A New Linguistic Approach to Go/NoGo Evaluation at the Front End in New Product Development

Van-Nam Huynh[†] **Yoshiteru Nakamori**[†]
[†]School of Knowledge Science
Japan Advanced Institute of Science and Technology
Nomi, Ishikawa 923-1292, Japan
{huynh,nakamori}@jaist.ac.jp

Abstract

This paper introduces a new linguistic approach to new-product go/nogo evaluation at the frond end in new-product development, based on the 2-tuple linguistic representation and the so-called preference-preserving 2-tuple transformation. A case study taken from the literature is used to illuminate the proposed technique and for a comparative study.

Keywords: New product screening, Linguistic assessment, Multi-criteria decision making, Computing with words

1 Introduction

New product development (NPD) is a dynamically complex and multi-stage process which ranges from idea generation through product lunch [3; 19]. Among numerous of activities regarding a NPD project, the screening of new-product ideas is perhaps the most critical NPD activity [1]. However, it has been poorly or inadequately performed, as reported in the literature [2; 5; 4; 21]. Due to the incompleteness of information available and the qualitative nature of most evaluation criteria regarding NPA process, a fuzzy linguistic approach may be necessary and a realistic approach for new-product screening, making use of linguistic assessments and the fuzzy-set-based computation [5; 6; 20]. However, an inherent limitation of such a fuzzy linguistic approach is the loss of information caused by approximation processes, which eventually implies a lack of precision in the final results. This limitation even becomes more critical when applying the approach to new product screening.

This paper proposes an approach to new-product go/nogo evaluation at the frond end in new-product development, based on the 2-tuple linguistic representation and the so-called preference-preserving transformation. It is shown that the proposed approach always yields a consistent result, while maintaining the flexibility for managers in making their decisions as in the fuzzy-set-based approach. Ultimately, this approach enhances the fuzzy logic-based screening model proposed in the previous studies by overcoming the mentioned limitation and with a low cost of computation. A case study taken from the literature is used to illuminate the proposed technique and to compare with the previous technique based on fuzzy computation.

2 A New-Product Screening Framework

The evaluation framework for new-product screening using linguistic assessments is depicted in Fig. 1, which consists of three main parts. The first part is the analysis of a new-product development situation and background. The second part of the framework is to select criteria as well as linguistic scales used by experts for assessing a new product project against criteria. And the third part is the development of a computational model for processing and integrating linguistic assessments aimed at providing an overall linguistic evaluation to managers as a guidance for making screening decision.

2.1 Selecting Criteria for Evaluation

Typically, a new product project is characterized by a multiple of factors and traits. Essentially, a screening evaluation for NPD depends not only on the new product's characteristics but also on a firm's technological competency and marketing competition. By referring to the factors proposed in previous

Table 1: Product Evaluation and Selected Criteria [5]

Criteria		Description
Competitive marketing advantages (C_1)	Marketing timing (C_{11})	Matches desired entry timing needed ny target segments
	Price superiority (C_{12})	Offers value for money to target segments
	Marketing competencies (C_{13})	Conforms to our salesforce, channels of distribution and logistical strengths
	Marketing attractiveness (C_{14})	Permits the company to enter into a growing, high-potential market
Superiority (C_2)	Functional competency (C_{21})	Has unique or special functions to meet and attract target segments
	Featured differentia (C_{22})	Has unique or special features to attract target segments
Technological suitability (C_3)	Design quality (C_{31})	Is design for the quality needed by target segments
	Material specialization (C_{32})	Uses materials of high quality and low rejection
	Manufacturing compatibility (C_{33})	Can be produced by our best manufacturing technology and flexibility
	Supply benefit (C_{34})	Allows the company to use very best suppliers
Risk (C_4)	Market competitiveness (C_{41})	Allows many competitive products in the market
	Technological uncertainty (C_{42})	Uses new technological skills that cannot be addressed by research
	Monetary risk (C_{43})	Products total dollar risk profile of product

