Optimization of project group security cost based on game model

Sun Yu[a], Li Guohui

Department of Management Science and Engineering, Hebei University of Engineering, Handan, 056038, China
[a]1091273788@qq.com

Abstract: It is easy for safety accidents to occur during the construction process of project groups in construction enterprises, which leads to a high proportion of project group safety costs in their total costs, mainly including guarantee costs and loss costs. On the basis of analyzing the composition and influencing factors of safety costs, taking the project group formed by construction enterprises as an example, this paper proposes to use game theory to evaluate the safety costs of the project group, and provides a game optimization mathematical model and algorithm to achieve the optimal safety investment decision. Case analysis shows that the application process of this model is simple and clear, with strong operability and applicability. It can effectively control safety costs, optimize the structure of safety costs, improve the project group benefits of construction enterprises, and ensure the sustainable development of construction enterprises.

Keywords: construction enterprises, project group, game model, security cost optimization primal dual path tracking algorithm

1. Introduction

The construction industry is one of the industries in China where accidents occur frequently. With the development of the times, construction companies have begun to increase the number of projects undertaken and form project groups to achieve benefits that cannot be achieved by a single project. While the project group brings benefits to construction enterprises, it also adds many problems. To ensure that all projects in the project group are completed on time, I have also added a lot of pressure to construction enterprises. At the same time, it has also increased the probability of safety accidents. Safety management is relatively complex, and safety investment is increasing, leading to an increase in safety costs. The safety cost investment and low-cost operation of construction enterprises are contradictory and unified. Without sufficient investment in security costs, secure operations cannot be guaranteed, and enterprises have no profit to speak of; Excessive investment in safety costs that exceed the company's capacity to bear will directly reduce profits, and a decrease in profits will compress the company's investment in safety, leading to a lack of guarantee for safety production and affecting the efficiency of construction enterprises. Therefore, while increasing the investment in safety costs, reasonable control of safety investment costs is the key to ensuring the sustainable development of construction enterprises.

Game theory is also widely applied in various fields. Yang Taihua and Liu Rui used wind farms as an example to evaluate the safety cost of wind farm projects using game theory, and provided a game optimization mathematical model and algorithm to achieve the optimal safety investment decision for the project [1]. Bukvi ć Using game theory models to solve the path selection problem in transportation network graphs [2].

Based on the analysis of the composition and influencing factors of safety costs, this article will take the project group formed by construction enterprises as an example to explore the optimization modeling problem of safety costs in construction enterprise project groups from the perspective of game theory, in order to provide decision-making basis for reasonable safety investment of construction enterprises.

2. Literature Review

2.1 Programme management

Li Dongping proposed the "regional chain and project group" management model, and introduced the organizational goals, framework, and operational management process of construction enterprises using this management model through practical cases. At the same time, he elaborated on the achievements of this model from multiple aspects, providing solutions for construction enterprises to solve cross regional and multi project group management problems [3]. Yan Hongyan et al. analyzed the elements of multi subject collaborative management in construction enterprise project groups through the McKinsey 7S framework. Based on the Hall three-dimensional structural framework, they constructed a four-dimensional institutional framework including knowledge dimension, logic dimension, space dimension, and time dimension. Through this framework, suggestions were provided for the construction enterprise to construct a multi subject management system for project groups [4]. Yang Chao et al. analyzed the definition, characteristics, and difficulties of construction enterprise project groups, and distinguished project groups from single project management. Through an example of an EPC project group in Saudi Arabia, they elaborated on the innovation in organizational mode, design control mode, logistics procurement mode, and construction management mode, providing a good case for construction enterprises to contract international project groups [5]. Han Erdong proposed a multi-dimensional heterogeneous preference information mixed decision-making method based on prospect theory for the optimal selection of construction enterprise project groups. By improving the multi-attribute decision-making method, the candidate project groups were ranked. Sensitivity analysis and comparative analysis were used to explore the impact of parameter variations on the ranking of construction enterprise candidate project groups [6].

