1s_6, 0)$	$(1s_5, 0s_6, 0)$	$(0s_5, 1s_6, 0)$	$(0.25s_5, 0.75s_6, 0)$
C_{22}	$(1s_5, 0s_6, 0)$	$(1s_5, 0s_6, 0)$	$(0s_5, 1s_6, 0)$	$(1s_5, 0s_6, 0)$	$(0.75s_5, 0.25s_6, 0)$
C_{31}	$(1s_5, 0s_6, 0)$	$(1s_5, 0s_6, 0)$	$(1s_5, 0s_6, 0)$	$(0s_5, 1s_6, 0)$	$(0.75s_5, 0.25s_6, 0)$
C_{32}	$(1s_4, 0s_5, 0)$	$(0s_4, 1s_5, 0)$	$(1s_4, 0s_5, 0)$	$(0s_4, 1s_5, 0)$	$(0.5s_4, 0.5s_5, 0)$
C_{33}	$(0s_5, 1s_6, 0)$	$(1s_5, 0s_6, 0)$	$(1s_5, 0s_6, 0)$	$(1s_4, 0s_5, 0)$	$(0.9375s_5, 0.0625s_6, 0)$
C_{34}	$(1s_3, 0s_4, 0)$	$(0s_3, 1s_4, 0)$	$(1s_3, 0s_4, 0)$	$(0s_3, 1s_4, 0)$	$(0.5s_3, 0.5s_4, 0)$
C_{41}	$(0s_1, 1s_2, 0)$	$(1s_1, 0s_2, 0)$	$(0s_1, 1s_2, 0)$	$(1s_1, 0s_2, 0)$	$(0.5s_1, 0.5s_2, 0)$
C_{42}	$(0s_1, 1s_2, 0)$	$(1s_1, 0s_2, 0)$	$(1s_2, 0s_3, 0)$	$(1s_2, 0s_3, 0)$	$(0.25s_1, 0.75s_2, 0)$
C_{43}	$(0s_3, 1s_4, 0)$	$(1s_2, 0s_3, 0)$	$(1s_3, 0s_4, 0)$	$(0s_3, 1s_4, 0)$	$(0.75s_3, 0.25s_4, 0)$

Table 6 Revised linguistic assessments of merit/risk ratings of criteria represented by proportional 3-tuples

Criteria	Evaluators			
	E_1	E_2	E_3	E_4
C_{11}	$(0.6s_4, 0.3s_5, 0.1)$	$(0.2s_5, 0.7s_6, 0.1)$	$(0.2s_5, 0.8s_6, 0)$	$(0.4s_4, 0.6s_5, 0)$
C_{12}	$(0.3s_2, 0.7s_3, 0)$	$(0.2s_3, 0.6s_4, 0.2)$	$(0.8s_2, 0.1s_3, 0.1)$	$(0.4s_2, 0.5s_3, 0.1)$
C_{13}	$(0s_2, 1s_3, 0)$	$(0.7s_2, 0.2s_3, 0.1)$	$(1s_2, 0s_3, 0)$	$(0.3s_2, 0.6s_3, 0.1)$
C_{14}	$(0.6s_5, 0.4s_6, 0)$	$(0.6s_5, 0.2s_6, 0.2)$	$(0.2s_5, 0.7s_6, 0.1)$	$(0.4s_5, 0.5s_6, 0.1)$
C_{21}	$(0.3s_5, 0.6s_6, 0.1)$	$(0.2s_5, 0.8s_6, 0)$	$(0.7s_5, 0.2s_6, 0.1)$	$(0s_5, 1s_6, 0)$
C_{22}	$(0.7s_5, 0.2s_6, 0.1)$	$(0.5s_5, 0.3s_6, 0.2)$	$(0.2s_5, 0.8s_6, 0)$	$(0.6s_5, 0.3s_6, 0.1)$
C_{31}	$(0.8s_5, 0.1s_6, 0.1)$	$(0.8s_5, 0.2s_6, 0)$	$(0.6s_5, 0.3s_6, 0.1)$	$(0.4s_5, 0.6s_6, 0)$
C_{32}	$(0.7s_4, 0.2s_5, 0.1)$	$(0.3s_4, 0.6s_5, 0.1)$	$(0.8s_4, 0.2s_5, 0)$	$(0.4s_4, 0.6s_5, 0)$
C_{33}	$(0.2s_5, 0.7s_6, 0.1)$	$(0.5s_5, 0.4s_6, 0.1)$	$(0.7s_5, 0.2s_6, 0.1)$	$(0.6s_4, 0.3s_5, 0.1)$
C_{34}	$(0.6s_3, 0.3s_4, 0.1)$	$(0.2s_3, 0.7s_4, 0.1)$	$(0.7s_3, 0.2s_4, 0.1)$	$(0.3s_3, 0.6s_4, 0.1)$
C_{41}	$(0.8s_4, 0.2s_5, 0)$	$(0.3s_4, 0.6s_5, 0.1)$	$(0.6s_4, 0.3s_5, 0.1)$	$(0.2s_4, 0.8s_5, 0)$
C_{42}	$(0.8s_4, 0.1s_5, 0.1)$	$(0.3s_4, 0.6s_5, 0.1)$	$(0.3s_3, 0.6s_4, 0.1)$	$(0.2s_3, 0.7s_4, 0.1)$
C_{43}	$(0.7s_2, 0.2s_3, 0.1)$	$(0.4s_3, 0.5s_4, 0.1)$	$(0.3s_2, 0.7s_3, 0)$	$(0.6s_2, 0.4s_3, 0)$

