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# Stability Analysis of EPC Consortium Cooperation Based on Evolutionary Game

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## ABSTRACT

Consortium contracting is a contracting model that China encourages and advocates. Due to the interest drive, members within the consortium are very prone to negative cooperation and midway withdrawal, which hinders the healthy development of the consortium. Therefore, this paper constructs a game model of EPC consortium cooperation evolution, analyzes the influence of different reward and punishment mechanisms on the cooperation of consortium members, and applies system dynamics to simulation. The results show that under the static reward and punishment and dynamic reward mechanism, the consortium cooperation is not stable; while under the dynamic punishment mechanism and the dynamic reward and punishment mechanism in which the maximum punishment is greater than the maximum reward, the evolution of consortium cooperation is gradually stable and the behavioral strategies are gradually unified. It also puts forward suggestions for measures conducive to stabilizing cooperation, which provide certain reference value for the internal management of consortium members' cooperation.

## KEYWORDS

EPC Consortium, Evolutionary Game, Stable Cooperation, System Dynamics

With the development of The Belt and Road Initiative (Bai & Chen, 2023), Engineering Procurement Construction(EPC)general contracting has been "going out." But with fewer dual-qualified enterprises, design and construction units forming consortiums for engineering contracting has been an inevitable trend. Due to the large number of stakeholders in an EPC project, the benefits of the entire project are affected once one party engages in opportunistic behavior. Therefore, the stability of EPC project consortium members' cooperation is crucial to enhancing project benefits. In this paper, the design unit is taken as the lead unit of the consortium to carry out the EPC consortium partnership stability research and data simulation.

Jiang and Tang (2023) collected a large amount of data about consortiums in the form of questionnaires, established a mechanism for EPC consortium cooperation from the perspective of trust, and tested the mechanism through structural equation modeling, which led to the conclusion that reputation, reciprocity, and communication are important factors in generating trust. Ribas et al.

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(2019) combined the fuzzy hierarchy analysis method (FAHP) with the trigonometric factorial function for the San Antonio Hydroelectric Power Plant project to rank the risk events from the perspectives of the owner and the EPC contractor and concluded that the subjects of the EPC consortium have similar perceptions of the risks, although the risk sharing is different. Li et al. (2019) used Netlogo to simulate the factors affecting the competitive relationship between individuals in the railroad consortium. To minimize the probability of betrayal behavior, they proposed improving the consortium's trust and punishment mechanism.

Based on the value co-creation behaviors (VCCB) and stakeholder value network (SVN) analysis method, Liang and Song (2023) constructed the VCCB-SVN qualitative model and proposed the driving path of VCCB in EPC projects and corresponding countermeasure suggestions. Wang et al. (2023) constructed an EPC project-specific control and residual control configuration model by fully considering the heterogeneous characteristics of the two sides of the consortium. They also analyzed the impact of the consortium's lead identity, decision-making preference, risk tolerance, and risk preference on self-interested input behavior. Lu and Li (2019) constructed a consortium partner selection index system based on task and context perspectives, used Z-number fuzzy numbers to establish an evaluation model, and introduced fuzzy reasoning into the PROMETHEE method to establish a preference model. Wang and Zang (2016) used the fuzzy comprehensive evaluation method to calculate the risk factor of the consortium members. They then incorporated the risk factor into the Shapley value model to establish a "contribution-based, risk-based" revenue allocation model and concluded that the project risk does not affect the total revenue of the consortium. However, it has an impact on the optimization of the revenue allocation ratio.

Guo et al. (2022) constructed a strategic alliance partner selection evaluation model based on entropy weight and technique for order of preference by similarity to ideal solution (TOPSIS) for assembled buildings. They concluded that commercial property sales capability, property management capability, capital investment, talent investment, and product innovation capability are the five most influential secondary indicators. Based on the perspective of government project quality supervision, through field research and in-depth interviews, Shen et al. (2021) adopted the constructive rooted theory approach to substantive coding of interview data, explored the core constituents of the EPC project quality supervision mechanism and its operation mechanism, and put forward suggestions and countermeasures from government supervision, industry governance, and internal project management. Wang et al. (2022) established a dynamic cooperation evolution game model and analyzed the evolutionary stabilization strategies using matlab2018bsoftware. It was concluded that cooperation willingness, sharing level, income distribution, and punishment mechanism have a significant influence on the direction of cooperation evolution in green technology innovation in construction enterprises.

