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Multi-Objective Ant Colony Algorithm in EPC Risk Control

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Abstract

According to the risks and risk control target in energy performance contracting (EPC), this paper has designed the risk control measure set. On the basis, a risk control model is put forward, including the risk evaluation, risk control cost, risk loss. Then, a multi-objective ant colony algorithm, based on Pareto theory, is used to solve the model. A series of Pareto optimal solutions are got by example. The result shows that the solutions have the better diversity and convergence. At the same time, the model can find the best combination of various risk control measures in EPC, which can provide direct evidence for the company of EPC.

Keyword: Multi-objective optimization; Pareto optimal; Ant colony algorithm; Energy performance contracting

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1. Introduction

EPC is a commercial operation mode of EMC, which company can provide energy saving technology and services for some customers by signing energy service contracts with the customer, ensure the realization of contract promised amount of energy and energy efficiency, take back investment and obtain profits from the customers' benefits gotten after energy saving renovation. EPC is widely used in higher degree of market of developed country. In the last century 90's, EPC is introduced into China. But it is not developed quickly. The reason is that the risk management ability of energy service company in China is not worth badly at present.

At present, many scholars make a study on EPC risk from the different viewpoints. K.H.Ng et al. studied the risk value and risk aversion of EPC project in energy service company[1]. Evan Mills et al.

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made a deep analysis on EPC risk by energy saving insurance transfer[2]. Gerald B. Sheble et al. established risk probability model and estimation principle method of energy service company by mathematical methods[3]. Evan Millsa put forward the analysis framework for the funds and risk of EPC projects, and made accurate analysis on existed risk by energy experts and investment experts' experience and knowledge[4]. T.C. Shang et al. discussed the evaluation index system of EPC project risk in China, and made quantitative evaluation on risk by using fuzzy comprehensive evaluation[5]. According to above documents analysis, the study on EPC risk has not effective control measures currently. Thus, in order to provide direct decision basis for contract energy project managers, the risk control model of EPC is established to find optimal control measures in this paper.

2. EPC Risks and Its Control Measures

2.1. EPC risk analysis

The core of EPC is energy saving service company, which risk comes from EPC inner. This risk has important effect on EPC's success or failure, and is an internal variable influencing on EPC mode operation performance. In the light of the current situation of EPC in China, the EPC risk is divided into management risk, human capital risk, system risk, credit risk, business risk, customer risk, coordination risk, implicit cost risk, market risk and performance risk.

Table 1. The risks in EPC

The risk in EPC	Sign	Influence factor	The risk in EPC	Sign	Influence factor
Management risk	R_1	Imperfect management system	Customer risk	R_6	Customers' understanding to major issues
		Management pattern difference of both sides			
		Management method backwardness			Improper customer selection
Human capital risk	R_2	Human capital mobility	Coordination risk	R_7	Communication barriers
		Human capital value uncertainty			Low trust
		Human capital initiative	Implicit cost risk	R_8	Ignoring finding cost
System risk	R_3	Imperfect system			Surrounding environment cost
		Hidden measure			Technology dissemination cost
Credit risk	R_3	Intentional bankruptcy	Market risk	R_9	Market uncertainty
		Energy saving benefit transfer			Fluctuation of market price
		Client default	Performance risk	R_{10}	Finance and financial management
Business risk	R_5	Operation management mistakes			Design and technology
		Embroiled in a legal dispute			Equipment and raw materials purchase
		Engaged in illegal business			Engineering construction

2.2. Establishing the risk control measures set in EPC

According to the risk characters of EPC, the risk control measures of this phase are divided into two sets in this paper, including main and auxiliary risk control measures. Among them, the main risk control measures refer to the measures adopted in practice after induction, which can solve some important risks by relative systematic and comprehensive way, and play an important role in mitigating risk. The auxiliary risk control measures are important complement of above measures, which can solve some specific problems in view of the specific risks. The specific risk control measures are showed in Table 2.

