Applying Interval Linguistic Variables on Project Evaluation of New Product Development

Chen-tung Chen, P.C. Fu, and W.Z. Hung

Abstract In recent years, the global financial storm causes the enterprises to face challenges more severely. To survive in the markets, the enterprises should provide the new products or services continuously to increase their competitiveness. However, the evaluation process of a new product development (NPD) project may face the uncertainties of technology and market in the future. It means that a NPD project will face the higher investment risk. To reduce development costs and risks, an effective evaluation model of the NPD project has become more important issue for enterprises. In this paper, a systematic evaluation model of new product development project is proposed by combining interval 2-tuple linguistic variables with multiple criteria decision making (MCDM). And then, a numerical example is implemented to illustrate the computation process of proposed model. Finally, the conclusion is provided at the end of this paper.

Keywords Interval 2-tuple linguistic variables • Multiple criteria decision making • New product development projects

1 Introduction

In recent years, the global financial turmoil has intensified negative impacts on the world economy. For the sake of assuring survival and increasing competitive advantage, enterprises should continuously introduce new products or services to

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increase their revenues and enhance their competitiveness [1]. A successful new product development (NPD) project will increase profits and competitive advantages for a company, but a failed project could pose a significant impact on the business operation. Therefore, a successful NPD project is a key factor for enterprises to increase their competitiveness. Barczak et al., pointed out that more than one-third of sales profits came from the development of new products within 5 years [2]. Furthermore, some studies showed that new products have made contributions to sales revenues and profits on a consistent upward trend from 20 % in the 1970s to 50 % in the 1990s [3–5]. Therefore, businesses can only rely on continuous development of new products or services to ensure their survival and thereby enhance their competitive advantages in the market.

A successful NPD project has become the most important factor for a company to create profits and competitive advantages; therefore, a systematic evaluation model of the possibility of success in NPD project has become an essential issue. Many influenced factors should be considered in the evaluation process of NPD projects. Therefore, it can be formulated as a multiple criteria decision making (MCDM) problem. Most of the traditional MCDM methods assume that both evaluation results and weights of criteria are crisp values for conducting decision-making rating and ranking. In real environment, decision-makers could probably need to encounter some evaluation criteria with fuzzy and qualitative characteristics, and hence the decision problems became more complex and difficult. Therefore, Bellman and Zadeh applied the fuzzy set theory in the decision-making environment firstly [6]. Since then, the fuzzy set theory is considered to be an important methodology to establish evaluation models for decision problems. The fuzzy set theory was widely applied in engineering, business, natural science and medical researches [7–9].

This paper will incorporate the fuzzy theory with MCDM methods based on 2-tuple interval linguistic variables to construct an evaluation model for measuring the degree of success of a new product development project.

2 Literature Review

2.1 Evaluation Methods of NPD Projects

During the implementation of a new product development project, the enterprises conduct periodic evaluations to ensure that the project can be successful and performed efficiently.

Wang proposed a 2-tuple fuzzy linguistic computing approach to measure the performance of a new product development project for an actual company [10]. Oliveira and Rozenfeld proposed a new method to support the development of front-end activities based on technology road mapping (TRM) and project portfolio management (PPM) methodologies [11]. Liu propounded a method of combining

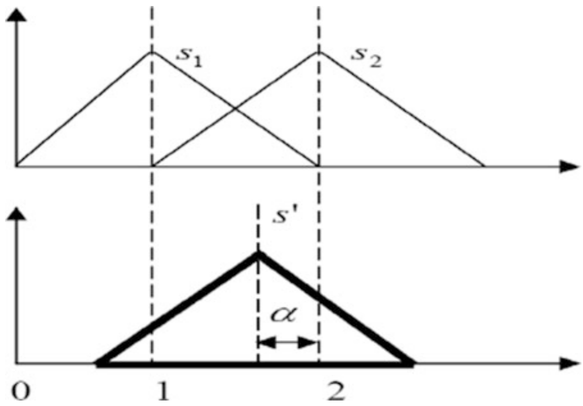

Fig. 1 The definition of 2-tuple linguistic variable

fuzzy and quality function deployment (QFD) for considering the necessary and quickness of product function changes which cause the needs to short process of NPD. Therefore, enterprises must develop a new product which can satisfy the requirement of consumers in a short time [12]. Senthil proposed the hybrid methodology based on analytical hierarchy process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) under fuzzy environment for selection and evaluation of reverse logistics operating channels [13]. In this paper, we combine 2-tuple linguistic variables and SAW method to help decision markers evaluate the possibility of success of a new product development project.

