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Modeling Risk Control Problems in VE under Complicated Situations and Its Solution Method

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Abstract Virtual Enterprise (VE) brings not only opportunities but also more uncertainties and risks for the enterprises. To deal with the uncertainty of the cost for risk control in virtual enterprise, this paper focuses on the method of VE multi-strategies multi-selections risk programming problem considering robustness. The risk programming model to minimize the global risk level with the constraint of risk control budget is established. To reduce the influences of the uncertainty of the cost for risk control on the solution of the problem, Robust Optimization (RO) method is presented to deal with the uncertainty of the cost for risk control and the multi-strategies multi-selections robust risk programming model is established. ILOG optimization software is used to solve the problem. Numerical experiments suggested the effectiveness of the proposed method which eliminates the impact of uncertainty with a negligible increase in risk level.

Keywords Virtual Enterprise; Risk Programming; Uncertainty; Robust Optimization; Multi-strategies Multi- selections

1 Introduction

VE [1-3] is an open business model, it helps enterprises to respond to market demand more quickly than conventional enterprises, meanwhile, it faces more risks due to uncertainties in its operational environment. Hence, risk management is very important for VE. Recently, much attention has been paid to risk management in a VE [4-8]. However, the uncertainty of risk control cost was neglect in most of these researches. In real world situations, the cost of risk control will change as time and conditions vary, making risk control cost an uncertain factor. The uncertainty of risk control cost is described in [8] by stochastic theory and a chance constraint model is proposed to deal with the cost uncertainty. However, the distribution of the variant parameter must be known in this method, which is not realistic as VE has little historical data. This paper uses interval number to describe this kind of uncertainty concerning control cost for modeling the MMRP(Multi-strategies Multi-selections Risk Programming) problem in VE, and build a 0-1integer programming model. To improve the robustness of solution, this paper uses Robust Optimization (RO) method [9, 10] to deal with the impact of cost uncertainty on the feasibility of solutions, which can guarantee the solution be feasible with a high probability.

2 Problem Description and Model

MMRP problem that there is more than one control strategies for each risk and more than one control strategies can be selected for each risk at the same time is considered in this paper. Suppose the each risk factors of each risk with and without risk control strategy are known. When the risk factors are dealt with the risk control strategies, the fuzzy description of the corresponding risk factors will change to the low risk status. Effects of different control strategies on risk are different, and the costs of the different control strategies are different also.

To ensure the completion of the VE project, control strategies are selected to control risks under certain risk control budget. MMRP problem is to minimize the global risk level by selecting among these strategies with the constraint of certain risk control budget. The mathematical model of this problem can be described as follows:

$$min \sum_{k=0}^{n} a_k(\vec{X})k \tag{1}$$

$$s.t. \sum_{i=1}^{m} \sum_{j=0}^{J_i} \tilde{c}_{ij} x_{ij} \le E \tag{2}$$

$$x_{ij} = \begin{cases} 1 & strategy\ j\ is\ selected\ by\ risk\ i \\ 0 & otherwise \end{cases} \quad i = 1, 2, \cdots, m;\ j = 0, 1, \cdots, J_i \tag{3}$$

where $\vec{X} = (x_{ij})$; E is the cost budget for the risk control; i is the index of the risk, j is the index of the strategy, k is the index of risk rank, m is the risk numbers; n is the risk rank numbers; $a_k(\vec{X})$ is the membership degree to level k risk for $\vec{X}$, J_i is the numbers of strategies for risk i, and $\tilde{c}_{ij}$ is the cost of strategy j for risk i.

Considering the uncertainty of the cost for control strategy, it is reasonable to estimate the mean and deviation of the cost for control strategy j of risk i as c_{ij} and $\hat{c}_{ij}$. Then, $\tilde{c}_{ij}$ can be described as an interval number $\tilde{c}_{ij} \in [c_{ij} - \hat{c}_{ij}, c_{ij} + \hat{c}_{ij}]$.

Formula (1) is the objective function, which means the overall risk status of VE under a set of strategies combination. It is obtained by the VE risk evaluation method based on HFMFs (Hypertrapezoidal Fuzzy Membership Functions) embedded fuzzy comprehensive evaluation [4]. Figure 1 illustrates the hierarchical model for risk evaluation. From figure 1, it can be seen that the risk evaluation is carried out from local to global that is from the bottom to the top. Namely, in level 4, HFMFs method is used. To obtain all the fuzzy description of risk factors in layer 3 while a combination of risk control strategies is determined. Then the risk of the process under sub-goal in level 2 can be evaluated. Further, the risk of sub-goals under the global objective level 1 can be evaluated. Finally, the fuzzy description of overall risk level in level 0 is obtained and the crisp value of the overall risk level is given by formula (1).