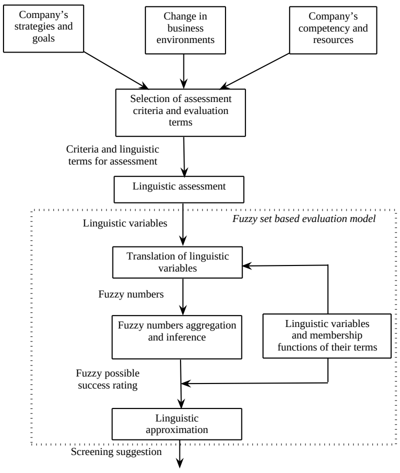

Figure 1: New product screening evaluation framework [5]

studies (e.g., [18; 22]), Lin and Chen [5; 6] suggested a selected set of criteria regarding the screening evaluation for a NPD project, which can be broadly categorized into four groups as shown in Table 1.

2.2 Selecting Linguistic Terms and Associated Semantics

In any linguistic approach to solving a problem, the term set of a linguistic variable and its associated semantics must be defined first to supply the users with an instrument by which they can naturally express their information. In developing their fuzzy logic-based screening model, Lin and Chen [5; 6] have designed four linguistic term sets with associated fuzzy set semantics for use as follows.

- The first term set for linguistically rating different criteria of the factors regarding the product-marketing competitive advantages, product superiority and technological suitability: $\mathcal{S}_1 = \{s^1_0 =$ *worst*, $s^1_1 =$ *very poor*, $s^1_2 =$ *poor*, $s^1_3 =$ *fair*, $s^1_4 =$ *good*, $s^1_5 =$ *very good*, $s^1_6 =$ *best*$\}$ and the associated fuzzy set semantics is shown in Fig. 2.

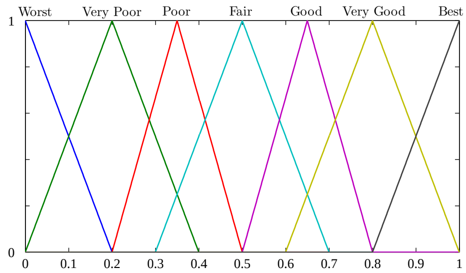

Figure 2: Linguistic effect rating values and their fuzzy number semantics

- The second term set for linguistically assessing risky factors such as market competitive, technological uncertainty and monetary risk regarding a NPD project: $\mathcal{S}_2 = \{s^2_0 =$ *low*, $s^2_1 =$ *fairly low*, $s^2_2 =$ *medium*, $s^2_3 =$ *fairly high*, $s^2_4 =$ *high*, $s^2_5 =$ *very high*, $s^2_6 =$ *extremely high*$\}$ with the associated fuzzy set semantics shown in Fig. 3.

- The third term set and associated fuzzy set semantics (Fig. 4) for linguistically evaluating the relative important of different criteria: $\mathcal{S}_3 = \{s^3_0 =$ *very low*, $s^3_1 =$ *low*, $s^3_2 =$ *fairly low*, $s^3_3 =$ *fairly high*, $s^3_4 =$ *high*, $s^3_5 =$ *very high*$\}$

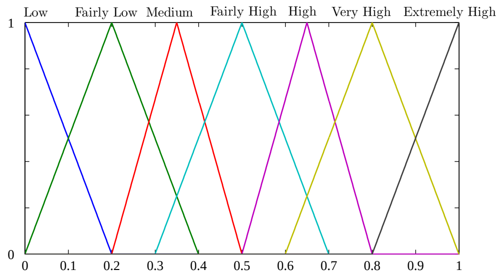

Figure 3: Linguistic risk possibility rating values and their fuzzy number semantics

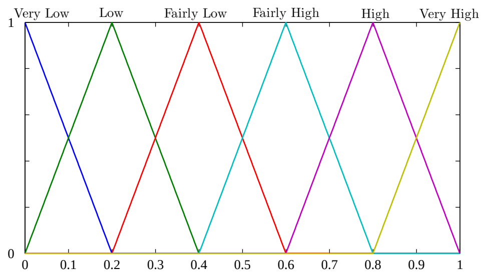

Figure 4: Linguistic weights and their fuzzy number semantics

- The fourth term set $\mathcal{S}_4$ consists of linguistic success levels associated with their fuzzy set semantics also as shown in Fig. 4 for approximating the so-called *fuzzy-possible-success-rating* (FPSR) of a NPD project which results from the computational procedure of the screening evaluation.