2.2 Project group security risks

Chaihailou analyzed the types and specialties of risk factors during the construction process of subway projects. Through literature review, expert on-site research, and other methods, the safety risk factors during the construction process of subway projects were identified, evaluated, analyzed, and classified. The AHP method was used to analyze and rank the weights of 41 risk factors. Based on the analysis results, it was concluded that a classification system for safety risk factors in subway project construction should be established, can provide guidance for contractors to manage and prevent safety risk factors in subway project construction [7].

Du Pengliang has developed a comprehensive security management system for cloud platforms based on SaaS cloud platform technology, including security hazard investigation and governance, security risk control, on-site video management, security education and training, statistical analysis, seasonal risk warning, and leadershi. The system has been applied in projects such as the Beibei project group and proposed the next development plan. The research results show that the cloud platform effectively reduces labor management costs, improved security management efficiency [8]. According to the characteristics of EPC project general contracting mode and related literature and data, Fang Jun qualitatively analyzed the safety risk factors in EPC project design, procurement and construction stage, established EPC project safety risk assessment index system, applied SVM algorithm to safety risk assessment, and built SVM-based EPC project safety risk assessment model. A project group consisting of 20 typical EPC projects was selected and the SVM model was used to evaluate the safety risk. The results showed that the prediction accuracy was 87.5%, and the model had a good prediction effect [9]. Based on the complex and changeable construction environment and coupled construction factors of construction project groups, Zhang Jinxun combined the theory of safety risk management system with the characteristics of construction project groups, defined the risk sources, risks and risk factors of construction project groups, defined the logical relationship among the three, clarified the classification content of the three, and proposed to take risk sources as the risk management objects. The safety risk management system of construction project group based on the risk source-risk-risk factor structure is established based on the risk response measures of special construction scheme [10].

2.3 Game theory

Liu Jia designed a bidding and quotation model for construction projects based on game theory. By using association rules to establish relevant mechanisms, risk attitude theory, and the relationship between game theory and the bidding process, a bidding price game model is established between the

bidding party and the bidding party, as well as between the bidding parties. The risk attitude factor is introduced into the bidding price game model between the bidding parties, and the design process of the optimal current quotation model is verified through experiments. The model converges and can be used as a basis for the bidding party to choose the winning bidder reasonably, Guide bidders to maximize their own interests while making it easier to win the bid [11]. Lin Zhijun constructed a topological structure model for gas explosion risk based on expert experience and accident causation theory. At the same time, he optimized the use of Analytic Hierarchy Process and Triangular Fuzzy Number method to determine the subjective and objective weights respectively through game theory. Then, he calculated the prior probability and conditional probability of risk factors based on fuzzy set theory, and used Bayesian inference technology to calculate the probability of gas explosion occurrence and the posterior probability distribution of risk factors. Finally, through sensitivity analysis and critical causation chain analysis, he identified the key risk factors and critical risk paths that affect gas explosion [12].

3. Theoretical basis

3.1 The composition of project group security costs

The safety cost of a construction enterprise project group is the sum of all expenses incurred to ensure the safety of the project group and all losses caused by safety accidents. It is mainly divided into guarantee safety cost and loss safety cost by nature. The more investment in protective safety costs, the higher the safety level, and the less losses such as accidents and work losses will be. As the safety level continues to improve, the overall safety cost does not always show a downward trend, but rather increases to a certain extent. When the cost of ensuring safety is equal to or close to the cost of loss of safety, the total safety cost reaches the lowest and is also the best safety investment. H1: The integration of the two chains has a positive impact on the innovation ability of electronic information enterprises

3.2 Basic theory of game theory

Game theory, as a mathematical tool, mainly studies how multiple competitive participants (players) in a competitive environment formulate corresponding strategies to obtain their maximum benefits or utility based on their environment. It mainly consists of three elements: player set, strategy set, and payment function set.

