Title	A proportional 3-tuple fuzzy linguistic screening evaluation model in new product development
Author(s)	Guo, Wen-Tao; Huynh, Van-Nam; Nakamori, Yoshiteru
Citation	Proceedings of The 14th International Symposium on Knowledge and Systems Sciences (KSS'2013): 82-88
Issue Date	2013
Type	Conference Paper
Text version	author
URL	http://hdl.handle.net/10119/12336
Rights	Copyright (C) 2013 JAIST Press. Wen-Tao Guo, Van-Nam Huynh, Yoshiteru Nakamori, Proceedings of The 14th International Symposium on Knowledge and Systems Sciences (KSS'2013), 2013, 82-88.
Description	

A Proportional 3-Tuple Fuzzy Linguistic Screening Evaluation Model in New Product Development

Wen-Tao Guo Van-Nam Huynh Yoshiteru Nakamori

School of Knowledge Science
Japan Advanced Institute of Science and Technology
1−1 Asahidai, Nomi, Ishikawa 923-1292, Japan
aswindassky@gmail.com

Abstract

It is particularly important for companies to screen new products before new products are launched to the markets. So far, lots of approaches have been excavated. However, due to uncertain, vague and incomplete information as well as dynamically complex process regarding to new product development (NPD), many approaches face with various limitations and restrictions, which lead to a dilemma that evaluators can't take into account the aspects related to human nature, such as confidence levels, integrity of subject judgments, to evaluate new products reasonably. In this paper, we propose a proportional 3-tuple fuzzy linguistic evaluation model for screening new products and related computation operator based on canonical characteristic values (*CCV*). It is shown that this new model has a good ability to reflect human nature through the probability and the variable representing missing information. Thus, it not only can reflect the confidence levels of evaluators in the way of probability, but is also able to refract accuracy of subject judgment, whereby improving the precision and reasonability of final result.

Keywords: Confidence Levels, Linguistic Modeling, Missing Information, New product screening, Proportional 3-Tuple

1 Instructions

New product development (NPD) is a dynamically complex and an overall process including strategy, organization, concept generation, product and marketing plan creation and evaluation, and commercialization of a new product [2], [9]. Faced with intense global competition, rapid change in technology, a dynamic economical situation and short product life cycles, in contrast to new products being a major contributor to the growth, profitability of a company, and providing access to new markets, companies have realized that NPD has become one of the most important strategies, which is crucial for their survival and competitive success [4], [10].

However, due to inevitable consequences of volatile markets and customer preferences, imprecise and uncertain information, NPD is also a dynamically complex process with high-risk rate of failure, which often leads to substantial monetary and non-monetary losses[3], [7]. In such situation, screening new product projects becomes the first critical evaluation in the NPD process before a company launching a successful new product [5], [13]. 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 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 uncertain. Another main reason is related to human nature. Evaluators often lack confidences when they supply subject judgments. This probably results from the reality that evaluators 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 leads to incomplete evaluation results due to a lack of evidence and understanding or human's inability of providing accurate judgments on the evaluation process [6]. Although there are many approaches which have been excavated to screen new products, most of these approaches face with various limitations and restrictions, which lead to a dilemma that evaluators cannot take into account the aspects related to human nature, such as confidence levels, integrity of subject judgments, to evaluate new products reasonably.

Given the foregoing, this research proposes a proportional 3-tuple fuzzy linguistic screening evaluation model and related computation operator to deal with the problems mentioned above. In this research, linguistic information is represented by a so-called proportional 3-tuple, that is, 2 subject judgments with probabilities and a numerical value, such as (0.3*A*, 0.6*B*, 0.1). It means someone gives linguistic evaluation as 30% *A*, 60% *B*, and 10% missing information. Compared with proportional 2-tuple [14], it is more flexible and allows evaluators to supply incomplete subject judgments under uncertainty. By combining proportional 3-tuples with linguistic evaluation framework [12], a proportional 3-tuple fuzzy linguistic screening evaluation model has been developed. It is shown that this new model has a good ability to reflect human nature through the probability and the variable representing missing information. Thus, it not only can reflect the confidence levels of evaluators in the way of probability, but is also able to refract the accuracy of subject judgment, whereby improving the precision and reasonability of final result.

