Risk evaluation of virtual enterprise's task decomposition based on fuzzy-linear program and entropy evaluation method

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Abstract
Virtual enterprise can not only enhance an enterprise's competitiveness but also increase risks it faces. According to the principles of virtual enterprise's risk analysis and control, this paper decomposes virtual enterprise project into several tasks (nodes) and establishes virtual enterprise's nodes as well as the whole alliance's risk evaluation model. Then, it uses weighting method combining subjective method with objective method based on fuzzy-linear program to determine the weight of each evaluation indicator and respectively conclude the risk degree of each project node, and then, it adopts transfer entropy to calculate the weight of every expert who participates in the evaluation and summarize the risk degree of each node. At last, the paper figures out the whole alliance project's comprehensive risk degree, introduces cases with representative significance and verifies the feasibility of the model, which can be closer to the objective reality.
Key words: VIRTUAL ENTERPRISE, RISK EVALUATION, FUZZY-LINEAR PROGRAM, TRANSFER ENTROPY.

Introduction

Virtual enterprise, also called dynamic alliance, means multiple enterprises integrate their core competence and core resource through information technology and information network, voluntarily obey agreed rules and regulations, and form an agile dynamic organization for the purpose of achieving resource sharing and jointly completing a project, thus gaining competitive advantages and winning market opportunities. However, due to external market environment's uncertainty and virtual enterprise's complexity, virtual enterprise's risks bring losses that cannot be ignored. For successful establishment and operation of virtual enterprise, it is crucial to effectively identify and control its risks [1].

The risk management of virtual enterprise has increasingly become the object of the researchers are interested in. Che and Feng(2002) made more specific classification of the risk of virtual enterprise , Which was divided into internal and external risks, and then divided into six classes, 27 kinds of risk factors[2]. IP and Huang (2003) established a selection model based on risk of partners, and the characteristics and project scheduling problem of knowledge of genetic algorithm was designed based on rules of the model [3]. Considering the project model and uncertain factors of virtual enterprise, Huang M and Yang H M (2004) put forward the risk evaluation model of virtual enterprises based on fuzzy comprehensive evaluation [4]. Because the virtual enterprise has the characteristics of uncertainty on the project organization mode and the information, in order to consider the time factor impact on the overall risk of the project, Huang Min (2005) set up the model of virtual enterprise risk evaluation based on program evaluation and review technique [5]. In order to solve the problem of uncertain information in formation evaluation system for virtual enterprises, Song Zuming and Ning Xuanxi (2008) introduced the theory and method of grey system [6].

Before,a lot of research work mainly focused on the risk identification, provide risk evaluation method and risk management model was set up. Most of the risk assessment method and the risk factors in the risk management model were deterministic [7].But, the uncertainty of risk factors is an unavoidable problem in risk evaluation. At present, there are a lot of tools including fuzzy mathematics, probability and mathematical statistics, reliability theory, rough set theory, evidence theory, utility theory and interval algebra that can evaluate uncertain risks. Conclusion these evaluation methods, some weighting methods rely on mathematical programming analysis of the inherent features of the objective data, often ignore the subjective preference, the evaluation results is hard to get decision makers [8], some methods rely on subjective judgment of policy makers, error may be caused and inconsistent judgments, easily influenced by policy makers cognition degree evaluation results [9]. To solve the above problems, this paper proposes a fuzzy linear program and entropy evaluation Method.

This paper decomposes virtual enterprise project into several tasks (nodes) and establishes virtual enterprise's nodes as well as the whole alliance's risk evaluation model. In specific, it uses weighting method based on fuzzy-linear program combining subjective method with objective method to determine the weight of each evaluation indicator and respectively conclude the risk degree of each project node, and then adopts transfer entropy to calculate the weight of every expert who participates in the evaluation and summarize the comprehensive value of each node, providing theoretical foundation for risk control.