2.3 Data Collection and Computational Model for Evaluation

Once the criteria for evaluation as well as measurement scales serving for linguistic assessments have been carefully selected and designed, a finite set of evaluators (i.e., experts), denoted by $P = \{E_1, \ldots, E_m\}$, is called to assess the new product project under consideration in terms of selected criteria, making use of linguistic assessments. In addition, the experts would be also asked to provide their opinions on the relative important of the different criteria. Formally, the linguistic data obtained by this way can be described as in Table 2, where x_{ij} $(i = 1, \ldots, m; j = 1, \ldots, k)$ is the linguistic rating of expert E_i regarding criterion c_j, and w_{ij} $(i = 1, \ldots, m; j = 1, \ldots, k)$ is the linguistic weight which expert E_i assigns to c_j.

From the linguistic evaluation data collected, we then aim at developing a suitable computing method which allows for aggregation of linguistic information to ultimately derive an overall merit or attractiveness value which is used to suggest for the screening decision of a NPD project. Basically, this evaluation problem is a multi-expert/multi-criteria evaluation problem and a method for solving it would be developed appropriately depending on which semantics representation of linguistic terms was used [13; 7; 10]. In [5; 6], Lin and Chen have used the above-mentioned mixed semantics of linguistic terms and developed a fuzzy logic-based screening model, making use of a fuzzy set-based computation method and linguistic approximations. In the following we will propose a novel linguistic based screening model based on the 2-tuple linguistic representation of linguistic information [9] and preference-preserving 2-tuple transformations. Before doing so, however, it is necessary to briefly review and analyze main features of Lin and Chen's fuzzy set based evaluation model taken in the following section.

3 Lin and Chen's Evaluation Model: A Fuzzy Set Based Approach

Lin and Chen [5] have recently proposed a fuzzy set based computational model to aggregate the different decision makers' opinions for deriving the *fuzzy-possible-success rating* of a new product project. Essentially, this computational model is based on Zadeh's *extension principle* [23] in computation with fuzzy numbers and a linguistic approximation method. In addition, their fuzzy logic-based screening model has been then illustrated detailedly with an application to go/no-go decision making for a new machining center development at Taiwan Victory Company [6].

Formally, assume that linguistic assessments gathered for a screening evaluation is formally described in Table 2, where:

- each x_{ij}, for $i = 1, \ldots, m$ and $j = 1, \ldots, k_1$ (i.e., for favorable criteria or

Table 2: Linguistic Assessments and Ratings of Criteria by a Group of Experts

Experts	Criteria							
	Favorable Criteria				Unfavorable Criteria			
	F_1	F_2	...	F_{k_1}	F_{k_1+1}	F_{k_1+2}	...	F_k
E_1	$[x_{11}, w_{11}]$	$[x_{12}, w_{12}]$	...	$[x_{1k_1}, w_{1k_1}]$	$[x_{1k_1+1}, w_{1k_1+1}]$	$[x_{1k_1+2}, w_{1k_1+2}]$	...	$[x_{1k}, w_{1k}]$
E_2	$[x_{21}, w_{21}]$	$[x_{22}, w_{22}]$	...	$[x_{2k_1}, w_{2k_1}]$	$[x_{2k_1+1}, w_{2k_1+1}]$	$[x_{2k_1+2}, w_{2k_1+2}]$	...	$[x_{2k}, w_{2k}]$
...	...	...	...	...	...	...	...	...
E_m	$[x_{m1}, w_{m1}]$	$[x_{m2}, w_{m2}]$	...	$[x_{mk_1}, w_{mk_1}]$	$[x_{mk_1+1}, w_{mk_1+1}]$	$[x_{mk_1+2}, w_{mk_1+2}]$	...	$[x_{mk}, w_{mk}]$

attractive factors), is a linguistic effect rating value semantically represented as a fuzzy number R_{ij} taken from the linguistic term set $\mathcal{S}_1$.