The rest of this paper is organized as follows. In section 2, after introducing the notion of proportional 3-tuple based on symbolic proportion and canonical characteristic values (*CCV*), we will introduce a computation operator of proportional 3-tuples based on *CCV*. Section 3 develops a proportional 3-tuple fuzzy linguistic screening evaluation model. Section 4 presents an example to illustrate the proposed method. Finally, Section 5 points out some concluding remarks of this paper.

2 Proportional 3-Tuple and Computation Operator

2.1 Proportional 3-tuple

Let's first recall some notions from previous literature [14].

Let $S = \{s_0, s_1, \dots, s_n\}$ be an ordinal term set with $s_0 < s_1 < \dots < s_n$, $I = [0, 1]$ and

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

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 $\alpha + \beta \le 1$. A symbolic proportion pair (α, s_i), (β, s_{i+1}) will be denoted by

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

where ε represents missing information. The set of all the symbolic proportion pairs is denoted by S^*, i.e., $S^* = \{(\alpha s_i, \beta s_{i+1}, \varepsilon): \alpha, \beta \in [0, 1], \varepsilon \in [0, 1)$ and $i = 0, 1, \dots, n\text{-}1\}$. The set S^* is called the ordinal proportional 3-tuple set generated by S and the members of S^* are called ordinal proportional 3-tuples, which can be used to represent evaluators' linguistic assessments with confidence levels and the integrity of subject judgments.

Remark: since for $i = 1, \dots, n\text{-}1$, ordinal term s_i can use either $(0s_{i-1}, 1s_i, 0)$ or $(1s_i, 0s_{i+1}, 0)$ as its representative in S^*, by no abuse of notion, we will only use the latter.

2.2 Position index function

Let $S = \{s_0, s_1, \dots, s_n\}$ be an ordinal term set and S^* is the ordinal proportional 3-tuple set generated by S. Define π: $S^* \rightarrow [0, n]$ by

$$\pi(\alpha s_i, \beta s_{i+1}, \varepsilon) = i + \beta = i + (1 - \alpha - \varepsilon) \quad (2)$$

where $i = 0, 1, \dots, n\text{-}1$, and $\alpha \in [0, 1]$. Here, π is called the position index function of proportional 3-tuples. Under the identification convention, the position index function becomes a bijection from S^* to $[0, n]$ and its inverse π^{-1}: $[0, n] \rightarrow S^*$ is defined by

$$\pi^{-1}(x) = ((1 - \theta - \varepsilon)s_i, \theta s_{i+1}, \varepsilon) \quad (3)$$

where $i = E(x)$, E is the integral part function, and $\theta = x\text{-}i$.

2.3 Canonical characteristic values

The semantics of elements in a term set, 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 related crisp values (*CV*) to summarize its information. The crisp values are called characteristic values. For example, for a symmetrical triangular fuzzy number T [c-δ, c, c+δ], we can find a set of characteristic values $CV_T = \{C_T^1, C_T^2, ..., C_T^n\}$, which are crisp values. In previous literature, various types of CV have been excavated, such as Expected Value (EV), Center of Gravity (CG), Mean of Maxima (MM), λ Mean Area Measure Value ($\lambda MAMV$), Mean Area Measure Value ($MAMV$) etc., and used for different purposes, e.g., in the defuzzification methods, ranking fuzzy numbers and so on. Actually, it is enough for us just only to choose one value from the set of characteristic values to represent the fuzzy number's meaning.

In view of symmetrical triangular fuzzy numbers that will be used in this research, while for a symmetrical triangular fuzzy number T [c-δ, c, c+δ], its expected value equals c, i.e. $EV(T) = c$. Hence, for convenience, $EV(T)$ will be used as a canonical (representative) characteristic values (CCV) of T in this research.

2.4 Computation operator of proportional 3-tuple

Let $S = \{s_0, s_1, ..., s_n\}$ be an ordinal term set with $s_0 < s_1 < \ldots < s_n$, and S^* is the ordinal proportional 3-tuple set generated by S. Define CCV of proportional 3-tuple (αs_i, βs_{i+1}, ε) as follows:

$$\begin{aligned} &CCV:\ S^* \to [0,\ 1] \\ CCV(\alpha s_i, \beta s_{i+1}, \varepsilon) &= (\alpha\, CCV(s_i) + \beta\, CCV(s_{i+1}), \varepsilon) \\ &= ((\alpha c_i + (1-\alpha-\varepsilon)c_{i+1}), \varepsilon) \end{aligned} \tag{4}$$

and call it the corresponding canonical characteristic value function on S^* generated by CCV on S. Here, $c_i \in [0, 1]$ with $c_0 < c_1 < \ldots < c_n$ is the CCV of s_i, i= 0, 1,..., n, and CCV is a bijection from S^* to [c_0, c_n] ($\subset$[0, 1]).