2.2 The 2-Tuple Fuzzy Linguistic Variables

Herrera and Martinez proposed the 2-tuple fuzzy linguistic representation model and used linguistic variables by two parameters with label $L=(s,\alpha)$ [14]. The parameter s is a value of the fuzzy linguistic variable. For example, let $S=\{s_0$: very unimportant, s_1: unimportant, s_2: fair, s_3: important, s_4: very important$\}$, then $s \in S$. The parameter α is the distance between s and the desired linguistic variable. If linguistic variable's value s' is between s_1 and s_2, then $L'=(s_2, \alpha)$ can be represented by using a 2-tuple linguistic variable as shown in Fig. 1.

In fact, decision makers based on their expertise in different situations would select suitable 2-tuple linguistic variables as evaluation basis. Different types of linguistic variables can also be set by different membership functions as shown in Table 1 [15].

Chen and Chen combined the concepts of 2-tuple linguistic variables and ordinal proportional 2-tuple sets that permit judgment by using not only single linguistic variable but also two adjacent linguistic variables for representing expert's subject opinions adequately [15]. Assume that l_i ($i=0, 1, \ldots, n-1$) is a 2-tuple linguistic

Table 1 Different types of linguistic variables

Figure	Linguistic variable	
5-scale linguistic variables (Fig. 2)	Evaluation values	Very low (s_0^5), low (s_1^5), medium (s_2^5), high (s_3^5), very high (s_4^5)
	Weights	Very unimportant (s_0^5), unimportant (s_1^5), medium (s_2^5), important (s_3^5), very important (s_4^5)
7-scale linguistic variables (Fig. 3)	Evaluation values	Pretty low (s_0^7), very low (s_1^7), low (s_2^7), medium (s_3^7), high (s_4^7), very high (s_5^7), pretty high (s_6^7)
	Weights	Pretty unimportant (s_0^7), very unimportant (s_1^7), unimportant (s_2^7), medium (s_3^7), important (s_4^7), very important (s_5^7), pretty important (s_6^7)
9-scale linguistic variables (Fig. 4)	Evaluation values	Extremely low (s_0^9), pretty low (s_1^9), very low (s_2^9), low (s_3^9), medium (s_4^9), high (s_5^9), very high (s_6^9), pretty high (s_7^9), extremely high (s_8^9)
	Weights	Extremely unimportant (s_0^9), pretty unimportant (s_1^9), very unimportant (s_2^9), unimportant (s_3^9), medium (s_4^9), important (s_5^9), very important (s_6^9), pretty important (s_7^9), extremely important (s_8^9)