- each x_{ij}, for $i = 1, \ldots, m$ and $j = k_1+1, \ldots, k$ (i.e., for unfavorable criteria or risk factors), is a linguistic risk possibility rating value semantically represented as a fuzzy number R'_{ij} taken from the linguistic term set $\mathcal{S}_2$.

- each w_{ij}, for $i = 1, \ldots, m$ and $j = 1, \ldots, k$, is a linguistic weight semantically represented as a fuzzy number W_{ij} taken from the linguistic term set $\mathcal{S}_3$.

Then Lin and Chen's procedure for deriving an overall merit value can be briefly summarized as follows.

1. *Experts' Opinion Aggregation.* For each $j = 1, \ldots, k$, the average effect rating R_j, the average risk possibility rating R'_j, and the average important weight W_j are computed as

$$R_j = \frac{1}{m} \otimes (R_{1j} \oplus R_{2j} \oplus \ldots \oplus R_{mj}), \quad j = 1, \ldots, k_1 \tag{1}$$

$$R'_j = \frac{1}{m} \otimes \left(R'_{1j} \oplus R'_{2j} \oplus \ldots \oplus R'_{mj}\right), \quad j = k_1 + 1, \ldots, k \tag{2}$$

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

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

2. *Criteria Aggregation.* Weighted aggregation of criteria by means of fuzzy weighted averaging operator to obtain a fuzzy-possible-success-rating (FPSR) $\mathcal{F}$:

$$\mathcal{F} = \frac{\sum_{j=1}^{k_1} R_j \otimes W_j \oplus \sum_{j=k_1+1}^{k} (1 \ominus R'_j) \otimes W_j}{\sum_{j=1}^{k} W_j} \tag{4}$$

where $\ominus$ stands for the extended subtraction over fuzzy numbers. Computing the expression of fuzzy weighted average (4) for the FPSR $\mathcal{F}$ is carried out using the fractional programming approach developed by Kao and Liu [16].

3. *Linguistic Approximation.* Once the fuzzy-possible-success-rating $\mathcal{F}$ for new product has been obtained, a linguistic approximation method based on Euclidean distance is used to match $\mathcal{F}$ with linguistic success levels from $\mathcal{S}_4$ with its associated fuzzy numbers semantics. The linguistic success level which matches best the FPSR $\mathcal{F}$ will be chosen as a guidance to the decision maker.

4 Linguistic 2-Tuple Based Evaluation Model

4.1 2-Tuple Linguistic Representation Model

The 2-tuple linguistic representation model has been recently proposed in [9] as a tool for computing with words which aims at overcoming the limitation of the loss of information caused by the process of linguistic approximation in the traditional fuzzy set based approach. This model has been applied to group decision making [11; 14], distributed intelligent agent systems [8], information filtering [12], information retrieval [17].

4.1.1 2-Tuple Representation of Linguistic Information

Let $\mathcal{S} = \{s_0, \ldots, s_g\}$ be a linguistic term set on which a total order is defined as: $s_i \leq s_j \Leftrightarrow i \leq j$. In addition, a negation operator Neg can be defined by: $\text{Neg}(s_i) = s_j$ such that $j = g - i$, where $g + 1$ is the cardinality of $\mathcal{S}$. In general, applying a symbolic method for aggregating linguistic information often yields a value $\beta \in [0, g]$, and $\beta \notin \{0, \ldots, g\}$, then a symbolic approximation must be used to get the result expressed in $\mathcal{S}$.

