Tripartite Subject Game Research Based on the Engineering, Procurement, and Construction Model

Yulong Xu[1], Yueming Wang[2]

Institute of Civil Engineering and Architecture, Southwest University of Science and Technology,Mianyang,China,

[1]2386716995@qq.com
[2]82218911@qq.com

ABSTRACT. Through the evolutionary game, this paper selects the general contracting unit, design unit, and construction unit as the tripartite game subjects to investigate the influence of income distribution coefficients on their behavioral strategies, and utilizes MATLAB R2016b for simulation. The results reveal that income distribution coefficients for the three subjects should not be too high or too low. Specifically, an income distribution coefficient of 0.4 or 0.5 for the general contracting unit and a combined income distribution coefficient of 0.6 or 0.5 for the design and construction units are found to be the optimal allocation methods. Otherwise, the goal of maximizing benefits cannot be achieved. Consequently, relevant suggestions are proposed to provide references for practical engineering construction.

KEYWORDS: EPC; Evolutionary Game; Income distribution coefficient; Simulation analysis

1 Introduction

With the “Belt and Road” initiative gaining momentum and robust policy support, the Engineering, Procurement, and Construction (EPC) model has become the most prominent contracting model in China[1]. In EPC projects, the general contracting unit maintains control over project quality and progress with the owner’s written consent, and subcontracts the design and construction work to other qualified construction engineering design units and construction units, excluding the core engineering tasks. However, in practice, the nature of EPC projects exerts substantial pressure on all participating units. To enhance efficiency, the general contracting unit should actively assume a leadership role, minimize resource wastage, improve construction quality, encourage optimization and innovation in design and construction, and ensure a three-way “win-win cooperation”, benefiting all subjects.

Currently, scholars have applied game theories to study the behavior strategies of different subjects in EPC projects. First, in terms of research subjects, Wang et al. constructed a tripartite game model involving the owner, the whole-process consulting

B. K. Kandel et al. (eds.), *Proceedings of the 2023 8th International Conference on Engineering Management (ICEM 2023)*, Atlantis Highlights in Engineering 23,
https://doi.org/10.2991/978-94-6463-308-5_4

party, and the EPC company based on the prospect theory, to analyze their strategic choices under various influencing factors[2]. Jin et al.studied the game behavior among the participants of the design-oriented EPC project under the consortium mode, selected the owner, design unit and construction unit as the game subjects, and used system dynamics to analyze its evolution path[3]. Wang and Liu established a tripartite evolutionary game model involving the government, the owner, and the construction company by using actual engineering cases, to analyze the behavior strategies and influencing factors of stakeholders during the development of the EPC model[4]. Based on bounded rationality, Sun et al.established an evolutionary game model including government, owner and general contractor, and studied the strategic evolution of three stakeholders in the application of Building Information Modeling (BIM) to EPC projects[5]. Second, in terms of research content, Song et al.constructed a two-agent game model of general contractor and subcontractor in EPC project, and explored the influence of various factors on knowledge transfer behavior from a dynamic perspective[6]. Zhang and Fang analyzed the advantages and disadvantages of two bidding models: decomposed bidding and EPC bidding, proposing that large-scale projects adopting the latter model are conducive to the owner's successful selection of the most qualified contractor[7]. Based on game theory, Zhao et al.studied the influence of the owner 's design depth on the contractor 's optimal design decision in the early stage of EPC project, and used numerical analysis to find a more suitable optimal strategy for both subjects[8]. Wang and Fu investigated the cooperative relationship between design units and construction units within EPC consortia according to the evolutionary game theory[9]. Xie et al. established a risk factor index system for EPC consortiums and discussed the rational risk-sharing proportions among participating subjects from a game theory perspective[10]. Most current literature treats the owner and other related stakeholders as game subjects, overlooking subcontracting units and resulting in insufficient research content in this field.

