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Evaluation of the Risks in High-Tech Enterprises' Technological Innovation Based on Two-Tuple Linguistic Information

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Abstract

Technological innovation is the foundation for high-tech enterprises to enhance competitiveness and achieve sustainable development. However, there are some uncertain factors existing in the process of technological innovation, which bring about risks. In the light of this, first, based on relevant studies and an expert questionnaire survey, an index system for evaluating the risks is constructed. Then, a two-tuple-linguistic-information-based evaluation model is proposed, wherein a two-tuple group-decision method and its aggregation operators are introduced and the specific evaluation steps are given. At last, an empirical study of technological innovation risk evaluation is conducted on an enterprise of Nanchang high-tech development zone. The result indicates that by applying this method, high-tech enterprises can easily learn the overall risk level of their technological innovation projects, and then weaken or control the risks.

Keywords: *Two-tuple linguistic information; high-tech enterprises; technological innovation risks; evaluation*

1. Introduction

As the main force of high-tech industry and an important force in the country's economic and social development, high-tech enterprises play an important role in the advancement of high technology, industrialization, promoting industrial restructuring and upgrading [1]. High-tech enterprises are knowledge-intensive, technology-intensive enterprises, for which technological innovation provides fundamental guarantee in building, maintaining and constantly enhancing the core competitiveness. Technological innovation in high-tech enterprises has characteristics of high input, fierce competition, high risk and high profit. On the one hand, the high profit brought by technological innovation attracts high-tech enterprises to carry out technological innovation. On the other hand, the risks and uncertainties in technological innovation mean that high-tech enterprises face significantly higher risks than common enterprises. High risks may hinder high-tech enterprises' enthusiasm in technological innovation. The dual nature of technological innovation put high-tech enterprises in a dilemma. Therefore, it is of great importance to perform risk analysis and take corresponding preventive measures before the implementing technological innovation projects. Risk evaluation of high-tech projects is the key to technological innovation.

High-tech projects risk evaluation is one of the most active areas in the technological innovation management research. It is receiving more and more concern of domestic and overseas scholars in recent years. The study of evaluation methods related to enterprises' technological innovation risk is flourishing, such as Fuzzy Comprehensive Evaluation [2-

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3], BP neural network technique [4], matter-element extension method [5], ANP-GRAP integrated method [6], *etc.* Their common objective is to select more effective risk evaluation methods to ensure the authenticity and reliability of evaluation result. However, the technological innovation risk evaluation is a subjective judgment, which is fuzzy and uncertain. Decision makers often find it difficult to make accurate numerical judgment. Therefore, they often present their preference information with linguistic variables such as "high", "very high", *etc*.

Decision methods based on linguistic evaluation information could be divided into two types roughly: (1) transforming the linguistic evaluation information into fuzzy numbers, and carrying out fuzzy number calculation and analysis under extension principle, (2) directly calculating or handling language terms according to the order and the nature of the linguistic evaluation set [7]. However, neither method, in which approximation is adopted nor inevitably leads to distortion or loss of vital information, can ensure that the calculation result accurately fits in the original linguistic evaluation set. To compensate these defects, Spanish academics Herrera first proposed the method in which linguistic information is described by two-tuple [8]. Using two-tuple to represent linguistic evaluation information and perform computations can effectively avoid information distortion and loss in the aggregation of linguistic variables so as to obtain more precise results. Therefore, it is applied in the evaluation of high-tech enterprise technological innovation risk. The paper specifies the evaluation process and steps and presents numerical examples to show the efficiency of the method.

2. High-Tech Enterprise Technological Innovation Risk Evaluating Index System

2.1. High-Tech Enterprise Technological Innovation Risk Identification

The identification of technological innovation risk is the foundation of establishing risk evaluation index system. Risks involved in technological innovation are various and complex. It is difficult to identify them thoroughly. Methods are applicable for enterprises to identify risks as completely as possible, such as Expert interviews, Delphi method, Analogy comparisons, Top-level risk matrix, etc. Referring to the existing index systems at home and abroad and starting from the characteristics of high-tech enterprises' technological innovation [3-6] and [9], first this paper sums up the innovation risks. Then, it presents the result of a questionnaire survey, which includes 20 experts from high-tech enterprises, universities and government. Through discussions their views are gradually sorted out into unanimity. Last, the paper divides the technological innovation risks of high-tech enterprises into 6 types and 22 sub factors, in which all indicators are independent, namely, policy risk, financial risk, technological risk, production risk, market risk, and managerial risk.