Define a function f: [0, n] → [c_0, c_n] by

$$f(x) = (1-\varepsilon)c_i + \theta(c_{i+1} - c_i) \tag{5}$$

where i= $E(x)$, E is the integral part function, and $\theta = x$-i. Then, f is a bijection. Since

$$\begin{aligned} CCV((1-\varepsilon-\theta)s_i, \theta s_{i+1}) &= (1-\varepsilon-\theta)c_i + \theta c_{i+1} \\ &= (1-\varepsilon)c_i + \theta(c_{i+1} - c_i) \\ &= f(i+\theta) = f(\pi((1-\theta-\varepsilon)s_i, \theta s_{i+1})) \end{aligned} \tag{6}$$

for all i = 0, 1,…, n-1, $\theta \in$ [0, 1], thus $CCV = f \circ \pi$. So CCV is a bijection. The inverse of CCV is denoted by CCV^{-1}.

3 Proportional 3-Tuple Fuzzy Linguistic Screening Evaluation Model

Based on 2-tuple linguistic evaluation framework [12], the procedure of proportional 3-tuple fuzzy linguistic screening evaluation model is as follows:

1) Proportional 3-tuple linguistic transformation and unification: This step aims at transforming original linguistic information of an NPD project assessed by evaluators against a set of criteria into a unified representation by means of proportional 3-tuples. It includes converting original linguistic assessments of merit ratings and weights.

2) Aggregate the average merit ratings and the average important weights of criteria: For No. d criterion, the computation and aggregation of the average merit rating and average weight represented by proportional 3-tuples are as follows.

In terms of the merit ratings ($\alpha s_{p,i}$, $\beta s_{p,i+1}$, $\varepsilon_{p,d}$), the average merit rating (αs_i, βs_{i+1}, ε_d) is given by

$$\begin{aligned} (\alpha s_i, \beta s_{i+1}) &= CCV^{-1}\Big(\sum_{p=1}^{q} \frac{1}{q}(CCV(\alpha\, s_{p,i}, \beta\, s_{p,i+1}))\Big) \\ &= CCV^{-1}\Big(\sum_{p=1}^{q} \frac{1}{q}(CCV(\alpha\, s_{p,i}, (1\text{-}\alpha\text{-}\varepsilon_{p,d}) s_{p,i+1}))\Big) \end{aligned} \tag{7}$$

$$\varepsilon_d = \sum_{p=1}^{q} \frac{\varepsilon_{p,d}}{q} \tag{8}$$

with p representing the current evaluator, $p \in$ [1, q], and d representing the No. d criterion.

In terms of weights $(\mu\omega_{p,i}, \rho\omega_{p,i+1}, \varepsilon'_{p,d})$, the average weight $(\mu\omega_i, \rho\omega_{i+1}, \varepsilon'_d)$ is given by

$$\begin{aligned} (\mu\omega_i, \rho\omega_{i+1}) &= CCV^{-1}\Big(\sum_{p=1}^{q} \frac{1}{q}(CCV(\mu\omega_{p,i}, \rho\omega_{p,i+1}))\Big) \\ &= CCV^{-1}\Big(\sum_{p=1}^{q} \frac{1}{q}(CCV(\mu\omega_{p,i}, (1\text{-}\mu\text{-}\varepsilon'_{p,d})\omega_{p,i+1}))\Big) \end{aligned} \tag{9}$$

$$\varepsilon'_d = \sum_{p=1}^{q} \frac{\varepsilon'_{p,d}}{q} \tag{10}$$

with ω representing the weights of evaluation criteria.

3) Compute the overall figure of merit: The overall figure of merit (λr_i, ηr_{i+1}, ε) typically expresses the evaluation rating regarding the NPD project under consideration, that is,

$$(\lambda r_i, \eta r_{i+1}) = CCV^{-1}\left[\frac{\sum_{d=1}^{k} CCV(\alpha s_{d,i}, \beta s_{d,i+1}) CCV(\mu\omega_{d,i}, \rho\omega_{d,i+1})}{\sum_{d=1}^{k} CCV(\mu\omega_{d,i}, \rho\omega_{d,i+1})}\right] \quad (11)$$

$$\varepsilon = \frac{\sum_{d=1}^{k} \varepsilon_d \cdot \varepsilon_{\mathrm{d}}^{'}}{\sum_{d=1}^{k} \varepsilon_{\mathrm{d}}^{'}} \quad (12)$$

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

4 Illustrative Application Example

In this section, we will consider an example so as to illustrate the practical application of proportional 3-tuple fuzzy linguistic screening evaluation model in NPD.