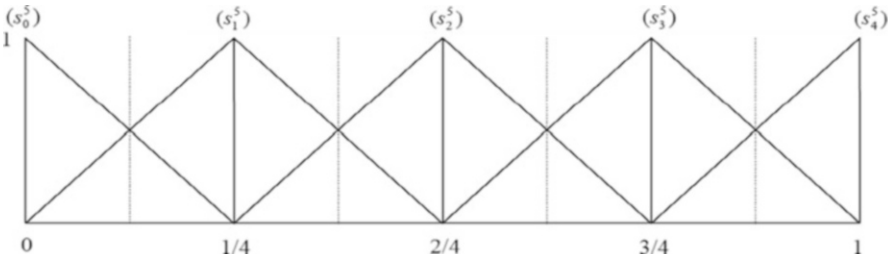

Fig. 2 Membership functions of five scale linguistic variables

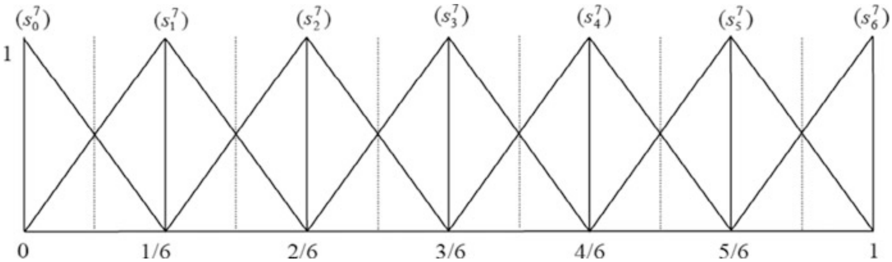

Fig. 3 Membership functions of seven scale linguistic variables

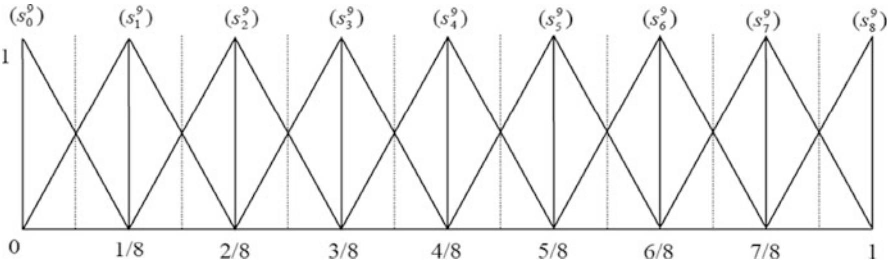

Fig. 4 Membership functions of nine scale linguistic variables

variable and represent it by $l_i = (s_i, \alpha_i)$. Let $\overline{L_i} = (pl_i, (1-p)\ l_{i+1})$ and the equations shown below can be used to transform $\overline{L_i}$ into crisp value β ($\beta \in [0,1]$) and the reverse.

$$\overline{\Delta}^{-1}\left(\overline{L_i}\right) = \overline{\Delta}^{-1}\left(pl_i, (1-p)\ l_{i+1}\right)$$
$$= p \cdot \Delta^{-1}(s_i, \alpha_i) + (1-p) \cdot \Delta^{-1}(s_{i+1}, \alpha_{i+1}) = \beta \quad (1)$$

$$\overline{\Delta}(\beta) = (pl_i, (1-p)\ l_{i+1}) \quad (2)$$

where $\Delta^{-1}(s_i, \alpha_i) \le \beta \le \Delta^{-1}(s_{i+1}, \alpha_{i+1})$, $p = g \cdot (\Delta^{-1}(s_{i+1}, \alpha_{i+1}) - \beta)$ and the reverse function Δ^{-1} was defined in [16].

Transform an interval linguistic variable with $n(t)$-scale $(pl_i^{n(t)}, (1-p)\ l_{i+1}^{n(t)})$ into $n(t+1)$-scale $(ql_k^{n(t+1)}, (1-q)\ l_{k+1}^{n(t+1)})$ as follows.

$$TF_{t+1}^{t}\left(pl_i^{n(t)}, (1-p)\ l_{i+1}^{n(t)}\right) = \overline{\Delta}_{t+1}\left(\overline{\Delta}_t^{-1}\left(pl_i^{n(t)}, (1-p)\ l_{i+1}^{n(t)}\right)\right)$$
$$= \left(ql_k^{n(t+1)}, (1-q)\ l_{k+1}^{n(t+1)}\right) = \left(qs_k^{n(t+1)}, (1-q)\ s_{k+1}^{n(t+1)}\right) \quad (3)$$

where, $q = g_{t+1} \cdot (\Delta_t^{-1}(s_{i+1}^{n(t+1)}, 0) - \beta)$, $g_{t+1} = n(t+1) - 1$, and $\Delta_{t+1}^{-1}(s_k^{n(t+1)}, 0) \le \beta \le \Delta_{t+1}^{-1}(s_{k+1}^{n(t+1)}, 0)$.

3 The Proposed Method

3.1 *To Establish Evaluate Hierarchy Framework*

To effectively evaluate the possibility of success in an NPD project, decision makers must collect critical factors and screen criteria index to build up a hierarchical structure of the probability evaluation. Suppose that there are n evaluation dimensions and each dimension contains t_i ($i = 1, 2, \ldots, n$) evaluation indices. The hierarchical structure can be specified as Fig. 5.

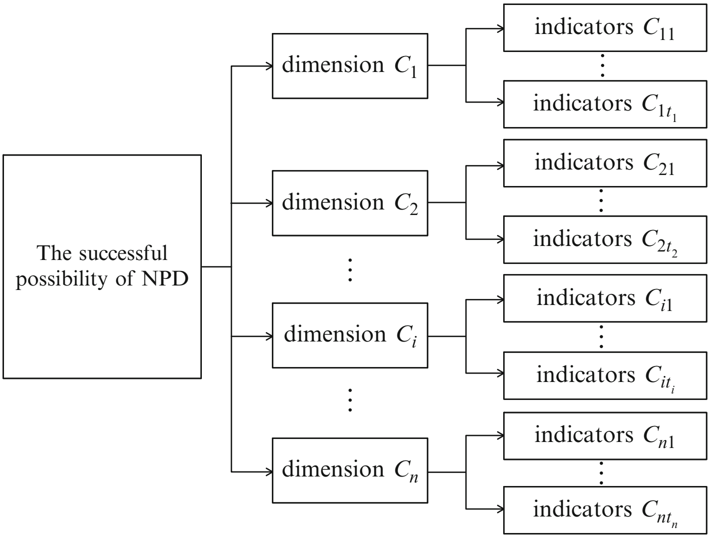

Fig. 5 Hierarchical evaluation framework

3.2 Evaluation Process

According to the evaluation framework, the evaluation process of the proposed model is illustrated as follows.