Each project in the project group has its own characteristics and functional positioning. Due to their different risk preferences, their strategies for controlling security costs are also different, and their interests and demands are also different. For each project, the greater the difference in benefits obtained, the more difficult it is to form a consensus on safety investment decisions, which inevitably leads to an uneven distribution of project safety performance. On the other hand, if the effectiveness of each project in the project group is consistent, it is possible to form a coordinated and mutually beneficial security cost control strategy in the system. In fact, the mutually beneficial coordination of safety cost control strategies for various projects in a project group depends on the balanced coordination of safety benefits, which are determined by multiple factors. Therefore, to solve the balanced coordination of safety benefits, the key is to solve the optimization problem of the utility function of multiple projects under various factors, which is consistent with the Nash equilibrium idea in game theory, Maximizing the overall utility of the project group under given constraints can be considered, and then a game hybrid strategy can be used to construct a project safety cost optimization model.

4. Research Design

4.1 Model player set

From the perspective of the constituent elements of safety cost, it includes various factors that affect the safety of project groups. These factors have social, economic, technological, and environmental characteristics, and are decomposed layer by layer to form a multi-level structural system that does not intersect with each other at the same level. The obtained security cost components are used as the player set A of the game model, based on the hierarchical structure system of influencing factors, to form a project group security cost control strategy indicator system to guide the determination of the payment function.

Table 1: Elements of project group security cost composition

Index	Indicator Name
A_1	Safety facility construction fee
A_2	Safety education and training fees
A_3	Emergency training and material support expenses
A_4	Operation and maintenance costs of occupational safety and health management system
A_5	Labor protection equipment costs
A_6	Safety insurance premium
A_7	Security equipment fee
A_8	Security technical measures fee
A_9	Cost of safety accident losses

The cost composition of project group security can be expressed as: P=A1+A2+A3+A4+A5+A6+A7+A8+A9

The specific meaning is:

A1: Cost of safety building facilities established to meet safety standards

A2: The cost for employees to receive safety education and publicity through on-the-job training and attending safety lectures

A3: Including emergency drill costs and emergency material costs, safety rescue system construction and maintenance costs, and expenses required for preparing emergency plans

A4: The system that the project party must establish for daily standardized safety management

A5: Cost of labor safety protection equipment for staff

A6: Including personnel insurance and property insurance

A7: Investment of safety monitoring equipment, such as noise detectors, wind power system lighting current detectors.

A8: Guarantee costs including new technology applications, security technology improvements, and development

A9: Comprehensive calculation based on various safety investments

The total loss cost of various safety accidents in the project group can be expressed as:

$$D = \sum_{i=1}^{n} N_{9i} \tag{1}$$

In the formula, D represents the total cost of project safety accident losses, including direct economic losses, personal injury losses, etc.

4.2 Game model strategy set

For project groups, due to different functions and strategic positioning during investment and construction, as well as different economic, social, and environmental conditions, their safety investment also varies. This forms a collection of safety cost control strategies for multiple projects. Through comprehensive analysis and comparison, it is found that one of these strategy sets is the optimal option, which serves as the decision-making basis for the best safety investment of the project group.

Assuming that the set of project groups participating in the analysis is A= {a1, a2, … am}, the set of safety cost control strategies is the set S of game model strategies. If there are n main influencing factors and m projects in the project group participating in the analysis, and the strategy of project i is Si (i =1,2, …., n), then the strategy set of its game model is Si {a | (a_{ij})} m × n.

4.3 Game model payment function set

Assuming that the selection of safety cost control strategies by project decision-makers in the project

group is rational. Based on Table 1, consider the impact intensity c_i (i =1,2,…, m) between the corresponding safety cost components of different projects, with a payment function of u (ci); The impact intensity c_j (j=1,2,…, n) between the constituent elements of the same control strategy is represented by the payment function u (c_j), where $c_i \geq c_j$ and u (c_i) $\geq$ (c_j). This forms a set of payment functions U={u | u_i (ci $\in$ N)} n x m between the safety cost control strategies of each project in the project group and their main constituent elements.

4.4 Building mathematical models

On the basis of the above assumptions, when there are n main influencing factors of the safety cost control strategy and m projects participating in the analysis, the mathematical expression for constructing the game model is G={N, S, U}.