Formula (2) is cost constraints which means that the actual total cost of risk control should not be more than the total risk control budget. Formula (3) is the range of the decision variables.

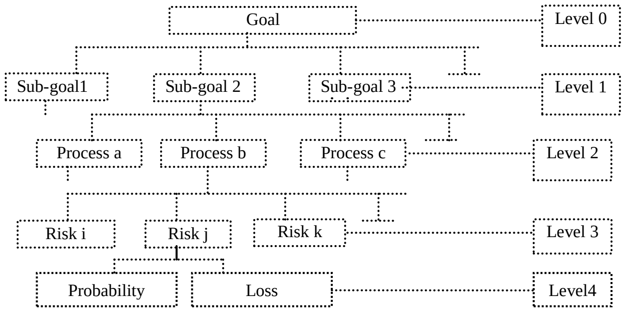

Fig 1 The hierarchic model for risk evaluation

When there is variability of parameters, the solution obtained by means of mean value cannot guarantee the feasibility or ensure very low probability of being feasible. To improve the robustness of solution, Robust Optimization (RO) method [9, 10] is used to deal with the impact of the uncertainty of cost for risk control on the feasibility of solutions for risk management in VE.

Let $JJ_i = \{ij / \hat{c}_{ij} > 0, i = 1, \cdots, m; j = 1, \cdots J_i\}$, $JJ = \{JJ_i, i = 1, ..., m\}$ be the uncertainty set. Then $|JJ_i|$ is the number of the uncertainty parameters of risk i , $|JJ|$ is the number of all uncertainty parameters. Let robustness level $\Gamma \in [0, |JJ|]$, $\lfloor \Gamma \rfloor$ is the maximum integer less than Γ . The role of the parameter Γ is used to adjust the robustness of the solution. Therefore, the RO model of the risk programming for VE is proposed as follows:

$$min \quad \sum_{k=0}^{n} a_k (\vec{X}) k \tag{4}$$

$$s.t. \sum_{i=1}^{m} \sum_{j=0}^{J_i} c_{ij} x_{ij} + \max_{\{S \cup \{t\} | S = \{S_i\}, JJ = \{JJ_i\}, S_i \subseteq JJ_i, |S| \le \lfloor \Gamma \rfloor, t \in JJ \setminus S, i = 1, \cdots, m\}} \left\{ \sum_{i=1}^{m} \sum_{s_i \in S_i} \hat{c}_{is_i} x_{is_i} + (\Gamma - \lfloor \Gamma \rfloor) \hat{c}_{\arg\{t\}} x_{\arg\{t\}} \right\} \le E \tag{5}$$

$$x_{ij} = \begin{cases} 1 & strategy\ j\ is\ selected\ by\ risk\ i \\ 0 & otherwise \end{cases} \quad i = 1, 2, \cdots, m; \ j = 0, 1 \cdots, J_i \tag{6}$$

where S_i is a subset of JJ_i , $|S|$ is the number of elements in set S , $|S| \le |\Gamma|$. The second item of formula (5) is used to reduce the probability of constraint violation, clearly, this probability is depending on Γ . The bigger Γ means the more volatility parameters are taken into account, so the probability of that the constraint is not satisfied would be less, but the risk level of the overall enterprise would increase. That is the feasibility is increased but the optimality is decreased. Hence, robustness means balance between feasibility and optimality by changing the value of Γ .

It is obvious that format (5) cannot be directly calculated, so the corresponding transformation is needed. For a Given vector $\vec{X}^*$, let:

$$\beta(\vec{X}^*) = \max_{\{S \cup \{t\} | S = \{S_i\}, JJ = \{JJ_i\}, S_i \subseteq JJ_i, |S| \le \lfloor \Gamma \rfloor, t \in JJ \setminus S, i = 1, \cdots, m\}} \left\{ \sum_{i=1}^{m} \sum_{s_i \in S_i} \hat{c}_{is_i} x^*_{is_i} + (\Gamma - \lfloor \Gamma \rfloor) \hat{c}_{\arg\{t\}} x^*_{\arg\{t\}} \right\} \tag{7}$$