(1) Policy risk

Policy risk refers to the adverse effects on innovative projects exercised by laws, regulations, policies and their changes and the possibility of failure thereof, such as economy fluctuation, inflation, incompliance with environmental protection policy, energy policy and science-technology policy, failure to obtain products, raw materials, equipment, technology and import licensing, *etc*. Policy risks mainly exist in the following aspects: changes of national macro-economic policy, new products industry's outlook, and compatibility between projects and policies and regulations.

(2) Financial risk

Financial risk refers to the factors that affect fund raising, using and repaying. It may lead to failure of technological innovation. The degree of financial risk depends on whether the venture capital mechanism is sound, loan interest rate, enterprise competency, the ability of enterprise financing, investment intensity and the timeliness of fully funding, *etc*. Financial risk mainly derives from the following aspects: loan interest rate, the ability of enterprise financing and return of investment.

(3) Technological risk

Technological risk is derives from immaturity and imperfection of the technology involved in the innovative project, or when the technology does not have evident competition superiority and alternative technologies emerge. Technological risk mainly exists in the following aspects: technological advancement, technological substitutability, technological reliability, and technological suitability.

(4) Production risk

Production risk arises when unpredictable obstacles exist in production conditions, including production technology, instruments and equipment, raw materials, etc. Production risk mainly comes from the following aspects: raw material supply, production personnel proficiency, production equipment advancement, and additional investment ability.

(5) Market risk

Market risk is the possibility of innovation failure due to market factors and their changes. Many technological innovations fail not because of technological defects, but failure to grasp the market information and market dynamics, which is one of the main causes of the uncertainties and risks in technological innovation. Market factors, such as difficulty in identifying with innovative products, market demands changes, sharp competition of market, limited market capacity, recession of market, appearance of imitation products or substitute products, *etc*. all increase market risk of technological innovation, even cause failure. Market risk mainly comes in the following aspects: market capacity, market share, product competitiveness, product life cycle, marketing strategies.

(6) Managerial risk

Managerial risk is the possibility of innovation failure due to management fault. Management fault, such as inadequate investigation, distorted market information, erroneous decision made by innovation subjects, wrong sales strategy, unreasonable resource allocation, imperfect risk-decision mechanism, disharmonious innovation process, *etc*. all increase managerial risk of technological innovation. Managerial risk mainly derives from the following aspects: the support of enterprises management, level and abilities of project manager, collaboration among departments of innovative enterprises.

2.2. High-Tech Enterprise Technological Innovation Risk Evaluation Index System

Enterprise technological innovation risk evaluation index system is the basis of innovation risk evaluation. Whether its design is scientific or not will directly influence veracity and reliability of the result. According to preceding text analysis of risk source of high-tech enterprise technological innovation, and following the scientific, systematic, comparable and workable principles, we build high-tech enterprise technological innovation risk evaluation index system, as shown in Table 1:

Table 1. High-tech Enterprise Technological Innovation Risk Evaluation Index System

First class indicator (target tier A)	**Second class indicators (criterion tier B)**	**Third class indicators (sub-criterion tier C)**
High-tech Enterprise Technological Innovation	Policy risk(B_1)	Changes of national macro-economic policy (C_{11})
		New products industry's outlook (C_{12})
		Compatibility between projects and