Risk Analysis and Control in Virtual Enterprise's Task Decomposition

According to the work breakdown structure, virtual enterprise can be divided into several works. Based on their own time sequence and plan arrangement, these works naturally form a hybrid network structure with multiple serial works in which each work can be either completed by a partner in the virtual enterprise or finished by the Integrated Product Team (IPT) composed of multiple partners. For uniformity, they can be collectively referred to as work units. These work units constitute virtual enterprise's underlying structure at operational level and as well form a task-based workflow, as shown in Figure 1[10].

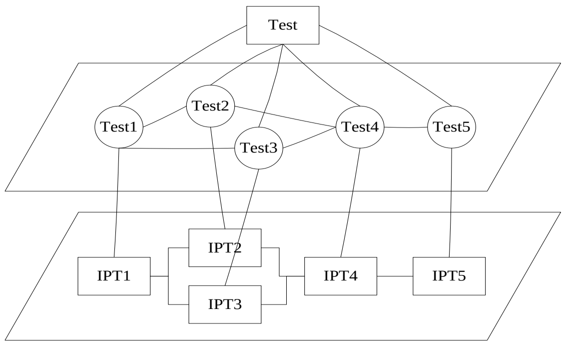

Figure1. Workflow of Virtual Enterprise Based on Tasks

Every work unit is a node. The risks of each node and the whole alliance can be evaluated by risk bottleneck adjustment method, i.e. evaluate the risks of each node participating in the dynamic alliance first and then calculate the alliance's overall expected risks, if the alliance can withstand this loss value, the process ends, but if not, start to find and identify the node enterprise suffering from the biggest risk loss in the alliance, and then adjust and optimize this node enterprise's risks, or conduct global risk optimization, to reach the optimal resource efficiency and minimize the alliance's overall risk. The above process constitutes a complete virtual enterprise's risk control framework, as shown in Figure 2.

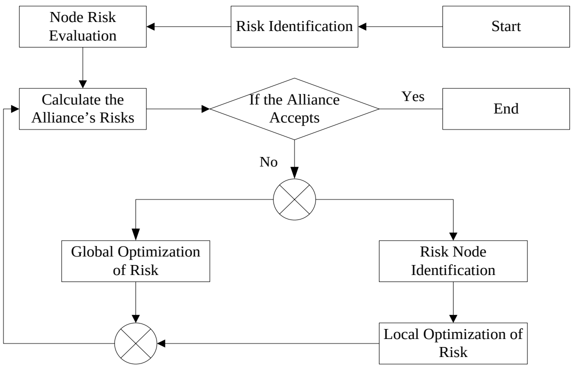

Figure 2. Virtual Enterprise's Risk Control Framework

To control virtual enterprise's risks, its risks should be identified first, and to identify the alliance's risks, the risks of each node in the virtual enterprise and the risks of the whole alliance should be evaluated first.

Weighting Method Combining Subjective Method with Objective Method Based on Fuzzy-Linear Program

This method is used to research multi-attribute evaluation problem when attribute weight is unknown on the principle of standardizing decision-making matrix, denoting each evaluated scheme's comprehensive evaluation value by the expression containing unknown attribute weight, expressing the decision maker's subjective judgment for each evaluation scheme in interval number, and deriving the weight of interval-number judgment matrixes. According to the fuzzy including relation between the comprehensive evaluation value of evaluated scheme containing unknown attribute weight and the decision maker's subjective judgment, the paper proposes using fuzzy linear program model to solve attribute weight [11].

Let X={x_1,…,x_m} be the evaluation scheme set of multi-attribute decision making problem, $U=\{u_1,...,u_n\}$ be the attribute set, w be the attribute weight, and the jth attribute value of scheme x_i be a_{ij} (if it is qualitative attribute, demarcating method is generally used), constituting decision-making matrix $A=(a_{ij})_{m\times n}$, then steps of weighting combining subjective method and objective method based on fuzzy-linear program are as follows:

Step 1: The decision maker adopts interval-number judgment matrixes $B=(b_{ij})_{m\times n}$ and $b_{ij}=[b_{ij}^L, b_{ij}^U]$ to express his preference to the scheme, calculates the weight of these interval-number judgment matrixes, and denote it by $\overline{p}_i=[p_i^L, p_i^U], i=1,...,m$;