Step 1. Each expert can select suitable linguistic variables based on their knowledge or experiences (shown as Table 3).

Step 2. Experts provide the interval 2-tuple linguistic weights with respect to each dimension and indicator.

Step 3. Each expert offers the interval 2-tuple linguistic evaluation values with respect to indicator in each dimension.

Step 4. Transform interval linguistic variables into the same type to aggregate the linguistic evaluation values and weights.

Step 5. Compute the weight of each indicator by aggregating the linguistic weights of K experts. The calculation can be shown as

$$\tilde{w}_i = \frac{1}{K}\left(\tilde{w}_i^1 + \tilde{w}_i^2 + \cdots + \tilde{w}_i^K\right), \quad k = 1, 2, \ldots, K \tag{4}$$

where $\tilde{w}_i = \left[w_i s_m^z, (1 - w_i)\ s_{m+1}^z\right]$ is the interval linguistic weight of the i-th dimension, and $\tilde{w}_i^k = \left[w_i^k s_m^z, \left(1 - w_i^k\right)\ s_{m+1}^z\right]$ is the k-th expert's interval weight of the i-th dimension.

Step 6. Aggregate the linguistic weights of k experts with respect to each indicator under each dimension. The calculation can be shown as

$$\tilde{w}_{ij} = \frac{1}{K}\left(\tilde{w}_{ij}^{1} + \tilde{w}_{ij}^{2} + \cdots + \tilde{w}_{ij}^{K}\right), \quad j = 1, 2, \ldots, t_i \tag{5}$$

where $\tilde{w}_{ij}^{k} = \left[w_{ij}^{k} s_m^z, \left(1 - w_{ij}^{k}\right) s_{m+1}^{z}\right]$ is the interval linguistic weight of the k-th expert with respect to the j-th indicator in dimension C_i.

Step 7. Aggregate the linguistic evaluation values of K experts with respect to each indicator under each dimension. The calculation can be shown as

$$\tilde{X}_{ij} = \frac{1}{K}\left(\tilde{X}_{ij}^{1} + \tilde{X}_{ij}^{2} + \cdots + \tilde{X}_{ij}^{K}\right), \quad j = 1, 2, \ldots, t_i \tag{6}$$

where $\tilde{X}_{ij}^{k} = \left[X_{ij}^{k} s_m^z, \left(1 - X_{ij}^{k}\right) s_{m+1}^{z}\right]$ is the k-th expert's interval linguistic evaluation value of the j-th indicator in dimension C_i.

Step 8. Calculate the aggregated interval evaluation value of each dimension as

$$\tilde{X}_i = \overline{\Delta}\left[\frac{\sum_{j=1}^{t_i} \overline{\Delta}^{-1}\left(\tilde{X}_{ij}\right) \cdot \overline{\Delta}^{-1}\left(\tilde{w}_{ij}\right)}{\sum_{j=1}^{t_i} \overline{\Delta}^{-1}\left(\tilde{w}_{ij}\right)}\right], \quad i = 1, 2, \ldots, n \tag{7}$$

where $\tilde{X}_i = \left[X_i s_m^z, (1 - X_i)\ s_m^z\right]$ is the weighted interval evaluation value in the i-th dimension.

Step 9. Compute the degree of success of the NPD project as

$$\tilde{p} = \Delta\left[\frac{\sum_{i=1}^{n}\left(\overline{\Delta}^{-1}\left(\tilde{X}_i\right) \cdot \overline{\Delta}^{-1}\left(\tilde{w}_i\right)\right)}{\sum_{i=1}^{n} \overline{\Delta}^{-1}\left(\tilde{w}_i\right)}\right] \tag{8}$$

where $\tilde{p}$ is the successful possibility of the NPD project and it can be represented in interval linguistic variables.