Equation (7) equals to the following Linear Problem [10] (LP):

$$\beta(\vec{X}^*) = \max \sum_{i=1}^{m} \sum_{s_i \in JJ_i} \hat{c}_{is_i} x^*_{is_i} z_{is_i} \tag{8}$$

$$s.t. \sum_{i=1}^{m} \sum_{s_i \in JJ_i} z_{is_i} \le \Gamma \tag{9}$$

$$0 \le z_{is_i} \le 1 \qquad i = 1, 2, \ldots, m, \quad s_i \in JJ_i \tag{10}$$

where formula (8) is the maximum cost fluctuations under a certain combination of control strategies $\vec{X}^*$. Formula (9) means that the actual fluctuations in the overall level cannot be more than the setting robust level. Formula (10) means the range of the cost fluctuations of strategy s_i of risk i. Clearly the optimal solution of problem (8)-(10) is with $\lfloor \Gamma \rfloor$ variables being 1 and one variable being $\Gamma - \lfloor \Gamma \rfloor$.

Then the dual of problem of above LP can be described as follows:

$$\min \sum_{i=1}^{m} \sum_{s_i \in JJ_i} p_{is_i} + \Gamma z \tag{11}$$

$$s.t. \quad p_{is_i} + z \ge \hat{c}_{is_i} x^*_{is_i} \qquad i = 1, 2, \ldots, m; \forall s_i \in JJ_i \tag{12}$$

$$z \ge 0 \tag{13}$$

$$p_{is_i} \ge 0 \qquad i = 1, 2, \cdots, m; \quad \forall s_i \in JJ_i \tag{14}$$

where formula (11) means that the minimize reserve funds for cost fluctuations. Formula (12) means that reserve fund for cost fluctuations of the strategy s_i of risk i can't be less than the cost fluctuations needed if the risk i is selected to be dealt with. Formula (13) means that average reserve funds for the unit robustness under robustness level Γ is non-negative. Formula (14) means that the additional reserve funds for the strategy s_i of risk factors i under robustness level Γ is non-negative.

Hence, the RO model of risk programming for VE can be rewrite as follows:

$$\min \sum_{k=0}^{n} a_k(\vec{X})k \tag{15}$$

$$s.t. \quad \sum_{i=1}^{m} \left(\sum_{j=0}^{J_i} c_{ij} x_{ij} + \sum_{s_i \in JJ_i} p_{is_i} \right) + \Gamma z \le E \tag{16}$$

$$p_{is_i} + z \ge \hat{c}_{is_i} x_{is_i} \qquad i = 1, 2, \cdots, m; \forall s_i \in JJ_i \tag{17}$$

$$z \ge 0 \tag{18}$$

$$p_{is_i} \ge 0 \qquad i = 1, 2, \cdots, m; \forall s_i \in JJ_i \tag{19}$$

$$x_{ij} = \begin{cases} 1 & strategy\ j\ is\ selected\ by\ risk\ i \\ 0 & other \end{cases} \quad i = 1, 2, \cdots, m; j = 0, 1 \cdots, J_i \tag{20}$$

It is clear that this model has $\sum_{i=1}^{m} (J_i + 1) + |S| + 1$ decision variables, $\sum_{i=1}^{m} (J_i + 1) + 2|S| + 2$ constraints. To deal with this model, ILOG [11] optimization software is used.

3 Numerical Experiments

In this section, the numerical experiment is used to analysis the performance of the proposed method. ILOG software is used to solve the proposed model.

The main performance measures used to evaluate the proposed method is defined as follows:

1. Probability Bound of Constraint Violation (PB) is defined as follows [10]:

$$PB = B(n,\Gamma) = 1 - \varphi(\frac{\Gamma - 1}{\sqrt{n}}) \tag{21}$$

where n is the number of fluctuations parameters, Γ is the robust level. φ is normal distribution.

2. Objective Change ($ObjC$) is defined as follows:

$$ObjC = (Obj - Obj_0) / Obj_0 \tag{22}$$

where Obj is the objective value when $\Gamma > 0$, Obj_0 is the objective value when $\Gamma = 0$.

3. Average Cost Change (ACC) is defined as follows:

$$ACC = (AC_0 - AC) / AC_0 \tag{23}$$

where AC is the average cost when $\Gamma > 0$, AC_0 is the average cost when $\Gamma = 0$.