Step 2: To remove the influence of different dimensions on decision result, conduct standardized processing for decision-making matrix and reach a decision-making matrix $R=(r_{ij})_{m\times n}$, then aggregate the comprehensive attribute value z_i of x_i by following formula:

$$z_i=\sum_{j=1}^{n} r_{ij} w_j, i=1,...m \quad (1)$$

Step 3: Obtain the weight expression of each scheme according to previous two steps as below:

$$p_i=\frac{z_i}{\sum_{i=1}^{m} z_i}, i=1,...m \quad (2)$$

Step 4: According to Step 1, 2, 3, establish the formula of fuzzy linear program as below, to solve attribute weight value w_i,i=1,…,n;

$$s.t.\begin{cases}\lambda\delta_i+\sum_{j=1}^{n}(b_j p_i^L-r_{ij})w_j\le\delta_i, i=1,...m\\ \lambda\delta_i+\sum_{j=1}^{n}(b_j p_i^L-r_{ij})w_j\le\delta_i, i=1,...m\\ \lambda\in[0,1]\\ \lambda\delta_i+\sum_{j=1}^{n}(b_j p_i^L-r_{ij})w_j\le\delta_i, i=1,...m\end{cases} \quad (3)$$

The constraint allowable violation limit δ_i in formula (3) is related to p_i^L and p_i^U. Let $\delta_i=(p_i^U-p_i^L)\xi$, of which, ζ is constant (its value is generally between 0 and 1). The decision accuracy gradually decreases as ζ increases, the decision maker can give corresponding numerical value according to his understanding level of the problem, and regarding criterion decision making, the bigger the λ is, the better it will be.

If the feasible region of formula (3) is empty, based on constraint allowable violation limit δ_i, the decision maker's subjective judgment fails agree with objective data features; whereas, if the feasible region is non-empty, the decision maker's subjective judgment agrees with objective data features.

Therefore, formula (3) is the train of thought based on mutual verification of subjective judgment and objective data. If the feasible region is empty, the decision maker can increase ζ appropriately; if the feasible region is still empty when ζ is large, the decision maker now should check interval-number judgment. In this case, how much is the deviation λ^* between subjective judgment and objective data and how much at least should constraint allowable violation limit be set so that a compromise between them on the basis of some satisfaction can be reached? This dissertation proposes establishing formula (4) for judgment.

$$s.t.\begin{cases} \lambda^*(p_i^U - p_i^L)\xi + \sum_{j=1}^{n}(b_j p_i^L - r_{ij})w_j \le (p_i^U - p_i^L)\xi, i = 1,...m \\ \lambda^*(p_i^U - p_i^L)\xi + \sum_{j=1}^{n}(-b_j p_i^U + r_{ij})w_j \le (p_i^U - p_i^L)\xi, i = 1,...m \\ \xi \ge 0 \\ \sum_{i=1}^{n} w_j = 1, w_j \ge 0,, j = 1,...n \end{cases}$$

(4)

In formula (3), similar to formula (4), the feasible region may be empty, and one solution is to let λ^* =0→1. When λ^* =0, there must be an optimum solution for formula (4). If the value of λ^* is improved step by step until the feasible region in formula (4) is empty, the minimal value ζ based on the maximum satisfaction λ^* will be found. According to the numerical magnitude (λ^*, ξ^*) obtained from formula (4), the decision maker can check subjective judgment or verify the accuracy of objective data, in order for appropriate adjustment.

Step 5: According to each attribute weight w_i obtained by step 4, the comprehensive attribute value z_i of each scheme is achieved by formula (1).