Table 2. The risk control measures set in EPC

The risk control measure classification	The risk control measure	Sign	The risk control measure classification	The risk control measure	Sign
The main risk control measures in EPC	Risk avoidance	S_1	The auxiliary control measures in EPC	Cost and benefit analysis	S_6
	Risk prevention	S_2		Establishing support alliance	S_7
	Risk dispersion	S_3		Setting up a special risk control mechanism	S_8
	Risk transfer	S_4			
	Risk retention	S_5		Providing effective incentive	S_9

3. The EPC Risk Control Model

The risk control of EPC is a risk control target in this implementation process. The economic and reasonable risk control measures are selected to establish the overall plan and actions of risk control. That is to say, it is from many alternative plans to select the most economical, the most effective risk control scheme.

The target of risk control is to optimize above risk control measures to minimize the overall risk level under the condition of invest minimum risk control cost. This paper describes the risk control measures adopted by EPC risk as decision variables. S_{ij} represents i risk control measure, thereinto, i=1, 2, …,n (n is the number of EPC risk); j=1, 2, …,m (m is the number of risk control measure)

$$S_{ij}=\begin{cases}1, & i \quad risk \quad selection \quad j \quad control \quad measure\\ 0, & i \quad risk \quad unselection \quad j \quad control \quad measure\end{cases} \tag{1}$$

Based on the above ideas, the model on risk control is established in this paper, which includes risk evaluation, risk control cost and risk loss. Each objective function is showed as the following:

$$\min P=\sum_{i=1}^{n}\sum_{j=1}^{m}W_i\times[CP_{ij}\times S_{ij}+SP_i(1-S_{ij})] \tag{2}$$

$$\min C=\sum_{i=1}^{n}\sum_{j=1}^{m}S_{ij}\times(c_{ij}+c'_{ij}) \tag{3}$$

$$\min L=\sum_{i=1}^{n}\sum_{j=1}^{m}S_{ij}\times l_{ij} \tag{4}$$

Thereinto, P, C, L respectively represent the risk evaluation, risk control cost and risk loss of EPC; W_i is the weight of i risk; SP_i is the initial evaluation of risk i; CP_{ij} is the evaluation of risk i processed by risk control measure j; c_{ij} is the cost to reduce risk i that is controlled early. c'_{ij} is the processing cost to take risk control measures after risk i happens; l_{ij} is the expected loss of risk i that is processed by risk control measure j. According to the model on above risk control, the model is a multi-objective optimization problem that considers risk evaluation, risk control cost and risk loss as objects.

4. Multi-objective Ant Colony Algorithm Based on Pareto Theory

When this paper solves the multi-objective optimization problem on EPC risk control model, as each object is conflicting, it is difficult to make all objective function achieve global optimal solution, only a group of Pareto optimal solution exists. Ant colony algorithm is put forward, which is used to solve the combinatorial optimization problem at present. Therefore, the ant colony algorithm based on Pareto is designed in this paper to solve multi-objective optimization problems of EPC risk control.

4.1. Ant colony optimization algorithm based on Pareto theory

Ant colony optimization algorithm based on Pareto is a multi-objective single population ant colony algorithm in essence, which is different from single target ant colony algorithm, namely, the corresponding *k* object of each path has *k* information element. They are showed as information element vector τ_i^k . The weights p_k ($0 \le p_k \le 1$), $\sum_{k=1}^{K} p_k = 1$ of *k* objects are determined randomly in the initial phase of each ant constructing solution.

(1) Ant state transition rule. Ant colony optimization algorithm based on Pareto adopts the pseudo-random proportional rule to select next path. It usually sets a constant q_0, and gets a random variable *q* which distributes [0,1] uniformly. If $q \le q_0$, it is calculated by formula 5, otherwise, by formula 6.