4.1 Select evaluation criteria

A new product project is very complicated and characterized by a variety of features of both quantitative and qualitative in nature. Selecting a set of criteria that can reflect a variety of features of new products and other indispensable traits is really difficult. Previous researches 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 [1], [11]. By reference to previous studies, we can easily find many sets of criteria for screening different new products. One can adopt and further modify them according to respective features of new products. For the purpose of just taking an illustrative example, we choose a list of general criteria, which are suitable for explanation of our model, from the following two literatures [8], [13], as shown in Table 1.

Table 1. The evaluation criteria of new product

	Criteria
C_1	Product differential advantage
C_2	Diversification strategy
C_3	Project financing
C_4	Marketing timing
C_5	Marketing competencies
C_6	Size of market
C_7	Marketing attractiveness
C_8	Price superiority
C_9	Product life
C_{10}	Technological and product synergy
C_{11}	Material specialization

4.2 Select 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. Another often used approach in literatures is to adopt and modify the linguistic terms and corresponding membership functions from previous studies so as to incorporate the specific requirements of respective application examples. For the sake of convenience, this research will use the latter approach.

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

$$S_1 = \{s_0^1(\text{Worst}),\ s_1^1(\text{Very Poor}),\ s_2^1(\text{Poor}),\ s_3^1(\text{Fair}),\ s_4^1(\text{Good}),\ s_5^1(\text{Very Good}),\ s_6^1(\text{Best})\} \quad (13)$$

and the associated fuzzy set semantics is shown in Fig.1.

2) The second term set is used to linguistically evaluate the relative importance of different criteria:

$$S_2 = \{s_0^2(\text{Very Low}),\ s_1^2(\text{Low}),\ s_2^2(\text{Fairly Low}),\ s_3^2(\text{Medium}),\ s_4^2(\text{Fairly High}),\ s_5^2(\text{High}),\ s_6^2(\text{Very High})\} \quad (14)$$

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

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

$$S_3 = \{s_0^3(\text{Very Low}),\ s_1^3(\text{Low}),\ s_2^3(\text{Fairly Low}),\ s_3^3(\text{Medium}),\ s_4^3(\text{Fairly High}),\ s_5^3(\text{High}),\ s_6^3(\text{Very High})\} \quad (15)$$

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

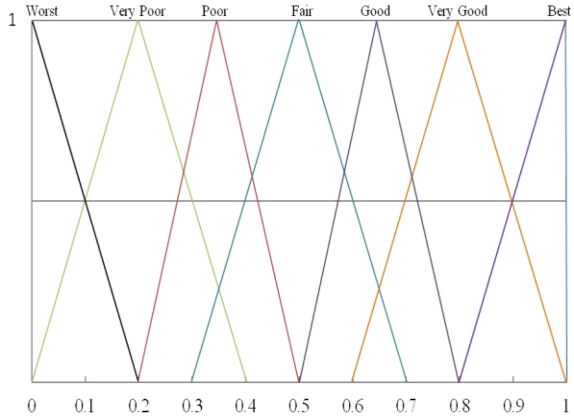

Fig 1. Linguistic effect rating values and associated fuzzy set semantics

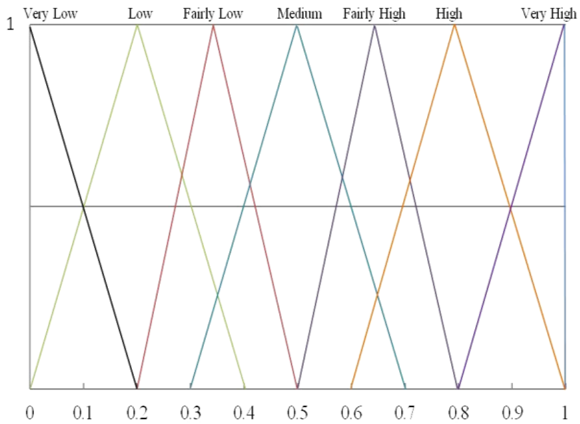

Fig. 2. Linguistic weights (success levels) and associated fuzzy set semantics

4.3 Assess criteria merit ratings and weights using linguistic terms

In case 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 ratings and weights of criteria.