Risk		policies and regulations (C_{13})
	Financial risk (B_2)	Loan interest rate (C_{21})
		The ability of enterprise financing (C_{22})
		Return of investment (C_{23})
	Technology risk (B_3)	Technological advancement (C_{31})
		Technological substitutability (C_{32})
		Technological reliability (C_{33})
		Technological suitability (C_{34})
	Production risk (B_4)	Raw material supply (C_{41})
		Production personnel proficiency (C_{42})
		Production equipment advancement (C_{43})
		Additional investment ability (C_{44})
	Market risk (B_5)	Market capacity (C_{51})
		Market share (C_{52})
		Product competitiveness (C_{53})
		Product life cycle (C_{54})
		Marketing strategies (C_{55})
	Managerial risk (B_6)	The support of enterprises management (C_{61})
		Level and abilities of project manager (C_{62})
		Collaboration among departments of innovative enterprises (C_{63})

3. Enterprise Technological Innovation Risk Evaluation Model Based on Two-tuple

3.1. Two-tuple Group-decision Method and Aggregation Operator

Two-tuple linguistic information [8-10] refers to the evaluation results given for a certain goal (or object, criterion) represented by two-tuples. The meaning of its element s_k and α_k is described as follows:

(1) s_k is the k^{th} element of the linguistic assessment set predefined as S. It represents linguistic evaluation information given or obtained most close to the language phrase of the linguistic evaluation set.

(2) α_k is called symbol transfer value, and satisfies $\alpha_k \in [-0.5, 0.5)$. It represents the deviation of evaluation result and s_k.

(3) Linguistic evaluation set S is an ordered set consisting of an odd number of language phrases that is predefined. $S = \{s_0, s_1, \cdots s_g\}$, $g+1$ is called granularity of set S, and $2 \le g \le 14$.

For example, a linguistic evaluation set consisting of 5 elements (namely, language evaluation) can be defined as:

$$S = \begin{Bmatrix} s_0 = VL(Very\ Low), s_1 = L(Low), s_2 = F(Fair), \\ s_3 = C(High), s_4 = HC(Very\ High) \end{Bmatrix}$$

Generally S have such properties as follows:

a) Order property: when $i \geq j$, $s_i \geq s_j$;

b) Inverse operation operator exists, $Neg(s_i) = s_j$, where $j = g - i$;

c) Maximizing operations and minimizing operations: when $s_i \geq s_j$, we have $\max\{s_i, s_j\} = s_i$; $\min\{s_i, s_j\} = s_j$.

Linguistic evaluation value can be represented by triangular fuzzy numbers, the method of which is: $S_i = \{a_i, b_i, c_i\}$, where $a_0 = 0, c_g = 1$, $a_i = (i-1)/g\ (1 \leq i \leq g)$ $b_i = i/g\ (0 \leq i \leq g)$, $c_i = (i+1)/g\ (0 \leq i \leq g-1)$. For example, Linguistic evaluation set that consists of 5 elements can be described by triangular fuzzy numbers as follows: $S_0 = (0, 0, 0.25)$, $S_1 = (0, 0.25, 0.5)$, $S_2 = (0.25, 0.5, 0.75)$, $S_3 = (0.5, 0.75, 1.0)$, $S_4 = (0.75, 1.0, 1.0)$. Their membership functions as shown in Figure 1:

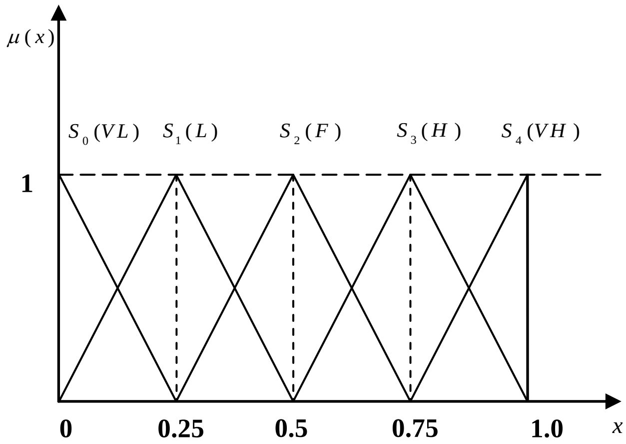

Figure 1. Language Terms Corresponding to Triangular Fuzzy Numbers and Their Membership Function