This paper excludes the owner and selects the general contracting unit, design unit, and construction unit as the related stakeholders, hypothesizing that all three subjects are limited rational groups aiming to maximize their benefits. Then, it examines the influence of income distribution coefficients on the strategies of each subject, providing references for practical engineering construction. It should be noted that this study leaves out the consortium model in EPC projects.

2 Construction of a Tripartite Evolutionary Game Model

2.1 Basic Hypotheses

Hypothesis 1: The general contracting unit, design unit, and construction unit are all in a state of bounded rationality, aiming to maximize their interests.

Hypothesis 2: The general contracting unit selects the strategy of "encouraging" and "not encouraging", the design unit chooses that of "optimizing" and "not optimizing", while the construction unit opts for "innovating" and "not innovating".

Hypothesis 3: The proportions of the general contracting unit's choice of "encouraging" and "not encouraging" strategies are X and $(1-X)$, respectively; the proportions of the design unit opting for "optimizing" and "not optimizing" strategies are Y and $(1-Y)$, respectively; the proportions of the construction unit selecting "innovating" and "not innovating" strategies are Z and $(1-Z)$, respectively. Specifically, $0 \le X, Y, Z \le 1$.

Hypothesis 4: The ultimate goal is attained when the design unit adopts the "optimizing" strategy while the construction unit selects the "innovating" strategy.

2.2 Setting of Relevant Variables

To achieve the research objectives, the setting of relevant variables for the costs and incomes of the general contracting unit, design unit, and construction unit are as follows:

1) Fixed income for the general contracting unit is A, and the cost increment for choosing the "encouraging" strategy is B. When the general contracting unit chooses "encouraging", the design unit adopts "optimizing", and the construction unit selects "innovating", the general contracting unit obtains additional income C, and the sharing coefficients for the general contracting unit, design unit, and construction unit are α, β, and θ ($0 \le \alpha, \beta, \theta \le 1$ and $\alpha + \beta + \theta = 1$). In this case, the general contracting unit's income is αC. When the design unit opts for "optimizing" and the construction unit chooses "innovating", but the general contracting unit elects for "not encouraging", the general contracting unit gains additional optimization income C', and $C > C'$.

2) Fixed income for the design unit is D, and the cost increment for "optimizing" is E. In the case of the general contracting unit's encouragement status, the joint action of the design and construction units leads to additional project income, and the design unit's benefit in this case is βC.

3) Fixed income for the construction unit is F, and the cost increment for "innovating" is G. Under the encouragement status of the general contracting unit, the joint action of the design and construction units leads to additional project income, and the construction unit's benefit is θC in this case.

2.3 Establishment of the Evolutionary Game Model

Based on the strategy choices of the three subjects, eight game combinations can be obtained, namely: (encouraging, optimizing, innovating), (encouraging, optimizing, not innovating), (encouraging, not optimizing, innovating), (encouraging, not optimizing, not innovating), (not encouraging, optimizing, innovating), (not encouraging, optimizing, not innovating), (not encouraging, not optimizing, innovating), and (not encouraging, not optimizing, not innovating).

As mentioned in Section 1.2, diverse stakeholders receive varying benefits from different behavioral strategies. For example, adopting the (encouraging, optimizing, innovating) combination entails the general contracting unit incurring partial costs B for activity promotion and management and the joint action of design and construction yielding additional income αC for the general contracting unit. The design unit incurs an additional cost for optimizing the design E but gains supplementary income βC. The construction unit invests in innovation cost G while obtaining income θC. This dynamic is encapsulated within payoff matrices, illustrated in Table 1 and Table 2.