Table 7 Revised linguistic assessments of weights of criteria represented by proportional 3-tuples

Criteria	Evaluators				Average
	E_1	E_2	E_3	E_4	$\overline{E}$
C_{11}	$(0.4s_4, 0.5s_5, 0.1)$	$(0.8s_4, 0.2s_5, 0)$	$(0.1s_4, 0.9s_5, 0)$	$(0.3s_4, 0.6s_5, 0.1)$	$(0.4s_4, 0.55s_5, 0.05)$
C_{12}	$(0.6s_2, 0.4s_3, 0)$	$(0.3s_3, 0.6s_4, 0.1)$	$(0.2s_3, 0.8s_4, 0)$	$(0.5s_3, 0.4s_4, 0.1)$	$(0.65s_3, 0.3s_4, 0.05)$
C_{13}	$(0.3s_4, 0.6s_5, 0.1)$	$(0.3s_4, 0.7s_5, 0)$	$(0.8s_4, 0.2s_5, 0)$	$(0.7s_4, 0.2s_5, 0.1)$	$(0.525s_4, 0.425s_5, 0.05)$
C_{14}	$(0.6s_4, 0.4s_5, 0)$	$(0.3s_4, 0.7s_5, 0)$	$(0.2s_4, 0.7s_5, 0.1)$	$(0.3s_4, 0.6s_5, 0.1)$	$(0.35s_4, 0.6s_5, 0.05)$
C_{21}	$(0.3s_4, 0.6s_5, 0.1)$	$(0.5s_4, 0.4s_5, 0.1)$	$(0s_4, 1s_5, 0)$	$(0.6s_4, 0.2s_5, 0.2)$	$(0.35s_4, 0.55s_5, 0.1)$
C_{22}	$(0.3s_2, 0.6s_3, 0.1)$	$(0.6s_2, 0.3s_3, 0.1)$	$(0.2s_2, 0.8s_3, 0)$	$(0.4s_2, 0.6s_3, 0)$	$(0.375s_2, 0.575s_3, 0.05)$
C_{31}	$(0.7s_4, 0.2s_5, 0.1)$	$(0.8s_4, 0.2s_5, 0)$	$(0.2s_4, 0.7s_5, 0.1)$	$(0.1s_4, 0.7s_5, 0.2)$	$(0.45s_4, 0.45s_5, 0.1)$
C_{32}	$(0.3s_3, 0.6s_4, 0.1)$	$(0.7s_3, 0.3s_4, 0)$	$(0.7s_3, 0.2s_4, 0.1)$	$(0.6s_2, 0.4s_3, 0)$	$(0.825s_3, 0.125s_4, 0.05)$
C_{33}	$(0.2s_3, 0.7s_4, 0.1)$	$(0.6s_3, 0.3s_4, 0.1)$	$(0.7s_2, 0.3s_3, 0)$	$(0.4s_2, 0.6s_3, 0)$	$(0.025s_2, 0.925s_3, 0.05)$
C_{34}	$(0.7s_3, 0.2s_4, 0.1)$	$(0.3s_3, 0.6s_4, 0.1)$	$(0.8s_3, 0.2s_4, 0)$	$(0.6s_3, 0.4s_4, 0)$	$(0.6s_3, 0.35s_4, 0.05)$
C_{41}	$(0.2s_4, 0.8s_5, 0)$	$(0.6s_4, 0.3s_5, 0.1)$	$(0.2s_4, 0.8s_5, 0)$	$(0.4s_4, 0.5s_5, 0.1)$	$(0.35s_4, 0.6s_5, 0.05)$
C_{42}	$(0.7s_4, 0.3s_5, 0)$	$(0.7s_4, 0.3s_5, 0)$	$(0.2s_4, 0.7s_5, 0.1)$	$(0.6s_4, 0.3s_5, 0.1)$	$(0.55s_4, 0.4s_5, 0.05)$
C_{43}	$(0.6s_3, 0.4s_4, 0)$	$(0.2s_3, 0.8s_4, 0)$	$(0.1s_2, 0.7s_3, 0.2)$	$(0.6s_2, 0.2s_3, 0.2)$	$(0.775s_3, 0.125s_4, 0.1)$