Definition 1 [8]: Let $s_k \in S$ be a set of linguistic terms, then the 2-tuple that expresses the equivalent information is obtained with the following function θ :

$$\theta : S \to S[-0.5, 0.5)$$

$$\theta(s_i) = (s_i, 0), s_i \in S \tag{1}$$

Definition 2 [8]: Let $\beta \in [0, T]$ is the real number obtained from that linguistic assessment set by some aggregate methods, where T is the element number of the linguistic assessment set, then β is represented in two-tuple linguistic information with the following function Δ :

$$\Delta : [0, T] \to S \times [-0.5, 0.5)$$

$$\Delta(\beta) = \begin{cases} s_k, & k = round(\beta) \\ \alpha_k = \beta - k, & \alpha_k \in [-0.5, 0.5) \end{cases} \tag{2}$$

Definition 3 [8]: Let (s_k, α_k) be a 2-tuple, where s_k is the k'th element of S , and $\alpha_k \in [-0.5, 0.5)$ There is always a function Δ^{-1} such that from a 2-tuple it returns its equivalent numerical value $\beta \in [0, T]$

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

$$\Delta^{-1}(s_k, \alpha_k) = k + \alpha_k = \beta \tag{3}$$

Let (s_k, α_k) and (s_l, α_l) be two 2-tuples, with each one representing a counting of information as follows:

(1) if $k < l$,then $(s_k, \alpha_k) < (s_l, \alpha_l)$;

(2) if $k = l$, a) $\alpha_k = \alpha_l$,then $(s_k, \alpha_k) = (s_l, \alpha_l)$;

b) $\alpha_k < \alpha_l$, then $(s_k, \alpha_k) < (s_l, \alpha_l)$;

c) $\alpha_k > \alpha_l$, then $(s_k, \alpha_k) > (s_l, \alpha_l)$.

Definition 4 [8]: Let $\{(s_1, \alpha_1), (s_2, \alpha_2), \cdots (s_n, \alpha_n)\}$ be a set of 2-tuples, then the 2-tuple arithmetic mean is computed as follows:

$$(\bar{s}, \bar{\alpha}) = \Delta\left(\frac{1}{n}\sum_{i=1}^{n} \Delta^{-1}(s_i, \alpha_i)\right), \ \bar{s} \in S \ ; \ \bar{\alpha} \in [-0.5, 0.5) \tag{4}$$

Definition 5 [8]: Let $\{(s_1, \alpha_1), (s_2, \alpha_2), \cdots (s_n, \alpha_n)\}$ be a set of 2-tuples, and $W = ((w_1, \beta_1), (w_2, \beta_2), \cdots, (w_n, \beta_n))$ be their associated weights. The 2-tuple weighted average operator is defined as follows:

$$(\tilde{s}, \tilde{a}) = \Delta\left(\sum_{j=1}^{n} \Delta^{-1}(w_j, \beta_j) \times \Delta^{-1}(s_j, \alpha_j) \Big/ \sum_{j=1}^{n} \Delta^{-1}(w_j, \beta_j)\right), \tilde{s} \in S; \tilde{\alpha} \in [-0.5, 0.5) \tag{5}$$

3.2. Evaluation Steps

Step 1: Define linguistic evaluation set. Define risk evaluation grading systems and the evaluating indexes of importance (the weight) respectively.

Step 2: Obtain evaluation matrix and weight matrix. Employ risk evaluation experts to evaluate each index of sub-criterion tier C and weight in the language terms of Step 1. Transform linguistic evaluation information of experts into two-tuple with Formula 1.

Step 3: Aggregate evaluation information of two-tuple in sub-criterion tier C into group evaluation information. Aggregate sub-criterion tier C given by experts and weight by formula 4, so that the evaluation result of each index and weight in two-tuple is obtained.

Step 4: Obtain the overall evaluation of each index in criterion tier B in two-tuple. Aggregate the weight of each index in criterion tier B by formula 4, to obtain the weight of each index. Aggregate the calculation results of Step 3 by Formula 5, so that the comprehensive values in two-tuple in criterion tier B are obtained.