Table 1. Payoff matrix for different strategies of design and construction units with encouragement from the general contracting unit

Design unit	Construction unit	
	Innovating Z	Not innovating $(1-Z)$
Optimizing Y	$(A-B+\alpha C, D-E+\beta C, F-G+\theta C)$	$(A-B, D-E, F)$
Not optimizing $(1-Y)$	$(A-B, D, F-G)$	$(A-B, D, F)$

Table 2. Payoff matrix for different strategies of design and construction units without encouragement from the general contracting uni

Design unit	Construction unit	
	Innovating Z	Not innovating $(1-Z)$
Optimizing Y	$(A+C', D-E, F-G)$	$(A, D-E, F)$
Not optimizing $(1-Y)$	$(A, D, F-G)$	(A, D, F)

3 Model Analysis

3.1 Construction of the Replicator Dynamics Equation

Based on Tables 1 and 2, the expected payoffs for the three subjects under different strategies can be determined as follows:

1) The expected payoffs for the general contracting unit choosing "encouraging" and "not encouraging" are U_{X1} and U_{X2}, respectively, with the average one as U_X:

$$U_{X1} = YZ(A-B+\alpha C) + Y(1-Z)(A-B) + Z(1-Y)(A-B) + (1-Y)(1-Z)(A-B) = YZ\alpha C + A - B \quad (1)$$

$$U_{X2} = YZ(A+C') + YA(1-Z) + A(1-Y)(1-Z) = YZC' + A \quad (2)$$

$$U_X = XU_{X1} + (1-X)U_{X2} \quad (3)$$

2) The expected payoffs for the design unit adopting "optimizing" and "not optimizing" are U_{Y1} and U_{Y2}, respectively, with the average one as U_Y:

$$U_{Y1} = XZ(D-E+\beta C) + X(1-Z)(D-E) + Z(1-X)(D-E) + (1-X)(1-Z)(D-E) = XZ\beta C + D - E \quad (4)$$

$$U_{Y2} = XZD + XD(1-Z) + ZD(1-X) + D(1-X)(1-Z) = D \quad (5)$$

$$U_Y = YU_{Y1} + (1-Y)U_{Y2} \quad (6)$$

3) The expected payoffs for the construction unit selecting "innovating" and "not innovating" are U_{Z1} and U_{Z2}, respectively, with the average one as U_Z :

$$U_{Z1} = XY(F-G+\theta C) + X(1-Y)(F-G) + Y(1-X)(F-G) + (1-X)(1-Y)(F-G) = XY\theta C + F - G \quad (7)$$

$$U_{Z2} = XYF + XF(1-Y) + YF(1-X) + (1-X)(1-Y) = F \quad (8)$$

$$U_Z = ZU_{Z1} + (1-Z)U_{Z2} \quad (9)$$

The replicator dynamics equation for the three subjects can be obtained from Equations (1)–(9).

$$F_{(X)} = X(U_{X1} - U_X) = X(1-X)\left[YZ(\alpha C - C') - B\right] \quad (10)$$

$$F_{(Y)} = Y(U_{Y1} - U_Y) = Y(1-Y)(XZ\beta C - E) \quad (11)$$

$$F_{(Z)} = Z(U_{Z1} - U_Z) = Z(1-Z)(XY\theta C - G) \quad (12)$$

Equilibrium Points and Stability Analysis

1) To find equilibrium points, we assume $F_{(X)} = 0$, $F_{(Y)} = 0$, $F_{(Z)} = 0$, and then the equilibrium points of the system can be obtained as follows: $O_1(0,0,0)$, $O_2(1,0,0)$, $O_3(0,1,0)$, $O_4(0,0,1)$, $O_5(1,1,0)$, $O_6(1,0,1)$, $O_7(0,1,1)$, and $O_8(1,1,1)$.

2) To construct the Jacobian Matrix, we take partial derivatives of Equations (10) to (12) and obtain the Jacobian matrix Q as follows:

$$Q = \begin{pmatrix} (2X-1)\left[YZ(\alpha C - C') + B\right] & XZ(1-X)(\alpha C - C') & XY(1-X)(\alpha C - C') \\ Z\beta CY(1-Y) & (1-2Y)(XZ\beta C - E) & X\beta CY(1-Y) \\ Z\theta CY(1-Z) & Z\theta CX(1-Z) & (1-2Z)(XY\theta C - G) \end{pmatrix} \quad (13)$$

3) To analyze the stability, each equilibrium point is substituted into the Jacobian matrix. If all resulting eigenvalues are negative, then the equilibrium point is a stable point ESS (Evolutionarily Stable Strategy). The computation results are shown in Table 3.