It is worth to mention here, in this research, evaluators are able to make linguistic evaluations with confidence levels, in other words with probability, rather than numerical assessments of the selected factors. This is because the nature of human judgments on uncertainty responses a basic bias with probability. More specifically, due to ambiguity and uncertainty about technology and the competitive environment with the limitations imposed by both nature and the timing of NPD, evaluators are allowed to supply incomplete assessments, such as $(0.3s_4, 0.5s_5, 0.2)$ in S_1^*. It means that this evaluator evaluates the current criterion as follows: 30% possibility is Good, 50% possibility is Very Good, and the other 20% possibility is uncertain that he cannot determine.

The assessment results of merit ratings and the important weights of the selected criteria are shown in Table 2 and Table 3 respectively.

4.4 Compute evaluation results of proportional 3-tuple fuzzy linguistic screening evaluation model

After information aggregation and unification, the average merit ratings and the average important weights as well as the average missing information of criteria represented by proportional 3-tuples can be got via (7) and (9), (8) and (10) respectively, as shown in the last columns of Tables 2 and 3. Then, the overall value reflecting the overall figure of merit regarding the NPD project can be obtained by (11) and (12), i.e.,

$$(0.518s_4^1,\ 0.379s_5^1,\ 0.103) = (51.8\%\ \text{Good},\ 37.9\%\ \text{Very Good},\ 10.3\%)$$

which is then converted into the related proportional 3-tuple of linguistic success levels in S_3^*. Because the fuzzy set semantics of merit ratings and success levels is the same, the *CCV* of S_1 and S_3 are also the same, the overall figure of merit can directly express the success levels. Hence,

$$(0.518s_4^1,\ 0.379s_5^1,\ 0.103) = (0.518s_4^3,\ 0.379s_5^3,\ 0.103) = (51.8\%\ \text{Fairly High},\ 37.9\%\ \text{High},\ 10.3\%)$$

that is, the proportional 3-tuple indicates that the possible success level of this new product project is 51.8% fairly high, 37.9% high, and 10.3% missing information, which gives the decision makers a reference whether it is suitable to launch this new product project or not.

5 Concluding Remarks

In this paper, we have defined the notion of proportional 3-tuple, which endows screening evaluation model with a particular feature to aggregate multi-evaluators' assessments and reveal the nature of NPD process. Then, a proportional 3-tuple fuzzy linguistic screening evaluation model and related computation operator based on *CCV* have been proposed. It is shown that this new model has a good ability to reflect human nature through the probability and the variable representing missing information, which can support evaluators to express assessments more accurately with confidence and improve the precision and reasonability of final result.

It is worth to mention here, Yang et al. [15] developed a new evidential reasoning approach for MADA under both probabilistic and fuzzy