Step 5: Obtain the comprehensive value of technological innovation risk. Aggregate the comprehensive value and weight in two-tuple of each index in criterion tier B, so that the comprehensive value of technological innovation risk is obtained.

4. Numerical Example

An enterprise of Nanchang high-tech development zone is about to embark on a technological innovation project. It employs three risk evaluation experts (E1, E2, E3) to evaluate risk of the project in the method proposed by this paper, as described below：

(1) Define linguistic evaluation set. Define risk evaluation grading systems and the evaluating indexes of importance (the weight) respectively, and define mutual equivalence transition relation of all language terms and triangular fuzzy numbers. (Table 2 and Table 3)

Table 2. Language Terms of Risk Evaluation Grades and Their Corresponding Triangular Fuzzy Numbers

Marking variable	Language terms	Triangular fuzzy number
s_0	Very Low (VL)	(0,0,0.25)
s_1	Low（L）	(0,0.25,0.5)
s_2	Fair（F）	(0.25,0.5,0.75)
s_3	High（H）	(0.5,0.75,1)
s_4	Very High (VH)	(0.75,1,1)

Table 3. Language Terms of Index Weight and Their Corresponding Triangular Fuzzy Numbers

Marking variable	Language terms	Triangular fuzzy number
s_{w0}	Very Unimportant(VU)	(0,0,0.25)
s_{w1}	Unimportant (U)	(0,0.25,0.5)
s_{w2}	Fair (F)	(0.25,0.5,0.75)
s_{w3}	Important（I）	(0.5,0.75,1)
s_{w4}	Very Important (VI)	(0.75,1,1)

(2) Ask three risk evaluation experts to evaluate each index and weight of sub-criterion tier C in language terms in Table 2 and Table 3 (Table 4). Transform linguistic evaluation information of each expert into two-tuple, such as from linguistic evaluation information VL into $(s_0, 0)$, VI into $(s_4, 0)$,*etc*.

Table 4. Experts' Fuzzy Evaluation of Each Index in Sub-criterion Tier C

Evaluation index	Grade			Weight		
	E1	E2	E3	E1	E2	E3
c_{11}	VL	L	F	VI	VI	I
c_{12}	F	L	F	I	VI	I
c_{13}	F	F	VL	I	I	VI
c_{21}	VL	L	L	F	I	I
c_{22}	L	VL	F	F	F	F
c_{23}	L	L	L	I	I	VI
c_{31}	VL	VL	VL	VI	VI	VI
c_{32}	F	VL	VL	I	VI	I
c_{33}	VL	L	F	VI	I	VI
c_{34}	H	H	F	I	I	VI
c_{41}	L	F	L	I	I	F
c_{42}	F	L	F	F	F	I
c_{43}	VH	H	H	I	I	F
c_{44}	L	VL	L	I	F	F
c_{51}	VL	VL	L	F	I	F
c_{52}	L	L	L	I	I	I

C_{53}	F	L	VL	VI	I	VI
C_{54}	VL	L	L	F	F	I
C_{55}	H	F	H	I	I	F
C_{61}	L	VL	L	VI	I	VI
C_{62}	F	L	F	I	VI	VI
C_{63}	L	L	VL	I	VI	I

(3) Aggregate respectively the indexes and weights given by experts in sub criterion tier C by Formula (4), so the evaluation results in two-tuple of each index and weight is obtained. Taking index C_{11} for example, its fuzzy evaluation and weight in two-tuple are computed as follows:

$$\overline{C}_{11} = \Delta\left(\tfrac{1}{3}\sum \Delta^{-1}(S_0,0),\Delta^{-1}(S_1,0),\Delta^{-1}(S_2,0)\right) = \Delta\left(\tfrac{1}{3}(0+0.25+0.5)\right) = \Delta(0.25) = (S_1,0)$$

$$\overline{W}_{11} = \Delta\left(\tfrac{1}{3}\sum \Delta^{-1}(S_4,0),\Delta^{-1}(S_4,0),\Delta^{-1}(S_3,0)\right) = \Delta\left(\tfrac{1}{3}(1+1+0.75)\right) = \Delta(0.92) = (S_4,-0.08)$$