$$P_m(i,j) = \underset{j \in L_m(i)}{\arg \mathrm{mas}} \left\{ [\sum_{k=1}^{K} p_k \times \tau_m^k(i,j)]^{\alpha} \times \eta_j^{\beta} \right\} \tag{5}$$

$$P_m(i,j) = \begin{cases} \dfrac{[\sum_{k=1}^{K} p_k \times \tau_m^k(i,j)]^{\alpha} \times \eta_{ij}^{\beta}}{\sum_{h \in L_m(i)} \left\{ [\sum_{k=1}^{K} p_k \times \tau_m^k(i,h)]^{\alpha} \times \eta_{ih}^{\beta} \right\}} & j \in L_m(i) \\ 0 & j \notin L_m(i) \end{cases} \tag{6}$$

Thereinto, $P_m(i,j)$ represents the transition probability of ant *m* to select forward path *j* in *i* step; $L_m(i)$ represents all forward paths selected by ant *m* in *i* step. $\tau_m^k(i,j)$ represents the information element vector of the corresponding object *k* when ant *m* selects the path *j* in *i* step. $\sum_{k=1}^{K} p_k \times \tau_m^k(i,j)$ represents the weighted sum of information elements vector in *j* path; η_j is visibility factor; *α* and *β* are two parameters, which reflect the corresponding importance accumulated information and heuristic information of ants in the movement process to select path.

(2) Biological information hormone correction rule. When an ant completes a search, the strength of information element is updated locally. If the path (*i*, *j*) is one of forward paths selected by ant *m*, the strength of information element is updated in formula 7:

$$\tau^k(i,j) = (1-\rho_0) \cdot \tau^k(i,j) + \rho_0 \cdot \Delta\tau^k(i,j) \tag{7}$$

Thereinto, ρ_0 ($0<\rho_0<1$) is a constant, $(1-\rho_0) \cdot \tau^k(i,j)$ represents the evaporation of information element.

When all ants complete a retrieval, for the path of the current optimal solution, the global information element is updated in formula 8:

$$\tau^k(i,j) = (1-\rho_1) \cdot \tau^k(i,j) + \rho_1 \cdot \Delta\tau^k(i,j) \tag{8}$$

For other paths, the global information element is updated in formula 9:

$$\tau^k(i,j) = (1-\rho_1) \cdot \tau^k(i,j) \tag{9}$$

Thereinto, ρ_1 ($0<\rho_1<1$) is a constant, $(1-\rho_1) \cdot \tau^k(i,j)$ represents the evaporation of information element.

4.2. Ant colony optimization solution of the EPC risk control model

For solving the problems on EPC risk control, each probable solution of risk control scheme is a set combined by specific risk control measures designed. The risk set of EPC is $R = \{R_1, R_2, \cdots, R_n\}$, in which,

n=10; the control scheme set is $S=\{S_1,S_2,\cdots,S_m\}$, in which, m=9. According to ant colony optimization algorithm based on Pareto, when each ant processes i risk in i step, it may select a risk control action in selected set S. This action is decided by formula 5 and formula 6. Then, after each ant walks n steps, a risk control set is get.

In formula 5 and 6, η_j is the visibility factor, which represents heuristic information. It has an effect of risk evaluation, risk control cost and risk loss on transfer probability. η_{ij} is shown as the following:

$$\eta_{ij}=1/\left[a\int_C\left(1-P_{ij}\right)l_{ij}dC\right]^{\xi}\left[\left(1-a\right)C_{ij}\right]^{\gamma} \tag{10}$$

Thereinto, ξ and γ are non-negative parameters, which respectively represent the importance of risk loss and control cost; P_{ij} is risk evaluation, which represents the probability of occurrence of risk; l_{ij} is risk loss; C_{ij} is risk control cost.

The corresponding information element of risk evaluation, risk control cost and risk loss are $\tau^1(i,j)$, $\tau^2(i,j)$ and $\tau^3(i,j)$. Before ants construct solution, the weights of risk evaluation are P_1, P_2, P_3, the sum of which is 1. In formula 7, $\Delta\tau^k(i,j)$ is showed as the following:

$$\Delta\tau^k(i,j)=\mathrm{Local}_k\,/\,f_k(m) \tag{11}$$

Thereinto, Local$_1$, Local$_2$, Local$_3$ are constants; $f_1(m)$, $f_2(m)$ and $f_3(m)$ respectively represent the objective function value gotten by formula 2, formula 3 and formula 4 when m ant selects risk control measures.