4.5 Seeking an Optimization Model for Security Costs in Project Groups

In the security cost optimization game model of the project group, the safety cost influencing factors established by the AHP method are treated as a limited set of players, and the project group participating in the analysis is treated as a limited set of game strategies, thus forming a standard mixed strategy game model. According to the Nash rule, the security cost optimization game model has at least one Nash equilibrium solution.

For the game of security cost control strategies, as the security investment of each project is calculated in advance, there may be problems where the advantages and disadvantages of each strategy are not obvious, resulting in the optimization algorithm not being able to proceed normally. Here, a hybrid strategy algorithm is used to equivalently transform the game model G={N, S, U} into a linear programming model for calculation:

$$
\begin{cases}
\min \sum_{j=1}^{m} P_j \\
s.t. \sum_{i=1}^{n} P_j K_{ij} \geq 1 \\
P_j \geq 0,1,2,\cdots m
\end{cases}
\tag{2}
$$

In the formula, pj is the strategy probability for selecting a certain project.

Use the primal dual path tracing interior point method quadratic programming algorithm (PFIPQP) to convert the above model into a standard form:

$$
\begin{cases}
\min F(p) = \sum_{j=1}^{m} P_j = e_1 T_p \\
s.t. A_p - w - e_1 = 0 \\
p - u = 0
\end{cases}
\tag{3}
$$

In the equation, w and u are the introduced relaxation variables, and the constraint conditions are transformed from inequalities to equations, where w and u are $\geq$ 0; W is an n-dimensional column vector; A is a matrix of n x m order; c. P and u are m-dimensional column vectors; E1 is an n-dimensional unit column vector.

To eliminate the influence of slack variables, disturbance parameters are introduced θ Construct the Lagrangian function L (p, y, z, w, u):

$$L = c^T - y^T(Ap - w - e_1) - z^T(p - u) - \theta \sum_{k=1}^{m} \ln(w_k) \tag{4}$$

The optimization solution needs to satisfy the extreme value condition of the Lagrangian function:

$$Lp = 0 = e_1 - A^T y - z \tag{5}$$

$$Ly = 0 = e_1 - Ap - w \tag{6}$$

$$Lz = 0 = UZe - \theta e \tag{7}$$

Complementary relaxation conditions:

$$Lw = 0 = WYe - \theta e \tag{8}$$

$$Lu = 0 = UZe - \theta e \tag{9}$$

In the formula, W, Y, U, and Z are diagonal matrices, and are diagonalized to vectors w, y, u, and z.

Next, use the Newton Raphson method to process the KKT equation and express it in the form of a modified equation:

$$\begin{cases} L_p = A^T \triangle y + \triangle z \\ -L_y = A \triangle y - \triangle w \\ -L_z = \triangle p - \triangle u \\ -L_w = W \triangle y + Y \triangle w \\ -L_u = U \triangle z + Z \triangle u \end{cases} \tag{10}$$

Can be obtained:

$$\triangle p = -(A^T W^{-1} YA + U^{-1} Z)^{-1}(A^T W^{-1} L_w + L_p + U^{-1} L_u + A^T W^{-1} YL_y + U^{-1} ZL_z) \tag{11}$$

$$\triangle y = -W^{-1} Y(A \triangle p + Y^{-1} L_w + L_y) \tag{12}$$

$$\triangle z = -U^{-1} Z(\triangle p + Z^{-1} L_u + L_z) \tag{13}$$

$$\triangle w = A \triangle p + L_y \tag{14}$$

$$\triangle u = \triangle p + L_z \tag{15}$$

This algorithm effectively handles a large number of inequality constraints in the model through simplified correction equations, and relaxes the requirements for selecting initial feasible values. The model calculation results represent the strategy probabilities of each project in the project group, which requires multiple iterations to improve accuracy. The probability of safety cost control strategies for each project is compared to select the optimal project.

5. Empirical Analysis

To verify the applicability of the above model, this paper selects a project group with three projects as an example. The strategy set of the game model here consists of three candidate projects. The safety investment values of the safety cost control strategy influencing factor index Nj (j=1,2,…, n) for each project obtained from relevant information are shown in Table 2. The accident losses were calculated based on the safety investment structure model of relevant enterprises. Nine indicator values form a set of players in the game, and then combined with the optimization indicator system to construct a set of payment functions U for each strategy, a game model can be used for analysis.