Zhao et al. (2022) explored the output mechanism of collaborative innovation in megaproject (CIMP) systems through an agent-based modeling approach, using the Netlogo tool to develop a multi-agent simulation of a CIMP model that covers the behavioral factors and interaction rules that affect organizational CIMP. Xia et al. (2020) proposed a green innovation partner selection method for the integrated green building materials supply chain (IGBMSC) to improve the co-innovation capability of IGBMSCs. Su et al. (2021) established a strategic framework for risk sharing in integrated project delivery (IPD) projects, used epidemiological modeling, network analysis, and regression analysis to simulate and analyze risk propagation, and proposed a methodology for further research on risk sharing practices in IPD projects.

Based on the theory of planned behavior, Yan et al. (2019) constructed an analytical model of the impact the three behavioral willingness elements, behavioral attitudes, subjective norms, and perceived behavioral control, have on the contractor's willingness to perform with due diligence. From the perspective of behavioral science, An et al. (2017; 2018) constructed the corresponding optimization gain model, fair concern function, and gain distribution model based on game theory; set up three scenarios of fair concern; and simulated and analyzed the impact of the subject's fair concern behavior on the optimization gain of the consortium general contracting project and its distribution. In the following year, based on the principle of revenue sharing, they introduced the negotiation mechanism into the optimized revenue allocation and further analyzed the impact of the subject's fair concern behavior on the negotiation cycle, revenue allocation coefficient, optimized net revenue, and optimized net revenue available to both parties when the negotiation is reached.

Zhao et al. (2021) studied the influence of the owner's design depth on the contractor's optimization design decision at the pre-project stage of EPC projects. They used numerical analysis to find the optimal strategy with stronger applicability for both parties. In addition, blockchain technology (Gupta et al., 2022) has been used to collaborate on projects. Lu et al. (2021) constructed a novel blockchain-based cloud storage protocol for data sharing of projects. Zhou et al. (2021) established a reliable and sustainable product evaluation management system to store, protect, and retrieve product evaluation data. In terms of security management, Nguyen et al. (2021) proposed a blockchain-based security intrusion detection, data transfer, and classification model to achieve project privacy. Yang et al. (2022) proposed an efficient identity-based aggregate signature encryption scheme with blockchain to secure the project. Rasmusen et al. (2022) introduced a knowledge graph-based consent solicitation user interface to improve the legal awareness of project personnel.

The above analysis of literature research shows that in terms of research methodology, EPC project-related studies mainly use TOPSIS (Liu & Ruan, 2015), genetic algorithm (Wang et al., 2009), particle swarm algorithm (Zhao et al., 2008), Pythagorean fuzzy set (Buyukozkan & Gocer, 2021; Naz et al., 2018), fuzzy analytic hierarchy process (FAHP) (Liu et al., 2020), social conflict theory (Lin et al., 2021), Owen's value approach (Meng et al., 2013), analytic hierarchy process (AHP) (Azadnia et al., 2015), and interpretative structural modeling (Zhao et al., 2019).

In terms of research content, the research on EPC projects mainly focuses on partner selection, risk management, and benefit distribution. In the partner selection, mainly for the owner of the EPC contractor selection, there is less consortium internal partner selection research. There is even less behavioral strategy selection research from consortium internal members, especially if the design-unit-led EPC consortium partnership stability has not yet formed a preliminary understanding.

While most of the research focuses on theory, this paper quantitatively analyzes the stability of EPC consortium cooperation through evolutionary game theory and introduces system dynamics for simulation, which realizes the viewability of the process, the objectivity of the conclusion, and the ease of implementation of the recommendations. In addition, although research exists on improving the stability of the equilibrium point of the game system through the dynamic reward or dynamic punishment strategy, none of the four mechanisms of static rewards and punishments, dynamic rewards, dynamic punishments, and dynamic rewards and punishments have been comprehensively considered and compared. Therefore, this paper stands in the perspective of EPC consortium cooperation led by the design unit, analyzes the different reward and punishment mechanisms and the EPC two main game evolution behavior strategy, and simulates with system dynamics, so that the consortium cooperation evolution game analysis is more specific and reasonable. This paper bridges the research gap on the stability of EPC consortium cooperation through comprehensive theoretical foundations and detailed modeling and provides dynamic insights into strategic interactions by exploring various reward and punishment scenarios through simulations.

## MODEL DESCRIPTION AND ASSUMPTIONS

### Model Description

The EPC project development process led by the design unit involves multiple parties, of which the core subjects are the design and construction units. To better implement the design concept, grasp the overall situation, and plan coordination, highlighting the advantages of the design unit's lead, this paper takes the design unit as the leading and supervising party of the EPC project, and the construction unit as the implementation of the design concept of the EPC project. Therefore, this paper mainly discusses the impact of the design unit developing different reward and punishment mechanisms on the behavioral strategies of both sides of the EPC consortium.