For global information element update in formula 8, $\Delta\tau^k(i,j)$ is calculated by two rules:

(1) If only these information elements are updated, which are in this path selected by the minimum of f_1, f_2 and f_3 that are situated in current Pareto frontier, $\Delta\tau^k(i,j)$ is calculated by formula 12:

$$\Delta\tau^k(i,j)=\mathrm{Global}_k\,/\min f_k(m) \tag{12}$$

(2) If only these information elements are updated, which are in this path selected by the minimum of integrated target that are situated in current Pareto frontier, $\Delta\tau^k(i,j)$ is calculated by formula 13:

$$\Delta\tau^k(i,j)=\mathrm{Global}_k\,/\min F_k \tag{13}$$

In formula 12 and formula 13, Global$_1$, Golbal$_2$ and Global$_3$ represent constants. F_1, F_2 and F_3 represent the integrated target minimum in Pareto frontier.

5. Example Analysis of EPC Risk Control

In order to test the validity of risk control model in EPC and multi-objective colony algorithm based on Pareto theory, this paper took energy management project as an example of some EMC to analyze the risks. The risk weights in risk control model are got by AHP.

The model solving program is designed by Matlab software, based on the principle of risk control model in EPC and multi-objective colony algorithm. 20 Pareto optimal solutions are got by, such as table 3. Each Pareto optimal solution expresses an optimal risk control scheme. The values of objective functions are different in 20 Pareto optimal solutions. If an objective function value in some scheme is better than the other, then the probability is higher that the other object of the optimal action is lower than other actions.

According to the simulation results in Table 3, among 10 sorts of risk of EPC, each risk has effective control measure. This paper takes Pareto optimum combination scheme 13 as an example, which scheme has the highest risk control cost and the lowest risk loss. In this scheme, the majority of risks use risk avoiding strategy, only parts of risks use risk dispersion and risk transfer strategies. In this condition, the company will reduce own risk loss to the minimum. It shows that if enterprises have their strength, they can properly select the corresponding risk control strategy according to the actual condition of oneself and risk importance in EPC.

Pareto optimal solution set calculated synthesizes in a scatter diagram by Matlab software. In figure 1, Pareto solution set of EPC risk distributes in Pareto frontier uniformly, which has better convergence effect. At the same time, it may directly reflect the effect of different risk control strategy on risk control cost, risk loss and risk evaluation of EPC project.