Table 3. Equilibrium point stability analysis

Equilibrium point	Eigenvalues	Stability
$O_1(0,0,0)$	$(-B,-E,-G)$	ESS
$O_2(1,0,0)$	$(B,-E,-G)$	Unstable
$O_3(0,1,0)$	$(E,-B,-G)$	Unstable
$O_4(0,0,1)$	$(G,-B,-E)$	Unstable
$O_5(1,1,0)$	$(B,E,\theta C-G)$	Unstable

$O_6(1,0,1)$	$(B, G, \beta C - E)$	Unstable
$O_7(0,1,1)$	$(E, G, \alpha C - C' - B)$	Unstable
$O_8(1,1,1)$	$(E - \beta C, G - \theta C, B + C' - \alpha C)$	To be determined

Corollary 1: $E - \beta C < 0$, $G - \theta C < 0$, and $B + C' - \alpha C < 0$ represent lower costs for "optimizing", "innovating", and "encouraging" than the respective income of the design, construction, and general contracting units. In this scenario, stable points exist at $O_1(0,0,0)$ and $O_8(1,1,1)$. The general contracting unit, design unit, and construction unit choose the strategies of (encouraging, optimizing, innovating) and (not encouraging, not optimizing, not innovating).

Corollary 2: When $E - \beta C > 0$, $G - \theta C > 0$, and $B + C' - \alpha C > 0$, the "optimizing" cost of the design unit surpasses its income, the "innovating" cost of the construction unit exceeds its income, and the "encouraging" cost of the general contracting unit outweighs its income, with the input cost of each unit higher than its income. Correspondingly, the stable point is only $O_1(0,0,0)$.

Corollary 3: When $E - \beta C > 0$, $G - \theta C < 0$, and $B + C' - \alpha C < 0$, the design unit refuses to optimize because of higher "optimizing" costs than income. Although the "innovating" cost of the construction unit and the "encouraging" cost of the general contracting unit are lower than their respective income, the ultimate objective remains elusive. At this point, the stable point is only $O_1(0,0,0)$. Similarly, when $G - \theta C > 0$ or $B + C' - \alpha C > 0$, both the construction and general contracting units reject innovation and encouragement due to greater expenses than income.

4 Simulation Analysis

Different factors have different effects on the tripartite game mechanism[11]. On the basis of previous studies, this paper focuses on the influence of income distribution coefficient on the evolution mechanism of the tripartite subject of EPC project.

Because the income distribution coefficient in the actual project is often determined by negotiations between the high-level echelons of each unit, it is difficult to establish consistent data between different projects due to factors such as the professional execution ability of the enterprise, the trust between the general contractor and the subcontractor, and the negotiation skills. Therefore, this paper sets the relevant parameters as follows. First, the general contracting unit bears greater risks in EPC project construction, making it more likely to proactively take measures to increase the income, while the cooperation possibility between the design and construction units is considered moderate. Hence, it is assumed that the initial evolution probability is set as: X =0.6, Y =0.5, Z =0.5. Second, other parameters are set as Array 1: B =15, E =20, G =25, C =300, C' =75, α =0.5, β =0.3, θ =0.2, which satisfies Corollary 1. Finally, because the three subjects have a relationship of management and being managed, if the income distribution coefficient of the general contracting unit (α) always surpasses that of the design unit or the construction unit (β, θ), there are three situations at this time: $\alpha > \beta = \theta$ and $\alpha + \theta + \beta = 1$; $\alpha > \beta > \theta$ and $\alpha + \theta + \beta = 1$; $\alpha > \theta > \beta$ and $\alpha + \theta + \beta = 1$.

For enhanced research, we assign values to α in three types of combination: (0.1, 0.2, 0.3); (0.4, 0.5, 0.6); (0.7, 0.8, 0.9).