The example involves 5 sub-goals, 5 sub-processes and 20 risks. The weight of sub-goals, process and risk is given in table 1, the cost for control strategies of each risk and description of risk states is given in table 2. The risk investment is 65,000 RMB. Biggest scale of robust optimization model of this risk programming has 95 decision variables and 116 constraints. Because the *PB* is theoretical value, defined *Pr* as the test value of the probability bound of constraint violation. *Pr* is the probability of the actual total cost of risk control more than the total risk control budget in the *N* times test.

Table 1 The weight of sub-goals, processes and risk

Weight	0.3 sub-goals1	0.15 sub-goals2	0.15 sub-goals3	0.22 sub-goals4	0.18 sub-goals5
process1	0.5 0.2(risk1) 0.8(risk2)	0.4 0.5(risk5) 0.5(risk4)	0.1 1.0(risk3)	0.4 0.8(risk7) 0.2(risk10)	0 0
process2	0.3 0.2(risk3) 0.8(risk17)	0.5 0.5(risk8) 0.5(risk9)	0.1 1.0(risk6)	0.2 1.0(risk19)	0.2 1.0(risk13)
process3	0.05 1.0(risk11)	0 0	0.3 0.8(risk7) 0.2(risk18)	0 0	0.3 1.0(risk12)
process4	0.15 1.0(risk8)	0.1 1.0(risk19)	0.3 1.0(risk11)	0.2 1.0(risk14)	0.3 1.0(risk14)
process5	0 0	0 0	0.2 1.0(risk15)	0.2 1.0(risk16)	0.2 1.0(risk20)

Table 2 The cost for control strategies of each risk and description of risk states

Risk	strategy	Cost	State	Risk	Strategy	cost	state
1	0	0	(0.02,0.05)	2	0	0	(0.52,0.65)
	1	1500	(0.15,0.01)		1	1000	(0.48,0.51)
3	0	0	(0.39,0.74)		2	2500	(0.35,0.4)
	1	500	(0.3,0.68)	4	0	0	(0.632,0.51)
	2	1000	(0.2,0.72)		1	2000	(0.459,0.28)
5	0	0	(0.95,0.32)	6	0	0	(0.73,0.85)
	1	3000	(0.589,0.256)		1	1500	(0.58,0.68)
	2	1000	(0.89,0.25)		2	500	(0.4,0.8)
	3	500	(0.69,0.28)		3	2000	(0.7,0.62)
	4	500	(0.89,0.31)		4	1200	(0.6,0.2)
7	0	0	(0.35,0.952)	8	0	0	(0.56,0.23)
	1	1000	(0.15,0.48)		1	500	(0.45,0.2)
9	0	0	(0.356,0.42)		2	1000	(0.5,0.1)
	1	500	(0.3,0.2)		3	500	(0.33,0.16)
10	0	0	(0.831,0.588)	11	0	0	(0.41,0.65)
	1	1000	(0.5,0.5)		1	1500	(0.32,0.58)
	2	800	(0.6,0.4)		2	500	(0.4,0.45)
12	0	0	(0.69,0.5)		3	2000	(0.32,0.15)
	1	500	(0.6,0.2)		4	600	(0.37,0.31)
	2	1000	(0.24,0.5)		5	500	(0.2,0.25)
	3	500	(0.15,0.44)	13	0	0	(0.489,0.5)
	4	500	(0.55,0.1)		1	1000	(0.26,0.39)
14	0	0	(0.9,0.7)	15	0	0	(0.639,0.5)
	1	500	(0.851,0.6)		1	2000	(0.2,0.3)
	2	800	(0.5,0.65)		2	1000	(0.4,0.26)
	3	1000	(0.758,0.3)		3	2000	(0.58,0.2)
	4	1000	(0.58,0.652)		4	1000	(0.45,0.263)
	5	500	(0.85,0.36)	16	0	0	(0.5,0.6)
	6	800	(0.45,0.326)		1	500	(0.4,0.3)
17	0	0	(0.9,0.5)		2	1000	(0.5,0.189)
	1	1000	(0.6,0.45)		3	2000	(0.45,0.33)
	2	5000	(0.45,0.4)	18	0	0	(0.58,0.62)
	3	2000	(0.63,0.22)		1	1500	(0.45,0.49)
	4	500	(0.4,0.45)		2	500	(0.5,0.2)
	5	1000	(0.36,0.4)	20	0	0	(0.5,0.4)
19	0	0	(0.269,0.8)		1	10000	(0.3,0.35)
	1	5000	(0.2,0.6)		2	3000	(0.45,0.15)

It can be obtained that the overall risk level is 4.9089 when no risk control strategies are selected for VE. The best combination of the control strategies is 0/12/12/1/1234/1234/1/123/1/12/ 2345/234/1/236/0/12/12345/ 12/1 /12, the overall risk level is 1.3495 and the total cost is 61，900 RMB without considering the fluctuations in the cost of risk control.