## Parameterization

### Assumption 1

Due to the many stakeholders of the EPC consortium, this paper defines the research subject as a construction unit and design unit, and only simulates the behavioral strategies of these two research subjects, to analyze the cooperation stability of the EPC consortium. Both are limited rational decision-makers and make behavioral strategies based on the principle of maximizing benefits. It does not consider the subject's risk preference for gains and losses when making decisions, i.e., it does not take risk-preferring strategies when facing losses and risk-averse strategies when facing gains.

### Assumption 2

In project cooperation, the construction unit may actively cooperate to improve the overall profitability of the project, or it may choose to opportunistically refuse to cooperate or even discontinue cooperation. The design unit may supervise whether the construction unit constructs the project according to the drawings, or it may take speculation to adopt non-supervisory strategies. Therefore, the choice of strategies of EPC consortium members is in a state of long-term dynamic evolution. Assume that the probability that the construction unit will provide high-quality cooperation is $x$ , Then the probability of providing low-quality cooperation is 1- $x$ . The probability that the design unit adopts a regulatory strategy is $y$ , then the probability of adopting non-regulatory is 1- $y$ .

### Assumption 3

In EPC projects, construction and design units form a consortium, bid together, cooperate, and complete the entire project, then there is a certain base income. It is assumed that the construction unit's base revenue is $\pi$ ( $\pi$ >0). The base return on the design unit is $G$ ( $G$ >0).

### Assumption 4

If the constructor wants to obtain higher revenues through this EPC project or to expand its own scale and increase its social influence, it may act in an activist manner and provide high-quality cooperation. By investing more human and material resources and adopting information technology, digitalization, and other technologies, the increase in input management costs is $C_H$ ( $C_H$ >0). Digital modeling and optimization resulted in an increase in total revenue for the entire project of $\pi_H$ ( $\pi_H$ >0). In addition, the positive cooperation of the construction unit brings the image and reputation of the $R_H$ ( $R_H$ >0), The conversion factor of image and word-of-mouth enhancement into future earnings is $\delta$ ( $\delta$ >0).

### Assumption 5

If the constructor acts opportunistically and provides low-quality cooperation, then by investing less manpower and material resources, the value of reduction in management cost compared to the basic cost is $C_L$ ( $C_L$ >0). If there is low-quality cooperation, then there is less use of information technology and digital and other technologies, and it is not optimized for the model, leading to a reduction in the overall total project benefits $\pi_L$ ( $\pi_L$ >0). In addition, the construction unit's image and reputation for providing low-quality cooperation has declined $R_L$ ( $R_L$ >0), The conversion factor of image word-of-mouth enhancement into future losses is $\varepsilon$ ( $\varepsilon$ >0).

### *Assumption 6*

In an EPC consortium led by a design unit, the design unit has lead and supervisory responsibilities in addition to completing the basic tasks of the EPC project with the construction unit. As a result, the increase in costs is due to the regulation of design units $M$ ($M > 0$). Because the increase in total return is reflected by the quality of the builder's work, whether regulation leads to an increase in total return is not discussed in this paper. And regulation indicates that the design unit plays a lead role in considering the image and reputation enhancement that regulation brings $T_H$ ($T_H > 0$), and the conversion factor of image and word-of-mouth enhancement into future earnings $\gamma$ ($\gamma > 0$).

### *Assumption 7*

The purpose of the consortium is to pursue the maximization of the benefits of the whole project, as well as the reasonable sharing of benefits and risks. Therefore, this paper considers the sharing ratio of gains and losses of the construction unit as $\alpha$ ($\alpha > 0$), The design unit's share of gain and loss is $\beta$ ($\beta > 0$). Where $\alpha + \beta = 1$.

### *Assumption 8*

In an EPC consortium led by a design unit, the design unit is responsible for the overall control and supervision of the EPC project, and the EPC consortium committee penalizes the design unit when there is a failure to supervise $Q$ ($Q > 0$). The design unit, as the leader of the consortium, supervises and checks the quality of cooperation of the construction unit, and rewards the construction unit accordingly according to the quality of cooperation $P_H$ ($P_H > 0$) or penalizes $P_L$ ($P_L > 0$).

## MODEL CONSTRUCTION AND ANALYSIS

### Game Payment Matrix Construction

In the design-unit-led EPC consortium cooperation process, the design unit and the construction unit repeat the game time and time again. Both sides have two strategy behaviors, constituting a 2 x 2 behavioral strategy matrix, to obtain the EPC consortium game payment matrix, as shown in Table 1.