Expert's Own Weight Based on Entropy Evaluation Method

As an important concept of simple giant system, entropy is a physical quantity which was first proposed by physicist R Clausius in *Mechanical Theory of Heat* in 1864 and it is used to describe system state. Transfer entropy is the effective measurement of information accuracy and value. Let the conditional probability of information *A* on state space x be $P(y_k, x_l)(k, l = 1,2,\cdots,n)$ and the transfer matrix of *A* be $E(A) = (e_1, e_2, \cdots, e_n)$, in which, $e_l(l = 1,2,\cdots,n)$ is the accuracy of information *A* at state l, and the greater the value is, the higher the accuracy will be.

$$e_l = \frac{1}{n-1}\sum_{k=1}^{n}\left[P(y_l / x_l) - P(y_k / x_l)\right],$$
$$l = 1,2,\cdots,n \qquad (5)$$

$H(A) = \sum_{k=1}^{n} h_k$ is the transfer entropy of information *A*. Transfer entropy indicates the uncertainty degree of given information *A*. Where,

$$h_k = \begin{cases} -e_k \ln e_k & (1/e \le e_k \le 1) \\ 2/e - e_k\left|\ln e_k\right| & (-1/n-1 \le e_k \le 1/e) \end{cases}$$

In the process of judgment matrix construction, let's assume there is an ideal optimal expert and the judgment matrix constructed by him is the most impartial and the most accurate. In actual calculation and judgment, an expert who has the highest consistency in the understanding of the evaluated object and expert group – an expert with the minimum overall difference can be chosen. If expert to be evaluated gives a result which is greatly different from that given by optimal expert, the result he gives is of low reliability. This difference is also denoted by entropy, with following model established:

Let $S_1, S_2, \cdots, S_m$ be *m* experts, constituting evaluation group *G*, the evaluated target be, $x_{ij}(i = 1,2,\cdots,m; j = 1,2,\cdots,n)$ be the *i*th expert's scoring value for the *j*th target, and vector $x_i = (x_{i1}, x_{i2}, \cdots, x_{in})^T \in E^n$ and matrix $X = (x_{ij})_{m\times n}$ be conclusion provided by all experts and expert group in an evaluation. S_* is denoted as the optimal expert, expert with the highest consistency with expert group is selected, and his scoring vector is $x = (x_{*1}, x_{*2}, \cdots x_{*n})^T \in E^n$. All experts' scoring results and the difference of S_* are used to measure the selected expert's strengths and weaknesses. The expert's evaluation level vector is:

$$E_i = (e_{i1}, e_{i2}, \cdots, e_{in}) \qquad (6)$$

Of which, $e_{ik} = 1 - \left| x_{ik} - \bar{x}_{ik} \right| / \max x_{ik}$ and $(i = 1,2,\cdots,m; k = 1,2,\cdots,j)$ reflect expert S_i 's level of evaluation conclusion for targets $B_1, B_2, \cdots, B_n$.

Hereto, entropy-based expert evaluation result assessment model can be established as follows:

$$H_i = \sum_{j=1}^{n} h_{ij} \qquad (7)$$

This model measures expert's ability of evaluating given problem with the uncertainty of scoring result given by him, and entropy value H_i denotes the degree of the uncertainty. The smaller the entropy value H_i is, the higher the expert's decision-making level will be; whereas, the bigger the entropy value is, the lower the reliability of the evaluation conclusion given by the expert and the unscientific the given score will be. Thus, following formula is adopted to denote expert's corresponding weight in each target, i.e. the i^{th} expert's weight is:

$$c_i = \frac{1/H_i}{\sum 1/H_i}, i = 1,2,\cdots,m \qquad (8)$$

The greater the c_i value is, the bigger the proportion of expert i's opinion in evaluation should be [12].

Virtual Enterprise's Risk Evaluation and Case

Project-based virtual enterprise's risks are classified, for the most important indicators are the project's completion time, product quality, product cost and teamwork. All factors possibly causing virtual enterprise's failure can be finally reflected in these four indicators. Risk evaluation for virtual enterprise's all nodes and the whole alliance can be reached by using fuzzy linear program and transfer entropy and combining a case.

Let's assume a virtual enterprise composed of five design research institutes is in charge of project P's design work. In early-stage preparations, project funds have been received, but to seize market share, the client attaches great importance to the project's turnover time. In view of this, we can control the risks of project P to meet the client's requirement for punctual completion.

The whole project can be implemented by four parts, namely, for nodes. Table 1 lists the contents of these four parts. These serial nodes are equally important to the whole alliance [13].