Table 8 Revised linguistic preferences of criteria represented by proportional 3-tuples

Criteria	Evaluators				Average
	E_1	E_2	E_3	E_4	$\overline{E}$
C_{11}	$(0.6s_4, 0.3s_5, 0.1)$	$(0.2s_5, 0.7s_6, 0.1)$	$(0.2s_5, 0.8s_6, 0)$	$(0.4s_4, 0.6s_5, 0)$	$(0.7625s_5, 0.1875s_6, 0.05)$
C_{12}	$(0.3s_2, 0.7s_3, 0)$	$(0.2s_3, 0.6s_4, 0.2)$	$(0.8s_2, 0.1s_3, 0.1)$	$(0.4s_2, 0.5s_3, 0.1)$	$(0.225s_2, 0.675s_3, 0.1)$
C_{13}	$(0s_2, 1s_3, 0)$	$(0.7s_2, 0.2s_3, 0.1)$	$(1s_2, 0s_3, 0)$	$(0.3s_2, 0.6s_3, 0.1)$	$(0.5s_2, 0.45s_3, 0.05)$
C_{14}	$(0.6s_5, 0.4s_6, 0)$	$(0.6s_5, 0.2s_6, 0.2)$	$(0.2s_5, 0.7s_6, 0.1)$	$(0.4s_5, 0.5s_6, 0.1)$	$(0.45s_5, 0.45s_6, 0.1)$
C_{21}	$(0.3s_5, 0.6s_6, 0.1)$	$(0.2s_5, 0.8s_6, 0)$	$(0.7s_5, 0.2s_6, 0.1)$	$(0s_5, 1s_6, 0)$	$(0.3s_5, 0.65s_6, 0.05)$
C_{22}	$(0.7s_5, 0.2s_6, 0.1)$	$(0.5s_5, 0.3s_6, 0.2)$	$(0.2s_5, 0.8s_6, 0)$	$(0.6s_5, 0.3s_6, 0.1)$	$(0.5s_5, 0.4s_6, 0.1)$
C_{31}	$(0.8s_5, 0.1s_6, 0.1)$	$(0.8s_5, 0.2s_6, 0)$	$(0.6s_5, 0.3s_6, 0.1)$	$(0.4s_5, 0.6s_6, 0)$	$(0.65s_5, 0.3s_6, 0.05)$
C_{32}	$(0.7s_4, 0.2s_5, 0.1)$	$(0.3s_4, 0.6s_5, 0.1)$	$(0.8s_4, 0.2s_5, 0)$	$(0.4s_4, 0.6s_5, 0)$	$(0.55s_4, 0.4s_5, 0.05)$
C_{33}	$(0.2s_5, 0.7s_6, 0.1)$	$(0.5s_5, 0.4s_6, 0.1)$	$(0.7s_5, 0.2s_6, 0.1)$	$(0.6s_4, 0.3s_5, 0.1)$	$(0.6875s_5, 0.2125s_6, 0.1)$
C_{34}	$(0.6s_3, 0.3s_4, 0.1)$	$(0.2s_3, 0.7s_4, 0.1)$	$(0.7s_3, 0.2s_4, 0.1)$	$(0.3s_3, 0.6s_4, 0.1)$	$(0.45s_3, 0.45s_4, 0.1)$
C_{41}	$(0.2s_1, 0.8s_2, 0)$	$(0.6s_1, 0.3s_2, 0.1)$	$(0.3s_1, 0.6s_2, 0.1)$	$(0.8s_1, 0.2s_2, 0)$	$(0.475s_1, 0.475s_2, 0.05)$
C_{42}	$(0.1s_1, 0.8s_2, 0.1)$	$(0.6s_1, 0.3s_2, 0.1)$	$(0.6s_2, 0.3s_3, 0.1)$	$(0.7s_2, 0.2s_3, 0.1)$	$(0.05s_1, 0.85s_2, 0.1)$
C_{43}	$(0.2s_3, 0.7s_4, 0.1)$	$(0.5s_2, 0.4s_3, 0.1)$	$(0.7s_3, 0.3s_4, 0)$	$(0.4s_3, 0.6s_4, 0)$	$(0.675s_3, 0.275s_4, 0.05)$