4 An Example

Suppose that a company want to evaluate the successful possibility of an NPD project. Three experts are formed a decision group. The evaluation dimensions include technology ability (C_1), marketing ability (C_2), and management ability (C_3). The evaluation indicators of each dimension are research technology ability of product (C_{11}), new product quality (C_{12}), market acceptance (C_{21}), possibility of

Table 2 The importance of each dimension

Dimensions	Weights		
	D_1	D_2	D_3
C_1	$(0.3s_3^5, 0.7s_4^5)$	$(0s_4^7, 1s_5^7)$	$(0s_6^9, 1s_7^9)$
C_2	$(0s_2^5, 1s_3^5)$	$(0.5s_5^7, 0.5s_6^7)$	$(0.3s_6^9, 0.7s_7^9)$
C_3	$(0s_2^5, 1s_3^5)$	$(0.5s_3^7, 0.5s_4^7)$	$(0.4s_7^9, 0.6s_8^9)$

Table 3 The importance of indicators in each dimension

Dimensions	Indicators	Weights		
		D_1	D_2	D_3
C_1	C_{11}	$(0.3s_3^5, 0.7s_4^5)$	$(0s_2^7, 1s_3^7)$	$(0s_5^9, 1s_6^9)$
	C_{12}	$(0.5s_3^5, 0.5s_4^5)$	$(0.3s_3^7, 0.7s_4^7)$	$(0.5s_6^9, 0.5s_7^9)$
C_2	C_{21}	$(0s_2^5, 1s_3^5)$	$(0s_3^7, 1s_4^7)$	$(0s_5^9, 1s_6^9)$
	C_{22}	$(0s_2^5, 1s_3^5)$	$(0.5s_5^7, 0.5s_6^7)$	$(0.8s_7^9, 0.2s_8^9)$
	C_{23}	$(0.8s_3^5, 0.2s_4^5)$	$(0s_5^7, 1s_6^7)$	$(0.5s_6^9, 0.5s_7^9)$
C_3	C_{31}	$(0.2s_1^5, 0.8s_2^5)$	$(0.2s_4^7, 0.8s_5^7)$	$(0.3s_7^9, 0.7s_8^9)$
	C_{32}	$(0.5s_2^5, 0.5s_3^5)$	$(0s_3^7, 1s_4^7)$	$(0s_7^9, 1s_8^9)$

Table 4 The evaluation values of all indicators

Dimensions	Indicators	Values		
		D_1	D_2	D_3
C_1	C_{11}	$(0s_3^5, 1s_4^5)$	$(0s_3^7, 1s_4^7)$	$(0.3s_6^9, 0.7s_7^9)$
	C_{12}	$(0.5s_3^5, 0.5s_4^5)$	$(0.5s_3^7, 0.5s_4^7)$	$(0s_5^9, 1s_6^9)$
C_2	C_{21}	$(0.3s_2^5, 0.7s_3^5)$	$(0.3s_5^7, 0.7s_6^7)$	$(0.5s_5^9, 0.5s_6^9)$
	C_{22}	$(0.7s_3^5, 0.3s_4^5)$	$(0.5s_5^7, 0.5s_6^7)$	$(0s_5^9, 1s_6^9)$
	C_{23}	$(0s_2^5, 1s_3^5)$	$(0s_2^7, 1s_3^7)$	$(0.5s_5^9, 0.5s_6^9)$
C_3	C_{31}	$(0s_1^5, 1s_2^5)$	$(0.5s_5^7, 0.5s_6^7)$	$(0.3s_7^9, 0.7s_8^9)$
	C_{32}	$(0s_2^5, 1s_3^5)$	$(0s_4^7, 1s_5^7)$	$(0s_7^9, 1s_8^9)$

new product profitability (C_{22}), market competition strength (C_{23}), human resource of new product development (C_{31}), and support degree of top manager (C_{32}).

The computational procedure of proposed method is shown as follows.

Step 1. The experts select suitable scales of linguistic variables to express their opinions (shown in Table 1).

Step 2. The importance of dimensions and indicators given by the three experts are shown in Tables 2 and 3.

Step 3. The evaluation values of all indicators are shown in Table 4.

Step 4. Transforming linguistic variables' values given by expert D_1 and D_3 into variables with 7-scale.

Step 5. The 2-tuple interval linguistic weights of dimensions are shown in Table 5.

Step 6. The 2-tuple interval linguistic weights of all indicators are shown in Table 6.