Table 1. Project Task Decomposition

Node	Name of Work Unit	Work Content	Partner in Charge
1	Project Analysis	To know customers' present operating mode	A
2	Project Design	To design the project's prototype and module	A, B
3	Project Implementation	To assign tasks and implement the project	B, C, D
4	Project Test	To test, check and accept the project	E

The given four indicators such as collaboration, time, cost and quality of each node are shown in Table 2

Table 2. Estimated Data Value of Each Node

Node	Collaboration	Time (week)	Cost (ten thousand)	Quality
1	95	7.8	4.2	60
2	28	4.4	1.1	48
3	20	25	5.3	56
4	24	4.2	1.2	80

Step 1: To remove the influence of different dimensions on the decision-making result, conduct standardized processing for matrix in Table 2. As for virtual enterprise node's indicators, the degree of completion can be used to evaluate its risks, i.e. estimated data

a_{ij} completed by all indicators and expected ideal data s_{ij} are compared. $r_{ij} = \frac{s_{ij}}{a_{ij}}$ is used to process cost-based indicators and $r_{ij} = \frac{a_{ij}}{s_{ij}}$ is used to process efficiency-based indicators. The bigger the value is, the greater the degree of completion and the smaller the risk will be. In this case, cost and time are cost-based indicators, and quality and collaboration level are efficiency-based indicators. Table 3 shows each evaluation indicator's ideal data value.

Table 3. Each Node's Ideal Data Value

Node	Collaboration	Time (week)	Cost (ten thousand)	Quality
1	100	7	3	100
2	100	4	1	100
3	100	12	5	100
4	100	3	1	100

According to Table 2 and Table 3, a standardized matrix can be reached as follows:

$$R = \begin{bmatrix} 0.95 & 0.90 & 0.71 & 0.60 \\ 0.28 & 0.90 & 0.94 & 0.48 \\ 0.20 & 0.48 & 0.94 & 0.56 \\ 0.24 & 0.72 & 0.89 & 0.80 \end{bmatrix} \quad (9)$$

Step 2: It is to determine each node's risk weight, namely, each node's degree of completion compared with the ideal value. The bigger the weight is, the greater the possibility of target accomplishment and the smaller the risk will be. Some expert gives the internal-number judgment matrix based on pairwise comparison of four nodes as below.

$$\overline{B} = \begin{bmatrix} [1,1] & [2,5] & [2,4] & [1,3] \\ [1/5,1/2] & [1,1] & [1,3] & [1,2] \\ [1/4,1/2] & [1/3,1] & [1,1] & [1/2,1] \\ [1/3,1] & [1/2,1] & [1,2] & [1,1] \end{bmatrix} \quad (10)$$

Solve internal-number judgment matrix $\overline{B}$ and reach the estimation range of node risk weight as follows: $\overline{p}_1$=[0.369,0.537], $\overline{p}_2$=[0.166,0.272], $\overline{p}_3$=[0.102,0.178], $\overline{p}_4$ =[0.143,0.245].

Step 3: Substitute R value and P value into formula (3) and assume ζ=20%, to reach the weight of four evaluation indicators such as collaboration, time, cost, and quality as below: $\lambda=1$, $w_1=0.49$, $w_2=0.31$, $w_3=0.11$, $w_4=0.09$

Step 4: Each node's comprehensive attribute value is reached by formula (1) as below: $z_1=0.8766$, $z_2=0.5628$, $z_3=0.3957$, $z_4=0.5107$

According to formula (1), $p_1=0.3747$, $p_2=0.2405$, $p_3=0.1691$, and $p_4=0.2210$ are reached. All of these four values are within interval $\overline{p}$ given by expert, thus, the decision maker's subjective judgment agrees with objective data features, and the results are effective.