(4) Get the comprehensive evaluation value of each index in criterion tier B. Take index B_1 for example, its importance and grade level are as follows:

$$\overline{W}_1 = \Delta\left(\tfrac{1}{3}\sum \Delta^{-1}(S_4,0),\Delta^{-1}(S_4,0),\Delta^{-1}(S_3,0)\right) = \Delta\left(\tfrac{1}{3}(1+1+0.75)\right) = \Delta(0.92) = (S_4,-0.08)$$

$$\overline{B}_1 = \Delta\left(\sum_{j=1}^{3}\overline{C}_{1j}\times\overline{W}_{1j}\Big/\sum_{j=1}^{3}\overline{W}_{1j}\right) = \Delta\left(\frac{0.25\times0.92+0.42\times0.83+0.33\times0.83}{0.92+0.83+0.83}\right) = \Delta(0.33) = (S_1,0.08)$$

In the same way, get the comprehensive evaluation values of other indexes in criterion tier B, as shown in Table 5.

Table 5. Experts' Fuzzy Evaluation of Each Index in Criterion Tier B

Criterion tier	Weight			Mean weight	Risk grade
	E1	E2	E3		
B_1	VI	VI	I	$(S_1,0.08)$	$(S_4,-0.08)$
B_2	I	I	VI	$(S_1,-0.03)$	$(S_3,0.08)$
B_3	VI	VI	VI	$(S_1,0.01)$	$(S_4,0)$
B_4	I	I	I	$(S_2,-0.05)$	$(S_3,0)$
B_5	I	I	F	$(S_1,0.04)$	$(S_3,-0.08)$
B_6	F	I	F	$(S_1,0)$	$(S_2,0.08)$

(5) Get the comprehensive evaluation value of technological innovation risk. Aggregate each index and weight experts give in criterion tier B by Formula (5), and the comprehensive evaluation value of technological innovation risk is obtained.

$$P = \left(\sum_{j=1}^{6}\overline{B}_j\times\overline{W}_j\Big/\sum_{j=1}^{6}\overline{W}_j\right)$$

$$= \left(\frac{0.33\times0.92+0.22\times0.83+0.26\times1+0.45\times0.75+0.29\times0.67+0.25\times0.58}{0.92+0.83+1+0.75+0.67+0.58}\right) = \Delta(0.30) = (S_1,0.05)$$

Contrast evaluation results with triangular fuzzy numbers given in Table 2 and conclusion can be drawn that the risk evaluation rating of the project is "low". Therefore, the project can be given positive consideration.

Furthermore, the evaluation method can be used for comparison of more than one project. First use the evaluation method to get the comprehensive evaluation value of each innovation project, and then sort the comprehensive evaluation values. The higher the evaluation value, and the higher the risk grade of the innovation project. On the contrary, the lower the evaluation value, the lower the risk grade of the innovation project.

5. Conclusion

The paper evaluates the risk of high-tech enterprises technological innovation using two-tuple evaluation model. The method adopts linguistic variables to represent the qualitative evaluation of each criterion tier and sub-criterion tier given by experts. Meanwhile, it transforms the qualitative evaluation into quantitative analysis according to the equivalence relation of two-tuple and triangular fuzzy numbers, so the final evaluation results can be obtained. The major advantage of the method is that it takes into account all experts' evaluation of every index and integrates all evaluation information into evaluation system, so as to ensure the completeness and sufficiency of evaluation information. Enterprise managers can easily and clearly find out the risk level of innovation projects according to the evaluation results, thus taking corresponding preventive measures to reduce these risks to a minimum level.

It is noted that in some practical decision problems, various types of relationships may exist among assessment indices, while this paper assumes that all assessment indices are independent. In future study, it would be interesting to integrate the Choquet integral into the proposed method to take the dependency between assessment indices into account.

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