5.6 Comparative Study

It is very interesting if we compare the final result obtained by proportional 3-tuple fuzzy linguistic representation model with that obtained by previous models, such as fuzzy-logic-based approach (Lin & Chen 2004b), and 2-tuple fuzzy linguistic representation model (Huynh & Nakamori 2011). With the same linguistic assessments, the final result obtained by fuzzy-logic-based approach is a fuzzy number (0.439, 0.666, 0.852) representing its approximated linguistic expression of s_3^4 = Fairly High. In fact, the associated fuzzy number semantics of s_3^4 is (0.4, 0.6, 0.8), as shown in Figure 4. Obviously, there is loss of information when fairly high is as the final result provided to decision makers. Further, the final result obtained by 2-tuple fuzzy linguistic representation model is a 2-tuple (s_3^4 = Fairly High, 0.32), which means the possible success level of this new product project is a little more than fairly high. Although there is no loss of information when 2-tuple fuzzy linguistic representation model was used to deal with this new product project screening problem, there is some vagueness about "0.32" in the final result so that we can only explain it as "a little more than". In contrast, there is no loss of information in the final result obtained by proportional 3-tuple fuzzy linguistic representation model and it indicates much more information which is very comprehensible to decision makers than the obtained results by previous models. Besides, the computation process of proportional 3-tuple fuzzy linguistic representation model is also much simpler than fuzzy-logic-based approach.

5.7 For Revised Linguistic Assessments

In the preceding part, we applied proportional 3-tuple fuzzy linguistic representation model to a new product project screening problem, in which the original linguistic assessments were used in order to compare the final result with fuzzy-logic-based approach (Lin & Chen 2004b), and 2-tuple fuzzy linguistic representation model (Huynh & Nakamori 2011). However, due to the limitations of the previous models, the original linguistic assessments have to be complete and can only use one linguistic term to evaluate a criterion. For the purpose of explaining the capability of proportional 3-tuple fuzzy linguistic representation model regarding to dealing with more general cases of linguistic assessments, especially for those reflecting human nature on uncertain subjective judgments as discussed in Section 3.1, we suppose a set of incomplete linguistic assessments which are modified from (Lin & Chen 2004b), as shown in Table 6 and Table 7 respectively.

Similarly, by using preference-preserving proportional 3-tuple transformation, we can obtain the unification of linguistic assessments represented by proportional 3-tuples easily, as shown in Table 8. Then, the average revised important weights and the average revised preferences as well as the average extent of ignoring information of criteria represented by proportional 3-tuples can be obtained easily and are shown in the last columns of Table 7 and Table 8 respectively. After that, the overall value of preference of the new product development project can be obtained by (28) and (29), i.e., (0.915 s_4^p , 0.018 s_5^p , 0.067), which is then converted into the related proportional 3-tuple of linguistic success levels in S_4^* , i.e.,

$$\Lambda(0.915\, s_4^p,\ 0.018 s_5^p,\ 0.067) = (0.687 s_3^4,\ 0.246 s_4^4, 0.067)$$
$$= (68.7\%\ \text{Fairly High},\ 24.6\%\ \text{High},\ 6.7\%).$$

This is the final result of the revised linguistic assessments. This proportional 3-tuple indicates that the possible success level of TV center-HX project is 68.7% fairly high, 24.6% high, and 6.7% ignoring information. Obviously, proportional 3-tuple fuzzy linguistic representation model is capable of dealing with the new product project screening problem with incomplete linguistic assessments, while fuzzy-logic-based approach (Lin & Chen 2004b), 2-tuple fuzzy linguistic representation model (Herrera & Martínez 2000), and proportional 2-tuple fuzzy linguistic representation model (Wang & Hao 2006) can only be applied to the situations where all the linguistic assessments are complete that seriously limit their applications.

6. Concluding Remarks

NPD process is a dynamically complex and multistage process that involves multiple criteria with uncertainty. It is very essential to conduct screening new product projects in a way that is rational, reliable, repeatable, and transparent. In this paper, we extended Wang and Hao's (2006) proportional 2-tuple and defined a new notion of proportional 3-tuple, which could not only indicate evaluators' confidence levels but also allow them to supply incomplete linguistic assessments when facing with uncertain, imprecise and incomplete information. This can be regarded as a special measure for handling uncertainty when evaluating new product projects. Then, a proportional 3-tuple computation operator and a notion of preference-preserving proportional 3-tuple transformation based on *CCV* were proposed so as to deal with various problems during the screening new product projects, such as the transformation and unification of proportional 3-tuple between two different linguistic term sets, the aggregation of proportional 3-tuples and so on.

On the basis of 2-tuple linguistic screening evaluation procedure, a proportional 3-tuple fuzzy linguistic representation model for screening new product projects was put forward. After applying this model to an example taken from previous literature, it demonstrated its ability of screening new product projects, especially at the aspect of reflecting human nature, such as taking evaluators' confidence levels and the ignoring information of subjective judgments into account. In addition, it is very obvious that the final result obtained by proportional 3-tuple fuzzy linguistic representation model indicates much more information than that of fuzzy-logic-based approach as well as 2-tuple fuzzy linguistic representation model.

For further work, the authors are planning to investigate the situation where the confidence levels provided by evaluators are expressed in more complicated combination in order to better catch the uncertain nature of NPD process, but further research is required.

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