Table 5 Average 2-tuple interval linguistic weights of all dimensions

Dimensions	Average weights	Linguistic variables
C_1	$(0.733\ s_5^7, 0.267\ s_6^7)$	(0.733 very important, 0.267 pretty important)
C_2	$(0.992\ s_5^7, 0.008\ s_6^7)$	(0.992 very important, 0.008 pretty important)
C_3	$(0.433\ s_4^7, 0.567\ s_5^7)$	(0.433 important, 0.567 very important)

Table 6 Average 2-tuple interval linguistic weights of all indicators

Dimensions	Indicators	Average weights
C_1	C_{11}	$(0.65s_4^7, 0.35s_5^7)$
	C_{12}	$(0.392s_4^7, 0.608s_5^7)$
C_2	C_{21}	$(0.667s_4^7, 0.333s_5^7)$
	C_{22}	$(0.867s_5^7, 0.133s_6^7)$
	C_{23}	$(0.775s_5^7, 0.225s_6^7)$
C_3	C_{31}	$(0.575s_4^7, 0.425s_5^7)$
	C_{32}	$(0.417s_4^7, 0.583s_5^7)$

Table 7 Average 2-tuple interval linguistic evaluation values of all indicators

Dimensions	Indicators	Average evaluation values
C_1	C_{11}	$(0.992s_5^7, 0.008s_6^7)$
	C_{12}	$(0.583s_4^7, 0.417s_5^7)$
C_2	C_{21}	$(0.375s_4^7, 0.625s_5^7)$
	C_{22}	$(0.017s_4^7, 0.983s_5^7)$
	C_{23}	$(0.125s_3^7, 0.875s_4^7)$
C_3	C_{31}	$(0.242s_4^7, 0.758s_5^7)$
	C_{32}	$(0.833s_5^7, 0.167s_6^7)$

Table 8 The aggregated values of three dimensions

Dimensions	Aggregated values	Linguistic variable
C_1	$(0.296s_4^7, 0.704s_5^7)$	(0.296 important, 0.704 very important)
C_2	$(0.511s_4^7, 0.489s_5^7)$	(0.511 important, 0.489 very important)
C_3	$(0.034s_4^7, 0.966s_5^7)$	(0.034 important, 0.966 very important)

Step 7. Compute the aggregated evaluation value of each indicator. The 2-tuple interval linguistic evaluation values of all indicators are shown in Table 7.

Step 8. Calculate the aggregated value of each dimension. For example, the aggregated evaluation value of "technology ability" can be computed as

$$\overline{\Delta}\left[\frac{\Delta^{-1}\left(0.992s_5^7,0.008s_6^7\right)\times\overline{\Delta}^{-1}\left(0.65s_4^7,0.35s_5^7\right)+\overline{\Delta}^{-1}\left(0.583s_4^7,0.417s_5^7\right)\times\overline{\Delta}^{-1}\left(0.392s_4^7,0.608s_5^7\right)}{\overline{\Delta}^{-1}\left(0.65s_4^7,0.35s_5^7\right)+\overline{\Delta}^{-1}\left(0.392s_4^7,0.608s_5^7\right)}\right]$$
$$=\left(0.296s_4^7, 0.704s_5^7\right)$$

By using the same steps, the aggregated values of three dimensions are calculated and shown in Table 8.

Step 9. Compute the degree of successful possibility of an NPD project as

$$\overline{\Delta}\left[\frac{\overline{\Delta}^{-1}\left(0.871s_4^7, 0.129s_5^7\right)+\overline{\Delta}^{-1}\left(0.253s_3^7, 0.747s_4^7\right)+\overline{\Delta}^{-1}\left(0.22s_3^7, 0.78s_4^7\right)}{\overline{\Delta}^{-1}\left(0.733s_5^7, 0.267s_6^7\right)+\overline{\Delta}^{-1}\left(0.992s_5^7, 0.008s_6^7\right)+\overline{\Delta}^{-1}\left(0.433s_4^7, 0.567s_5^7\right)}\right]$$

$$=\left(0.288s_4^7, 0.712s_5^7\right)$$

It means that the successful degree of the NPD project is between “high” and “very high”.

5 Conclusions

It is an important issue for every business to evaluate the degree of possibility success of an NPD project effectively. In this paper, the 2-tuple fuzzy interval linguistic variables are used to express the subjective opinions of decision makers. The proposed model combines fuzzy set theory with MCDM method to construct a systematic evaluation model of success possibility for new product development projects. According to the computation results of the example, we find that the proposed method can measure the success possibility of new product development project effectively. The measurement result of the proposed method is more reasonable for decision maker to understand the risk of the NPD project.

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