To avoid any approximation process which causes a loss of information in the processes of computing with words, alternatively the 2-tuple linguistic representation model takes $\mathcal{S} \times [-0.5, 0.5)$ as the underlying space for representing information. In this representation space, if a value $\beta \in [0, g]$ representing the result of a linguistic aggregation operation, then the 2-tuple (s_i, α) that expresses the equivalent information to β is obtained by means of the following transformation:

$$\begin{array}{rcccl} \Delta & : & [0,g] & \longrightarrow & \mathcal{S} \times [-0.5, 0.5) \\ & & \beta & \longmapsto & (s_i, \alpha), \end{array}$$

with

$$\left\{ \begin{array}{l} i = \text{round}(\beta) \\ \alpha = \beta - i \end{array} \right.$$

and then α is called a *symbolic translation*, which supports the "difference of information" between a counting of information $\beta \in [0, g]$ obtained after a symbolic aggregation operation and the closest value in $\{0, \ldots, g\}$ indicating the index of the best matched term in $\mathcal{S}$.

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

$$\begin{array}{rcccl} \Delta^{-1} & : & \mathcal{S} \times [-0.5, 0.5) & \longrightarrow & [0,g] \\ & & (s_i, \alpha) & \longmapsto & i + \alpha. \end{array}$$

Under such transformations, it should be noticed here that any original linguistic term s_i in S is then represented by its equivalent 2-tuple $(s_i, 0)$ in the 2-tuple linguistic model.

Using two 2-tuple transformations defined above, the negation operator over 2-tuples is defined as follows:

$$\text{Neg}((s_i, \alpha)) = \Delta(g - (\Delta^{-1}(s_i, \alpha))) \quad (5)$$

In addition, 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. Therefore, many aggregation operators proposed in the literature for dealing with numerical information can be easily extended to work out with linguistic 2-tuples [9; 12; 8].

4.2 Preference-Preserving 2-Tuple Transformation

In a numerical context of multi-criteria aggregation, information are often needed to be unified before performing any aggregation process by means of normalization methods. This is basically due to inhomogeneous nature of different measurement scales/units used for different criteria in the evaluation process. Such an unification operation is usually needed in the linguistic setting of multi-criteria aggregation as well. It should be emphasized here that a process of unifying linguistic information has been implicitly used in [5; 6] by embedding membership functions of all linguistic terms from different term sets into the space of fuzzy numbers on $[0, 1]$. Therefore, in order to make the 2-tuple linguistic representation model applicable to the problem of multi-expert/multi-criteria linguistic evaluation for go/no-go decision in NPD, it is necessary to find out a mechanism for unifying linguistic information represented by means of 2-tuples from different term sets.

To this end, we first define the following notion of preference-preserving 2-tuple transformation between two term sets. Let $\mathcal{S} = \{s_0, \ldots, s_g\}$ and $\mathcal{S}' = \{s'_0, \ldots, s'_{g'}\}$ be two linguistic term sets. Note that the total order on $\mathcal{S}$, denoted by $\leq_{\mathcal{S}}$, (and $\mathcal{S}'$ as well) is either 'in agreement with' or 'reverse to' the preference order, denoted by $\preceq_{\mathcal{S}}$, imposed on the criterion assessed by means of linguistic values in $\mathcal{S}$. That is, for the case of 'in agreement with', the greater a linguistic value, the higher preference; and by contrast, the greater a linguistic value, the lower preference for the case of 'reverse to'. For example, the order relation on $\mathcal{S}_1$ defined above is in agreement with the preference order imposed on factors of the product-marketing competitive advantages, product superiority and technological suitability, while the order relation on $\mathcal{S}_2$ is reverse to the preference order imposed on risky factors as market competitive, technological uncertainty and monetary risk. Now, without loss of generality, assuming that $\leq_{\mathcal{S}}$ is in agreement with $\preceq_{\mathcal{S}}$. Having these considerations in mind, we are ready to define the preference-preserving 2-tuple transformation between $\mathcal{S}$ and $\mathcal{S}'$ as follows:

$$\begin{aligned} \Lambda: \quad & \mathcal{S} \times [-0.5, 0.5) && \longrightarrow \mathcal{S}' \times [-0.5, 0.5) \\ & (s_i, \alpha) && \longmapsto (s'_j, \alpha') \end{aligned} \tag{6}$$

such that

$$\begin{cases} j = \text{round}(\frac{g'}{g}(i+\alpha)) \\ \alpha' = \frac{g'}{g}(i+\alpha) - j \end{cases} \tag{7}$$