The impact intensity ci (i=1,2,…, m) between the constituent elements of the security cost control

strategy for each project, as well as the impact intensity c_j (j=1,2,..., n) between the elements within a certain project, constitute the payment function set U of the game model. This forms a winning matrix for the payment function values of the entire system. In this article, the total sum of all payment function values can be taken as 100, where the total corresponding payment function values for each indicator of N1, N3, N5, and N8 are all 15; The sum of the payment functions corresponding to each of the other 5 indicators is 8. Finally, the winning matrix of the model is shown in Table 3.

Table 2: Composition of project group security costs

Project group	1	2	3
Guaranteed security costs	266.8	266.8	266.8
Safety construction project cost	30	30	30
Safety education, publicity and training expenses	10	10	10
Emergency training and material support expenses	30	30	30
Security system operation and maintenance costs	10	10	10
Labor protection equipment costs	31.5	31.5	31.5
Safety insurance	20	20	20
Security equipment fee	10.3	10.3	10.3
Security technical measures fee	90	90	90
Cost of safety accident losses	6.78	6.78	6.78

Table 3: Winning matrix table for safety cost components of project group

Index	Project1	Project 2	Project 3
A_1	4	8	3
A_2	4	1	3
A_3	2	4	9
A_4	2	4	2
A_5	5	5	5
A_6	3	2	3
A_7	2	4	2
A_8	6	3	6
A_9	3	3	2

Based on the winning matrix, establish a game model G= {S1, S2; A} for project group safety cost optimization, and solve the following linear programming problem using the primal dual path tracking algorithm. Set the initial data as p (0) = [1,1,1] and use an iterative program to solve it, the safety benefits of each project in the project group are shown in Table 4.

$$p^T = \begin{bmatrix} 0.193520 \\ 0.125001 \\ 0.056480 \end{bmatrix}$$

The optimal solution is obtained as:

Table 4: Safety benefits of each project in the project group

Index	Project A	Project B	Project C
Safety investment/10000 yuan	273.58	337.9	507.92

On the other hand, from the analysis of the total safety cost investment of each project in the project group, Project A has the least investment, followed by Project B, and Project C has the most safety investment, which is almost twice the safety investment of Project A. This indicates that more safety investment is not better. When the safety investment reaches a certain level, in order to achieve a certain level of safety guarantee, the safety investment will actually increase, which is consistent with the characteristics of the safety cost of the project. Therefore, the safety cost of Project A tends to be closer to the optimal state.

6. Research conclusions and suggestions

Construction enterprises should attach great importance to safety, educate employees to improve safety awareness, strictly implement operating procedures, and create a good safety atmosphere. At the same time, they should further improve the statistical analysis system of safety costs, fully implement safety investment, and focus on the weak links of construction enterprises. Through in-depth analysis and exploration of proportion schemes, reasonable increases in guaranteed safety costs can be made to avoid accidents and reduce economic losses, Promote the healthy development of construction enterprises.

This article conducts a comparative study on the composition of safety costs in project groups from the perspective of game theory, focusing on the decision-making problem of safety investment in project groups. For the first time, an evaluation index system for safety cost control strategies in project groups is proposed. Based on this, the main components of safety costs in project groups are taken as the set of players in the game model, and the impact intensity of relevant elements is determined as the payment function. A game model is established. This breaks the limitations of making security investment decisions based on the risk preference of a single project, and solves the collaborative optimization problem of security cost control in distributed project groups while ensuring the overall security of the project group system. The research results also prove that the more security investment, the better the security benefits, but the closer the total security cost is to the lowest, the better the control strategy. In addition, for the solution of the security cost mixed strategy optimization game model of the project group, this article also proposes a new method of transforming it into a linear programming model and using the primal dual path tracking algorithm to solve it. Practice has shown that this calculation process is simple and clear, and has strong practicality and operability.

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