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

Criteria	Evaluators				Average
	E_1	E_2	E_3	E_4	$\overline{E}$
C_1	$(0.3s_4, 0.7s_5, 0)$	$(0.3s_5, 0.6s_6, 0.1)$	$(0.3s_5, 0.5s_6, 0.2)$	$(0.3s_4, 0.6s_5, 0.1)$	$(0.74s_5, 0.16s_6, 0.1)$
C_2	$(0.3s_2, 0.6s_3, 0.1)$	$(0.3s_3, 0.7s_4, 0)$	$(0.7s_2, 0.2s_3, 0.1)$	$(0.3s_2, 0.5s_3, 0.2)$	$(0.15s_2, 0.75s_3, 0.1)$
C_3	$(0.4s_2, 0.5s_3, 0.1)$	$(0.6s_2, 0.3s_3, 0.1)$	$(0.8s_2, 0s_3, 0.2)$	$(0.2s_2, 0.6s_3, 0.2)$	$(0.5s_2, 0.35s_3, 0.15)$
C_4	$(0.5s_5, 0.4s_6, 0.1)$	$(0.6s_5, 0.3s_6, 0.1)$	$(0.4s_5, 0.5s_6, 0.1)$	$(0.4s_5, 0.5s_6, 0.1)$	$(0.48s_5, 0.42s_6, 0.1)$
C_5	$(0.3s_5, 0.6s_6, 0.1)$	$(0.2s_5, 0.7s_6, 0.1)$	$(0.4s_5, 0.3s_6, 0.3)$	$(0.1s_5, 0.8s_6, 0.1)$	$(0.25s_5, 0.6s_6, 0.15)$
C_6	$(0.7s_5, 0.2s_6, 0.1)$	$(0.6s_5, 0.3s_6, 0.1)$	$(0.4s_5, 0.6s_6, 0)$	$(0.2s_5, 0.6s_6, 0.2)$	$(0.48s_5, 0.42s_6, 0.1)$
C_7	$(0.8s_5, 0.1s_6, 0.1)$	$(0.7s_5, 0.2s_6, 0.1)$	$(0.6s_5, 0.3s_6, 0.1)$	$(0.4s_5, 0.5s_6, 0.1)$	$(0.63s_5, 0.27s_6, 0.1)$
C_8	$(0.7s_4, 0.2s_5, 0.1)$	$(0.3s_4, 0.7s_5, 0)$	$(0.8s_4, 0.2s_5, 0)$	$(0.4s_4, 0.5s_5, 0.1)$	$(0.55s_4, 0.4s_5, 0.05)$
C_9	$(0.3s_5, 0.5s_6, 0.2)$	$(0.6s_5, 0.4s_6, 0)$	$(0.6s_5, 0.3s_6, 0.1)$	$(0.5s_4, 0.4s_5, 0.1)$	$(0.69s_5, 0.21s_6, 0.1)$
C_{10}	$(0.6s_3, 0.3s_4, 0.1)$	$(0.4s_3, 0.5s_4, 0.1)$	$(0.7s_3, 0.2s_4, 0.1)$	$(0.5s_3, 0.4s_4, 0.1)$	$(0.55s_3, 0.35s_4, 0.1)$
C_{11}	$(0.7s_2, 0.3s_3, 0)$	$(0.6s_2, 0.3s_3, 0.1)$	$(0.6s_3, 0.3s_4, 0.1)$	$(0.6s_2, 0.2s_3, 0.2)$	$(0.4s_2, 0.5s_3, 0.1)$

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_1	$(0.4s_4, 0.6s_5, 0)$	$(0.8s_4, 0.1s_5, 0.1)$	$(0.1s_4, 0.9s_5, 0)$	$(0.3s_4, 0.6s_5, 0.1)$	$(0.4s_4, 0.55s_5, 0.05)$
C_2	$(0.6s_2, 0.4s_3, 0)$	$(0.3s_3, 0.5s_4, 0.2)$	$(0.2s_3, 0.6s_4, 0.2)$	$(0.6s_3, 0.4s_4, 0)$	$(0.67s_3, 0.23s_4, 0.1)$
C_3	$(0.3s_4, 0.6s_5, 0.1)$	$(0.3s_4, 0.6s_5, 0.1)$	$(0.7s_4, 0.2s_5, 0.1)$	$(0.8s_4, 0.1s_5, 0.1)$	$(0.53s_4, 0.37s_5, 0.1)$
C_4	$(0.5s_4, 0.4s_5, 0.1)$	$(0.3s_4, 0.6s_5, 0.1)$	$(0.3s_4, 0.5s_5, 0.2)$	$(0.4s_4, 0.6s_5, 0)$	$(0.37s_4, 0.53s_5, 0.1)$
C_5	$(0.3s_4, 0.6s_5, 0.1)$	$(0.6s_4, 0.4s_5, 0)$	$(1s_5, 0s_6, 0)$	$(0.6s_4, 0.3s_5, 0.1)$	$(0.37s_4, 0.58s_5, 0.05)$
C_6	$(0.3s_2, 0.6s_3, 0.1)$	$(0.6s_2, 0.4s_3, 0)$	$(0.2s_2, 0.7s_3, 0.1)$	$(0.4s_2, 0.6s_3, 0)$	$(0.37s_2, 0.58s_3, 0.05)$
C_7	$(0.7s_4, 0.2s_5, 0.1)$	$(0.7s_4, 0.2s_5, 0.1)$	$(0.3s_4, 0.7s_5, 0)$	$(0\ s_4, 0.8s_5, 0.2)$	$(0.43s_4, 0.47s_5, 0.1)$
C_8	$(0.3s_3, 0.6s_4, 0.1)$	$(0.6s_3, 0.3s_4, 0.1)$	$(0.7s_3, 0.2s_4, 0.1)$	$(0.5s_2, 0.4s_3, 0.1)$	$(0.75s_3, 0.15s_4, 0.1)$
C_9	$(0.2s_3, 0.8s_4, 0)$	$(0.6s_3, 0.4s_4, 0)$	$(0.6s_2, 0.3s_3, 0.1)$	$(0.4s_2, 0.5s_3, 0.1)$	$(0.9s_3, 0.05s_4, 0.05)$
C_{10}	$(0.5s_3, 0.3s_4, 0.2)$	$(0.3s_3, 0.7s_4, 0)$	$(0.6s_3, 0.2s_4, 0.2)$	$(0.6s_3, 0.4s_4, 0)$	$(0.5s_3, 0.4s_4, 0.1)$
C_{11}	$(0.2s_4, 0.7s_5, 0.1)$	$(0.6s_4, 0.4s_5, 0)$	$(0.2s_4, 0.8s_5, 0)$	$(0.4s_4, 0.5s_5, 0.1)$	$(0.35s_4, 0.6s_5, 0.05)$