Table 3. Pareto optimal solution of EPC risk control model

Number	Optimal portfolio	Risk evaluation	Risk control cost (yuan)	Risk loss (yuan)
1	$\{S_1\ S_3\ S_5\ S_8\ S_2\ S_1\ S_4\ S_6\ S_3\ S_6\}$	66.03	12594.56	7985.80
2	$\{S_5\ S_6\ S_3\ S_2\ S_9\ S_6\ S_2\ S_8\ S_1\ S_4\}$	74.01	12307.26	2914.89
3	$\{S_4\ S_6\ S_2\ S_1\ S_7\ S_9\ S_4\ S_1\ S_3\ S_1\}$	77.96	7161.56	15844.87
4	$\{S_8\ S_2\ S_4\ S_5\ S_1\ S_5\ S_7\ S_2\ S_3\ S_2\}$	84.95	4124.39	25379.88
5	$\{S_5\ S_1\ S_2\ S_5\ S_7\ S_1\ S_2S_3\ S_2\ S_4\}$	59.77	14334.07	4640.69
6	$\{S_2\ S_1\ S_3\ S_3S_5\ S_1\ S_8\ S_4\ S_2\ S_6\}$	92.54	879.71	46667.85
7	$\{S_5\ S_8\ S_1\ S_9\ S_4\ S_3\ S_1\ S_2\ S_5\ S_7\}$	88.63	2899.73	35899.38
8	$\{S_7\ S_4\ S_1\ S_3\ S_6\ S_2\ S_9\ S_4\ S_5\ S_3\}$	70.78	8981.38	9783.94
9	$\{S_9\ S_7\ S_5\ S_2\ S_1\ S_7\ S_6\ S_1\ S_3\ S_8\}$	84.90	4240.81	22670.96
10	$\{S_4\ S_3\ S_3\ S_2\ S_3\ S_4\ S_6\ S_3\ S_7\ S_2\}$	83.29	4413.02	19700.35
11	$\{S_1\ S_8\ S_2\ S_1\ S_2\ S_3\ S_2\ S_2\ S_9\ S_1\}$	80.62	6782.79	17610.05
12	$\{S_3\ S_1\ S_2\ S_4\ S_4\ S_7\ S_3\ S_2\ S_1\ S_1\}$	82.86	5247.61	23165.96
13	$\{S_1\ S_3\ S_3\ S_4\ S_4\ S_5\ S_1\ S_7\ S_1\ S_1\}$	81.83	6596.27	17892.71
14	$\{S_7\ S_3\ S_1\ S_7\ S_5\ S_4\ S_5\ S_4\ S_8\ S_4\}$	88.02	2981.21	23713.72
15	$\{S_9\ S_3\ S_1\ S_5\ S_3\ S_9\ S_7\ S_5\ S_2\ S_1\}$	69.35	9231.68	9279.63
16	$\{S_3\ S_2\ S_4\ S_5\ S_1\ S_2\ S_5\ S_7\ S_1\ S_2\}$	93.52	1656.65	44452.79
17	$\{S_2\ S_5\ S_1\ S_3\ S_4\ S_9\ S_4S_6\ S_1\ S_2\}$	77.46	13281.02	7883.27
18	$\{S_2\ S_5\ S_7\ S_3\ S_2\ S_8\ S_9\ S_4\ S_5\ S_1\}$	57.67	17614.56	3815.33
19	$\{S_3\ S_6\ S_9\ S_4\ S_1\ S_1\ S_4\ S_8\ S_1\ S_4\}$	85.73	3655.56	31252.16
20	$\{S_9\ S_6\ S_1\ S_4\ S_3\ S_2\ S_1\ S_3\ S_1\ S_4\}$	77.90	7951.82	9791.72

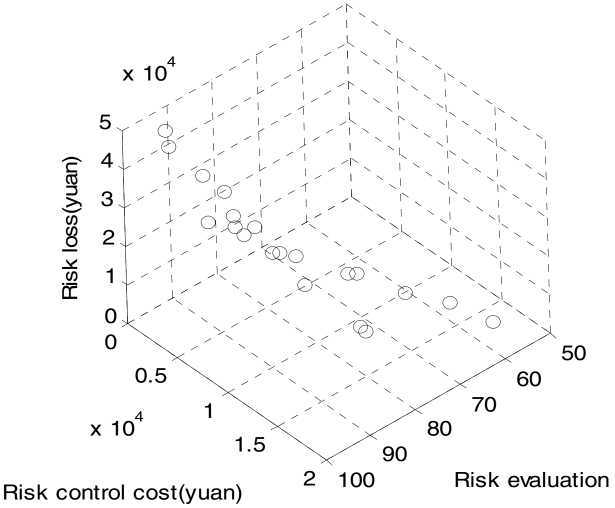

Fig. 1. Pareto solution set distribution of EPC risk control model

6. Conclusion

As EPC risk has already become the bottleneck to restrict EPC development in China, the research on risk control methods of EPC has an important role in EPC of China. This paper designs risk control measures set, and establishes a multi-objective risk control model. For the scale of EPC risks is larger, and it can appear risk measures combination explosion, the multi-objective ant colony algorithm based on Pareto is designed to solve this model. This algorithm can achieve global optimization and is ensured its fast and rationality in the case of no manual intervention. In view of example analysis, a series of Pareto optimal solutions are get. The study shows that the model has better diversity and convergence. At the same time, the model sustains multi-object optimization, and can find the optimal combination of EPC risk control measures, which provides direct basis for EPC project manager.

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