if $\leq_{\mathcal{S}'}$ is in agreement with $\preceq_{\mathcal{S}'}$, i.e. $\preceq_{\mathcal{S}'} \equiv \leq_{\mathcal{S}'}$, and

$$\begin{cases} j = \text{round}(g' - \frac{g'}{g}(i+\alpha)) \\ \alpha' = g' - \frac{g'}{g}(i+\alpha) - j \end{cases} \tag{8}$$

otherwise, i.e. $\preceq_{\mathcal{S}'} \equiv \leq_{\mathcal{S}'}^{-1}$ – the inversion of $\leq_{\mathcal{S}'}$.

Due to the order-preserving property of Δ and Δ^{-1} as well as the definition of Λ, it then straightforwardly follows that Λ is preference-preserving. As such, the transformation Λ allows us to transform inhomogeneous linguistic information into the 2-tuple representation of a specific linguistic term set preserving the preference of all the criteria.

4.3 2-Tuple Linguistic Evaluation Model

Let us return to the screening evaluation problem with linguistic information as described in Table 2. For the sake of simplicity but without loss of generality, we assume that the same linguistic term set $\mathcal{S}_1$ is used for rating favorable criteria F_j ($j = 1, \ldots, k_1$), and the same linguistic term set $\mathcal{S}_2$ is used for rating unfavorable criteria F_j ($j = k_1+1, \ldots, k_1+k_2$). Also, the term set $\mathcal{S}_3$ is used for representing the relative important weights of criteria.

With all the preparations made previously, the screening evaluation procedure based on 2-tuple linguistic representation is described as following.

4.3.1 2-Tuple Linguistic Transformation and Unification

This step aims at transforming original linguistic information of a NPD project assessed by experts against a set of criteria into an unified representation by means of 2-tuples. It is composed of the following steps.

i) Convert original linguistic assessments and weights as shown in Table 2 into corresponding linguistic 2-tuples by adding a symbolic translation value of 0: $x_{ij} \Rightarrow (x_{ij}, 0)$ and $w_{ij} \Rightarrow (w_{ij}, 0)$.

ii) Choose a specific linguistic term set used for information unification. For example, in the context of screening evaluation problems, a term set of linguistic preferences $\mathcal{S}_p$ could be chosen.

iii) Transform 2-tuple linguistic assessments $(x_{ij}, 0)$ into 2-tuples represented in $\mathcal{S}_p \times [-0.5, 0.5)$, making use of the following preference-preserving 2-tuple transformations:

$$\Lambda_1: \quad \mathcal{S}_1 \times [-0.5, 0.5) \rightarrow \mathcal{S}_p \times [-0.5, 0.5)$$
$$\Lambda_2: \quad \mathcal{S}_2 \times [-0.5, 0.5) \rightarrow \mathcal{S}_p \times [-0.5, 0.5)$$

where Λ_1 and Λ_2 are defined by (7) and (8), respectively. Let us denote

$$(y_{ij}, \alpha_{ij}) = \begin{cases} \Lambda_1((x_{ij}, 0)), & j = 1, \ldots, k_1 \\ \Lambda_2((x_{ij}, 0)), & j > k_1 \end{cases}$$

4.3.2 2-Tuple Linguistic Computation and Aggregation

i) Multi-expert aggregation for computing 2-tuples of the average important weights and the average preferences of criteria as

$$(w_j, \alpha_j^w) = \Delta\left(\sum_{i=1}^{m} \frac{1}{m} \Delta^{-1}(w_{ij}, 0)\right) \tag{9}$$

$$(r_j, \alpha_j) = \Delta\left(\sum_{i=1}^{m} \frac{1}{m} \Delta^{-1}(y_{ij}, \alpha_{ij})\right) \tag{10}$$

for $j = 1, \ldots, k$.

ii) Computing an overall figure of merit which typically expresses the preference