uncertainties. This evidential reasoning approach used a distributed fuzzy belief structure to model precise data, ignorance and fuzziness under the unified framework. Although proportional 3-tuple fuzzy linguistic screening evaluation model and the new evidential reasoning approach both can exhibit good performances under incompleteness, probabilistic and fuzzy uncertainties, the way that they deal with the problems of fuzziness is different. The former uses label index rather than membership functions which are employed by the latter to handle fuzzy assessments. Compared with membership function, label index method perhaps is more easily to operate when transforming fuzzy assessments grades. Hence, an interesting direction for future work perhaps could be combining proportional 3-tupel and the new evidential reasoning approach to screen new products under complicated contexts.

Acknowledgment

The authors would like to thank the anonymous referees for their detailed comments and suggestions that helped significantly improve the version of this paper.

References

[1] T. Astebro. Key success factors for technological entrepreneurs' R&D projects. *IEEE Transactions on Engineering Management*, 51(3): 314–328, Aug., 2004.

[2] P. Belliveau, A. Griffin, and S. Somermeyer. *The PDMA Toolbook for New Product Development*. New York, John Wiley & Sons, 2002.

[3] U. de Brentani. Do firms need a custom-designed new product screening model? *Journal of Product Innovation Management*, 3(2):108–119, 1986.

[4] U. de Brentani. Success and failure in new industrial services. *Journal of Product Innovation Management*, 6(4): 239–258, 1989.

[5] R. J. Calantone, C. A. di Benedetto, and J. B. Schmidt. Using the analytic hierarchy process in new product screening. *Journal of Product Innovation Management*, 16:65–76, 1999.

[6] K. S. Chin, J. B. Yang, M. Guo, and J. P. K. Lam. An evidential-reasoning-interval-based method for new product design assessment. *IEEE Transactions on Engineering Management*, 56(1): 142–156, February, 2009.

[7] R. G. Cooper. Stage-Gate systems: a new tool for managing new products," *Business Horizons*, 33(3): 44–45, 1990.

[8] R. G. Cooper, and U. de Brentani. Criteria for screening new industrial products. *Industrial Marketing Management*, 13(3): 149–156, August, 1984.

[9] A. Craig, and S. Hart. Where to now in new product development research. *European Journal of Marketing*, 26(11):2–49, 1992.

[10] A. Griffin. PDMA research on new product development practices: updating trends and benchmarking best practices. *Journal of Innovation Management*, 14(6):429–458, 1997.

[11] K. M. M. Holtta and K. N. Otto. Incorporating design effort complexity measures in product architectural design and assessment. *Design Studies.*, 26(5):463–485, 2005.

[12] V. N. Huynh, and Y. Nakamori. A linguistic screening evaluation model in new product development. *IEEE Transactions on Engineering Management*, 58(1):165–175, 2011.

[13] C. T. Lin, and C. T. Chen. New product go/no-go evaluation at the front end: a fuzzy linguistic approach. *IEEE Transactions on Engineering Management*, 51(2):197–207, 2004.

[14] J. H. Wang, and J. Hao. A new version of 2-tuple fuzzy linguistic representation model for computing with words. *IEEE Transactions on Fuzzy Systems*, 14(3):435–445, June, 2006.

[15] J. B. Yang, Y. M. Wang, D. L. Xu, and K. S. Chin. The evidential reasoning approach for MADA under both probabilistic and fuzzy uncertainties. *European Journal of Operational Research*, 171(1) 309–343, May, 2006.