4.1 Analysis of the First Type of Assignment Combination

When the α assignment combination is (0.1, 0.2, 0.3), the income distribution coefficient of the general contracting unit may fall below that of the design and construction units. For example, when α=0.3, β=0.4 and θ=0.3. Therefore, the first type of combination contradicts the hypothesis.

4.2 Analysis of the Second Type of Assignment Combination

When the α assignment combination is (0.4, 0.5, 0.6), there are three situations:

1) When $\alpha > \beta = \theta$ and $\alpha + \theta + \beta = 1$, we assume the value combination of α, β, and θ as (0.4, 0.3, 0.3), (0.5, 0.25, 0.25), and (0.6, 0.2, 0.2). The simulation results are shown in Figure 1.

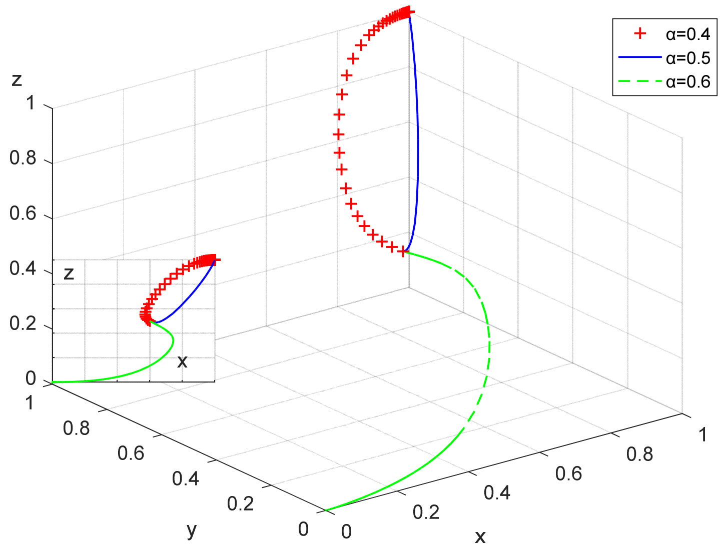

Fig. 1. Influence of income distribution coefficients

2) When $\alpha > \beta > \theta$ and $\alpha + \theta + \beta = 1$, we assume the value combination of α, β, and θ as (0.4, 0.35, 0.25), (0.5, 0.3, 0.2), and (0.6, 0.3, 0.1). Figure 2 illustrates the simulation results.

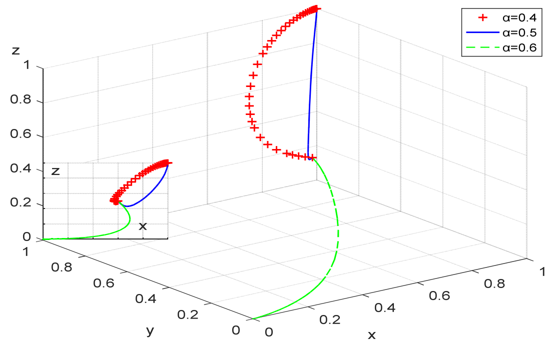

Fig. 2. Influence of income distribution coefficients

3) When $\alpha > \theta > \beta$ and $\alpha + \theta + \beta = 1$, we assume the value combination of α, β, and θ as (0.4, 0.25, 0.35), (0.5, 0.2, 0.3), (0.6, 0.1, 0.3). The simulation results are depicted in Figure 3.

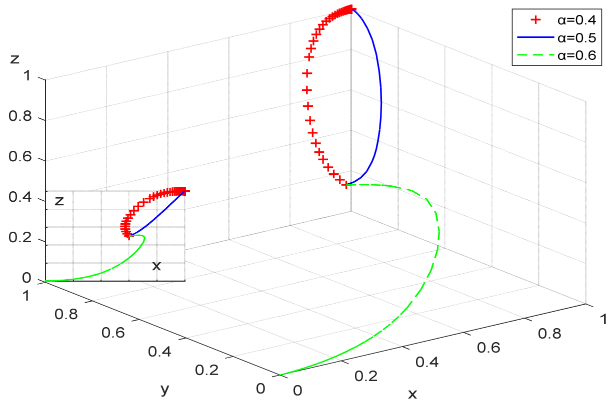

Fig. 3. Influence of income distribution coefficients

By analyzing Figures 1–3, we draw the following conclusions:

1) When $\alpha = 0.4$ or $\alpha = 0.5$, income distribution coefficients of the design and construction unit are consistent ($\beta = \theta = 0.3$ or $\beta = \theta = 0.25$), and the three subjects can reach an ideal state: attaining a stable strategy as soon as possible. When these coefficients are inconsistent (β=0.35, θ=0.25 or β=0.25, θ=0.35), the subject with a lower income distribution coefficient may exhibit initial passivity due to comparatively lower income. However, driven by ultimate benefits, it would still choose the stable strategy.

2) When α=0.6, β=0.3, θ=0.1, or β=0.1, θ=0.3, or $\beta = \theta$=0.2, the income distribution coefficient of the general contracting unit becomes larger. Irrespective of the size relationship of the income distribution coefficient held by the design and

construction unit, the coefficient of the general contracting unit significantly surpasses that of any subject. The general contracting unit makes substantial cost investments to encourage the design and construction units to optimize and innovate. Despite the relatively low coefficient of the design unit, it still exceeds the fixed income. Therefore, the design unit initially exhibits reluctance towards optimization, but as the project progresses and income outweighs costs, it finally embraces the optimization strategy. However, the substantial cost input of the construction unit choosing the innovation strategy contrasts with relatively low income. Whether the eventual income can balance the innovation costs remains uncertain, so the construction unit finally chooses the non-innovation strategy.

4.3 Analysis of the Third Type of Assignment Combination

When the α assignment combination is (0.7, 0.8, 0.9), i.e., $\alpha > \beta = \theta$, we assume the value combination of α, β, and θ as (0.7, 0.15, 0.15), (0.8, 0.1, 0.1), and (0.9, 0.05, 0.05). The simulation results are shown in Figure 4.

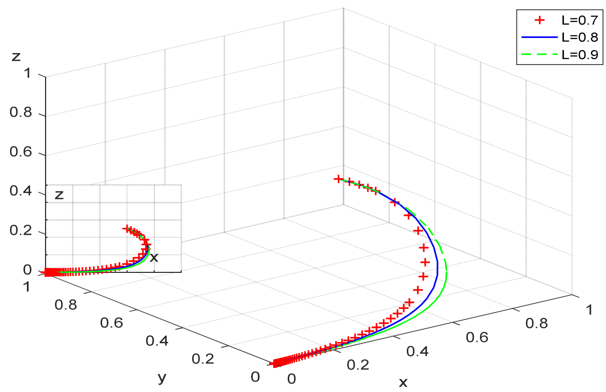

Fig. 4. Influence of income distribution coefficients

By analyzing Figure 4, we can conclude as follows:

When α=0.7, 0.8, 0.9, the general contracting unit enjoys greater income, so it greatly inclines to invest costs for encouragement. Conversely, the design or construction unit has lower income and faces a heightened risk that input costs might outweigh actual income, so it refuses optimization and innovation. Similarly, when $\alpha > \beta > \theta$ and $\alpha > \theta > \beta$, the design and construction units decline to take action because of low income, thereby hindering the attainment of maximizing benefits.

5 Conclusions and Recommendations

According to previous research on EPC projects, this paper excludes the owner from the game subjects, takes the general contracting unit, design unit, and construction unit as the research subjects, and focuses on the influence of different income distribution coefficients on the strategy of the relevant stakeholders. The results show that excessively high or low income distribution coefficients of the three subjects impede the maximum benefits. The optimal distribution entails an income distribution coefficient of 0.4 or 0.5 for the general contracting unit, while the combined proportion of the design and construction units stands at 0.6 or 0.5. The specific distribution coefficient should integrate the ability and performance of all subjects in practical projects.