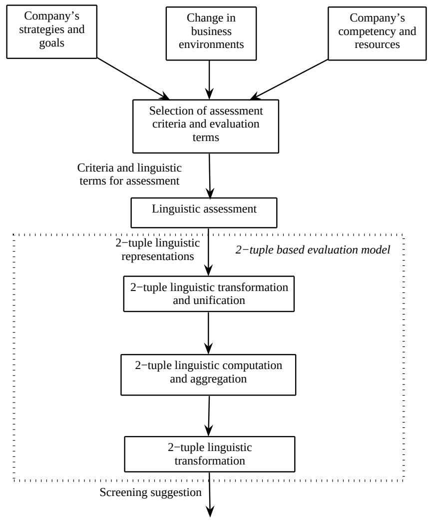

Figure 5: 2-Tuple based screening evaluation framework

regarding the NPD project under consideration as

$$(r, \alpha) = \Delta \left(\frac{\sum_{j=1}^{k} \Delta^{-1}(r_j, \alpha_j) \Delta^{-1}(w_j, \alpha_j^w)}{\sum_{j=1}^{k} \Delta^{-1}(w_j, \alpha_j^w)} \right) \tag{11}$$

4.3.3 2-Tuple Linguistic Conversion

Convert the overall value of preference for the NPD project represented by 2-tuple (r, α) in $\mathcal{S}_p \times [-0.5, 0.5)$ into the corresponding 2-tuple of linguistic success levels in $\mathcal{S}_4 \times [-0.5, 0.5)$, i.e. $\Lambda((r, \alpha))$,which will be provided to the decision maker as a guidance for his/her screening decision.

Integrating this 2-tuple based evaluation model into the new product screening evaluation framework, instead of fuzzy set based evaluation model developed by Lin and Chen [5], suggests a 2-tuple based screening evaluation framework as shown in Fig. 5.

5 Concluding Remarks

As for a comparative study, we have applied the 2-tuple based screening evaluation model to a case study of the TVcenter-HX project implemented by Lin and Chen [5; 6]. Due to the limitation of page number, we could not report this comparative study in detail here (see [15]), but some interesting implications pointed as follows:

- While the computational processes in the fuzzy set based screening model may cause a loss of information, and consequently yield an imprecise result, these do not happen in the proposed evaluation model.

- The 2-tuple based screening model not only yields the screening evaluation by means of a linguistic expression as in the fuzzy set based screening model, but also supplies an additional information indicating how much difference exists between the true evaluation and linguistic one serving as a guidance for the screening decision making.

- By performing direct computation on linguistic terms in the proposed approach, the burden of quantifying a qualitative concept is eliminated and then the computational cost is considerably reduced.

References

[1] R. Balachandra, "Critical signals for making go/nogo decisions in new product development," *J. Prod. Innov. Manag.*, vol. 1, no. 2, pp. 92–100, 1984.

[2] A. Griffin, "PDMA research on new product development practices: updating trends and benchmarking best practices," *J. Prod. Innov. Manag.*, vol. 14, no. 6, pp. 429–514, 1997.

[3] R. G. Cooper, E. J. Kleinschmidt, "An investigation into the new product process: Steps, deficiencies, and impact," *J. Prod. Innov. Manag.*, vol. 3, no. 2, pp. 71–85, 1986.

[4] D. Liginlal, S. Ram, L. Duckstein, "Fuzzy measure theoretical approach to screening product innovations," *IEEE Trans. Syst., Man, Cybern.–Part A*, vol. 36, no. 3, pp. 577–591, 2006.

[5] C.-T. Lin, C.-T. Chen, "A fuzzy-logic-based approach for new product go/nogo decision at the front end," *IEEE Trans.*

Syst., *Man*, *Cybern.–Part A*, vol. 34, no. 1, pp. 132–142, 2004.

[6] C.-T. Lin, C.-T. Chen, "New product go/nogo evaluation at the front end: A fuzzy linguistic approach," *IEEE Trans. Eng. Manag.*, vol. 51, no. 2, pp. 197–207, 2004.

[7] S. M. Chen, "Fuzzy group decision making for evaluating the rate of aggregative risk in software development," *Fuzzy Sets Syst.*, vol. 118, pp. 75–88, 2001.