Figure 2 to 4 show the performance measures changing with Γ while different fluctuations degree and fluctuation number.

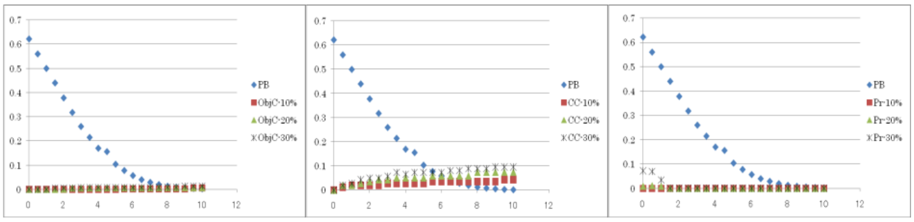

Fig 2 The performance measures changing with Γ, while the fluctuation number is 10

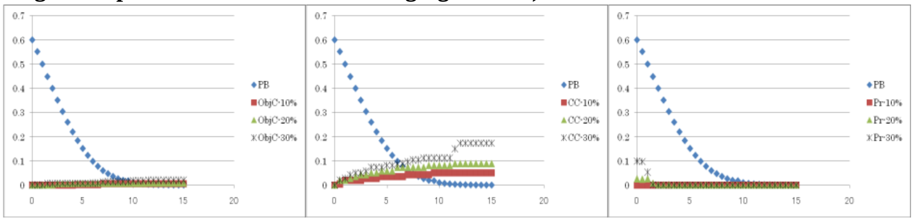

Fig 3 The performance measures changing with Γ, while the fluctuation number is 15

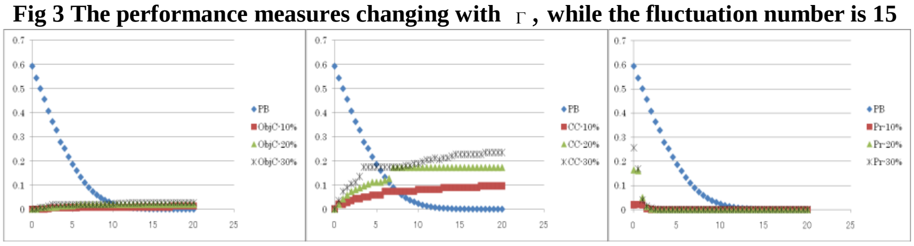

Fig 4 The performance measures changing with Γ, while the fluctuation number is 20

Figure 2 to 4 show that $ObjC$ and ACC increase with the increment of fluctuation degree while the fluctuation number is same or with the increment of fluctuation numbers while the fluctuation degree is same. This is because the greater the fluctuation degree of the cost or the greater the fluctuation number in the cost for risk control, the more cost is needed to eliminate the impact of such fluctuation. That is less cost is used to control risk, and the overall risk level is higher. Hence, $ObjC$ and ACC are increased. And show the Pr is very low that means the probability of the actual total cost of risk control more than the total risk control budget is very small. That shows the method can provide good robustness solution as it considers the variability of the risk cost.

4 Conclusions

VE is a temporary alliance of different enterprises by sharing their capacities and resources. This mode can enhance their competitiveness. However, the risk faced by VE may higher than general enterprise. Hence, to make an effective risk programming is necessary and significant. In the actual operation of VE, the control cost for risk may be uncertain, that is, the existence of fluctuations may affect the feasibility of the original best decision obtained while the cost is treated as a determine factor. Therefore, in order to give a robust combination of risk control strategies, in this paper, robust optimization model is used to deal with the uncertainty of the cost for risk control strategies for the MMRP problem. Numerical experiment analyses show that the method can provide good robustness solution as it considers the variability of the risk cost. The total risk level in the proposed robust models is increased compared to the determined model, since the considered robust approach reflects the conservative attitude of the decision makers. However, the incensement in the total risk level is slight, and is well compensated by the large reduction in variability. Hence, the robust versions of MMRP method provide a good risk management tool for VE.

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