To facilitate the adoption of stable strategies by all subjects, relevant recommendations are proposed. First, the income distribution coefficient should be fairly determined through team assessment. In EPC projects, each unit appoints representatives to form an assessment team to score the professional competence, coordination, and overall contributions of each unit, ensuring an equitable determination of the income distribution coefficient. Furthermore, implementing a system of rewards and penalties during execution can actively incentivize each unit's subjective initiative. Second, they should strengthen information construction and jointly improve profits. Effective communication is of paramount importance in EPC projects. Strengthening information construction can enhance communication and cooperation efficiency and reduce associated management costs. By optimizing information exchange and refining communication efficiency among the general contracting unit, design unit, and construction unit, cost increments can be minimized, which heightens the probability of the three subjects opting for the strategies (encouraging, optimizing, and innovating).

Additionally, this paper also has certain limitations. First, there are inherent constraints in the selection and assignment of related parameters, which have led to disparities between the data outcomes and actual project scenarios. Second, this paper neglects the involvement of other relevant stakeholders. Introducing other stakeholders such as owners, government, and even supervisors for a four-subject game will be the next research direction.

REFERENCES

1. Lu T. J., Cui Z. Q. Integration mode of "the Belt and Road Initiative" project and internationalization strategy of Chinese standards [J]. International Economic Cooperation, 2021, (6): 87-92. https://kns.cnki.net.
2. Wang X. X., Wang Y. L., Wu N. S. Research on the cooperative game of EPC project subjects under the whole process consultation mode [J]. Journal of Engineering Management, 2022, 36 (5): 19-24.10.13991/j.cnki.jem.2022.05.004.
3. Jin Y., Li Y. P., Li Y. F., et al. Game research on EPC mode cooperation led by design institute [J]. Journal of Engineering Management, 2021, 35 (6): 107-112.10.13991/j.cnki.jem.2021.06.019.
4. Wang S. W., Liu X. J. Development of EPC model in Chinese public projects: evolutionary game among stakeholders [J]. Journal of Asian Architecture and Building Engineering. 2022, 21, 5: 2095-2113.10.1080/13467581.2021.1971681.
5. Sun C. S., Wang M., Man Q. P., Wan D. J. Research on the BIM Application Mechanism of Engineering-Procurement-Construction Projects Based on a Tripartite Evolutionary Game [J]. Journal of Asian Architecture and Building Engineering. 2023, 149, 3: 04022182.10.1061/JCEMD4.COENG-12052.

6. Song H. B., Hao S. Y., Ren X. Research on the subject of knowledge transfer in EPC general contracting project based on evolutionary game theory [J]. Research on Science and Technology Management, 2016, 36 (17): 177-184.10. 3969 /j. issn. 1000 — 7695. 2016. 17. 031.
7. Zhang X. Z., Fang J. Design of EPC bidding mechanism based on game theory [C]//International Conference on Construction and Real Estate Management. Guangzhou, 2017. https://ascelibrary.org/doi/abs/10.1061/9780784481066.024.
8. Zhao Y., Qiang M. S., Wang H. Design decision game between owner and contractor of EPC project [J]. Journal of Tsinghua University (Natural Science Edition) 2021, 61 (10): 1195-1201.10.16511/j.cnki.qhdxxb.2021.22.027.
9. Wang D. D, Fu H. W. Evolutionary game analysis of EPC consortium cooperation relationship [J]. Journal of Engineering Management, 2019, 33 (1): 84-89.10.13991/j.cnki.jem.2019.01.016.
10. Xie X. D., Zhou Y. S., You W. F., et al. Research on risk sharing of EPC project consortium from the perspective of the game [J]. Journal of Engineering Management, 2022, 36 (6): 97-102.10.13991/j.cnki.jem.2022.06.017.
11. Zhu L. L., Rong J. M. Tripartite evolutionary game and simulation analysis of drug safety and quality supervision under government reward and punishment mechanism [J]. China Management Science, 2021, 29 (11): 55-67.10.16381/j.cnki.issn1003-207x.2019.0481.