[8] M. Delgado, F. Herrera, E. Herrera-Viedma, M. Martin-Bautista, L. Martinez, M. Vila, "A communication model based on the 2-tuple fuzzy linguistic representation for a distributed intelligent agent system on Internet," *Soft Computing*, vol. 6, pp. 320–328, 2002.

[9] F. Herrera, L. Martinez, "A 2-tuple fuzzy linguistic representation model for computing with words," *IEEE Trans. Fuzzy Syst.*, vol. 8, pp. 746–752, 2000.

[10] F. Herrera, E. Herrera-Viedma, "Linguistic decision analysis: steps for solving decision problems under linguistic information," *Fuzzy Sets Syst.*, vol. 115, pp. 67–82, 2000.

[11] F. Herrera, L. Martinez, "A model based on linguistic 2-tuples for dealing with multigranular hierarchical linguistic contexts in multi-expert decision-making," *IEEE Trans. Syst.*, *Man*, *Cybern.–Part B*, vol. 31, pp. 227–234, 2001.

[12] E. Herrera-Viedma, F. Herrera, L. Martinez, J.C. Herrera, A.G. Lopez-Herrera, "Incorporating filtering techniques in a fuzzy linguistic multi-agent model for information gathering on the Web," *Fuzzy Sets Syst.*, vol. 148, no. 1, pp. 61–83, 2004.

[13] V. N. Huynh, Y. Nakamori, "A satisfactory-oriented approach to multi-expert decision-making under linguistic assessments," *IEEE Trans. Syst.*, *Man*, *Cybern.–Part B*, vol. 35, no. 2, pp. 184–196, 2005.

[14] V. N. Huynh, C. H. Nguyen, Y. Nakamori, "MEDM in general multi-granular hierarchical linguistic contexts based on the 2-tuples linguistic model," *Proceedings of IEEE International Conference on Granular Computing* (GrC 2005), July 2005, Beijing, China, IEEE, pp. 482–487.

[15] V. N. Huynh, Y. Nakamori, "A computing-with-words approach to go/stop evaluation at the front end in product innovations," submitted to *IEEE Trans. Eng. Manag.*.

[16] C. Kao, S.-T. Liu, 'Competitiveness of manufacturing firms: An application of fuzzy weighted average,' *IEEE Trans. Syst.*, *Man*, *Cybern.–Part A*, vol. 29, pp. 661–667, 1999.

[17] E. Herrera-Viedma, A. G. Lopez-Herrera, M. Luque, C. Porcel, "A fuzzy linguistic IRS model based on a 2-tuple fuzzy linguistic approach," *Int. J. Uncertain. Fuzziness Knowl.-Based Syst.*, vol. 15, no. 2, pp. 225–250, 2007.

[18] R. J. Calantone, C. A. Di Benedetto, J. B. Schmidt, "Using the analytic hierarchy process in new product screening," *J. Prod. Innov. Manag.*, vol. 16, no. 1, pp. 65–76, 1999.

[19] M. Ozer, "A survey of new product evaluation models," *J. Prod. Innov. Manag.*, vol. 16, no. 1, pp. 77–94, 1999.

[20] L.L. Machacha, P. Bhattacharya, "A fuzzy-logic-based approach to project selection," *IEEE Trans. Eng. Manag.*, vol. 47, no. 1, pp. 65–73, 2000.

[21] V. Mahajan, J. Wind, "New product models: Practice, shortcomings and desired improvements," *J. Prod. Innov. Manag.*, vol. 9, no. 2, pp. 128–139, 1992.

[22] X. M. Song, M. E. Parry, "What separates japanese new product winners from losers," *J. Prod. Innov. Manag.*, vol. 13, no. 5, pp. 422–439, 1999.

[23] L. A. Zadeh, "The concept of a linguistic variable and its applications to approximate reasoning. Part I," *Inf. Sci.*, vol. 8, pp. 199–249, 1975; Part II, *Inf. Sci.*, vol. 8, pp. 301–357, 1975; Part III, *Inf. Sci.*, vol. 9, pp. 43–80, 1975.