Step 5: In the same way, the other four experts' z value obtained from weight estimation can be reached, and the five experts' final results are as below:

$$z = \begin{bmatrix} 0.8766 & 0.5628 & 0.3957 & 0.5107 \\ 0.6858 & 0.6714 & 0.4062 & 0.5621 \\ 0.7032 & 0.4907 & 0.3749 & 0.5671 \\ 0.9349 & 0.6042 & 0.3036 & 0.4992 \\ 0.7534 & 0.5310 & 0.2885 & 0.6013 \end{bmatrix} \quad (11)$$

According to the indicators in above table, entropy evaluation method is used for subjective weight, and formula (6), (7) and (8) evaluate experts' opinions, to obtain expert's own weight as shown in Table 4.

Table 4. Entropy-based Expert's Own Weight Calculation Result

Expert	Expert Level Vector $E = (e_1, e_2, e_3, e_4)$	Entropy Value H	Weight C	Sequence
Expert A	(0.9082, 0.9863, 0.8968, 0.9378)	0.259	0.247	①
Expert B	(0.8877, 0.8520, 0.8710, 0.9767)	0.385	0.166	⑤
Expert C	(0.9063, 0.8789, 0.9481, 0.9684)	0.284	0.225	②
Expert D	(0.8459, 0.9521, 0.8764, 0.9187)	0.382	0.167	④
Expert E	(0.9599, 0.9389, 0.8392, 0.9115)	0.329	0.194	③

According to the calculation results, it can be known that the opinion of expert B who has the biggest entropy value and the poorest accuracy accounts for the smallest proportion in each node's risk evaluation, and the opinion of expert A who has the smallest entropy value and the best accuracy should account for the largest proportion. In addition, it can be seen that expert A's group opinion is the most approximate, so his weight is the largest, and expert B's group opinion is the most deviant, so his weight is the smallest, which proves it is reasonable to use above entropy evaluation method to solve expert weight.

Weighted summation for each node's risk value obtained from estimated weight given by each expert and expert's own weight is conducted to reach each node's final risk degree.

$$Z = \begin{bmatrix} 0.8766 & 0.6858 & 0.7032 & 0.9349 & 0.7534 \\ 0.5628 & 0.6714 & 0.4907 & 0.6042 & 0.5310 \\ 0.3957 & 0.4062 & 0.3749 & 0.3036 & 0.2885 \\ 0.5107 & 0.5621 & 0.5671 & 0.4992 & 0.6013 \end{bmatrix} \times \begin{bmatrix} 0.247 \\ 0.166 \\ 0.225 \\ 0.167 \\ 0.194 \end{bmatrix} = \begin{bmatrix} 0.7908 \\ 0.5650 \\ 0.3562 \\ 0.5471 \end{bmatrix} \quad (12)$$

At last, it can be concluded that the whole virtual enterprise's project completion degree is $Z = \sum_{i=1}^{4} z_i = 2.2537$. Assume the whole project's ideal completion degree is 4 and it is acceptable when it reaches 3 according to risk evaluation standard, the risk is acceptable. Now that we fail to reach this standard, we should make some adjustment. Find the bottleneck node 3, adjust and optimize this node enterprise's risk, and finally make optimum adjustment for each node enterprise's risk reduction from the perspective of the whole alliance, striving to minimize the risk under existing resource condition.

Conclusions

In this paper, a risk evaluation method of virtual enterprise's task decomposition based on fuzzy-linear program and entropy evaluation method are proposed, the method steps are as follows: Firstly, the virtual enterprise project is divided into several tasks (nodes), we establish the risk evaluation model of alliance and the nodes of the virtual enterprise; Secondly, we determine the weight of every evaluation index and assembled out of the risk of each node; Then, Transfer entropy method is used to evaluate the weight of every evaluation expert, the comprehensive value of each node and the alliance project risk degree is calculated. Finally, the validity of the model is verified with cases, the results show that each node's final overall risk value not only integrates every expert's opinion, but also makes more authoritative and reliable experts' opinion dominant in final results, furthermore, considering the preference of decision makers and the inherent characteristics of quantitative data, thus reaching weight results that are closer to the objective reality. The method is simple and practical, more easily accepted by policy makers.

Acknowledgements

This work has been supported MOE (Ministry of Education in China) Project of Humanities and Social Sciences (Project No. 14YJC630059) ; Natural Science Foundation of Shandong Province, under Grant (Project No. BS2014SF021).

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