### Game Payment Matrix Logic Analysis

The construction unit is profit-seeking. When the design unit chooses non-supervision, the construction unit is in the expansion of its revenue considerations and will certainly choose to provide low-quality cooperation. Providing low-quality cooperation creates greater revenue than providing high-quality cooperation. Therefore, $\pi - \alpha\pi_L + C_L > \pi + \alpha\pi_H - C_H$, i.e., $(C_H + C_L) - \alpha(\pi_H + \pi_L) > 0$ where

**Table 1. Payment Matrix for the Design-Led EPC Consortium Game**

| | | Design Unit | |
|---|---|---|---|
| | | **Supervisory** $y$ | **Non-Supervisory** $1 - y$ |
| Construction Unit | High-quality Cooperation $x$ | $\pi + \alpha\pi_H + \delta R_H + P_H - C_H$<br>$G + \beta\pi_H + \gamma T_H - M$ | $\pi + \alpha\pi_H - C_H$<br>$G + \beta\pi_H$ |
| | Low-quality Cooperation $1 - x$ | $\pi - \alpha\pi_L - \varepsilon R_L - P_L + C_L$<br>$G - \beta\pi_L - M$ | $\pi - \alpha\pi_L + C_L$<br>$G - \beta\pi_L - Q$ |

$C_H + C_L = \Delta C$ represents the difference in cost arising from the difference in the quality of the cooperation provided by the constructor, thus $\Delta C > 0$. Similarly, $\pi_H + \pi_L = \Delta\pi$ represents the difference in total revenue generated by the construction unit due to differences in the quality of cooperation provided, thus $\Delta\pi > 0$. $\Delta C - \alpha\Delta\pi > 0$ suggests that the cost differential is greater than the construction unit's benefit differential when the design unit takes a non-supervisory approach, thus inversely explaining the construction unit's choice to provide low-quality cooperation.

When the design unit chooses to supervise, the construction unit will certainly choose to provide high-quality cooperation when considering its revenue maximization. Therefore, $\pi + \alpha\pi_H + \delta R_H + P_H - C_H > \pi - \alpha\pi_L - \varepsilon R_L - P_L + C_L$, i.e., $\delta R_H + \varepsilon R_L + P_H + P_L > C_H + C_L - \alpha(\pi_H + \pi_L)$. These represent the positive indirect benefits of construction companies providing high-quality services. $\varepsilon R_L + P_L = \Delta\pi_2$ represents the indirect negative benefits of construction companies providing low-quality services. $\Delta\pi_1 + \Delta\pi_2$ represents the change in indirect benefits resulting from the decision-making behavior of the construction unit. $\Delta\pi_1 + \Delta\pi_2 > \Delta C - \alpha\Delta\pi$ indicates that the indirect benefit changes brought about by decision-making behavior are much larger than the direct benefit changes brought about by their business activities, which inversely explains why the construction unit will choose to provide high-quality services under the supervision of the design unit.

When the constructor provides high-quality cooperation, the design organization is more likely to choose a non-supervisory strategy to save labor and resources. Therefore, $G + \beta\pi_H > G + \beta\pi_H + \gamma T_H - M$, i.e. $M > \gamma T_H$. It is indicated that the increased cost of the design unit due to regulation is greater than the benefit of image and reputation enhancement, thus inversely justifying the design unit's choice of a no-regulation strategy when the construction unit improves its quality cooperation.

When construction companies provide low-quality cooperation, design organizations often opt for regulatory strategies. Therefore, $G - \beta\pi_L - M > G - \beta\pi_L - Q$, i.e. $Q > M$. Suggesting that the increase in costs due to regulation is much smaller than the penalties, this also inversely explains the design unit's choice of regulatory strategy when firms provide low-quality cooperation.

## Construction of Replicated Dynamic Equations

The two core concepts of evolutionary game theory are evolutionarily stable strategy (ESS) and replicator dynamics equation (RDE). ESS provides the judgment conditions for stability, and RDE dynamically simulates the process of convergence to stability using mathematical calculations.

Assuming that the expected benefit to the builder of adopting a high-quality cooperation is $E_x$ and the expected benefit of adopting a low-quality cooperation is $E_{(1-x)}$, according to Table 1, then $E_x = y(\pi + \alpha\pi_H + \delta R_H + P_H - C_H) + (1-y)(\pi + \alpha\pi_H - C_H)$. Then:

$$E_x = y(\delta R_H + P_H) + \pi + \alpha\pi_H - C_H \tag{1}$$

For the same reason, $E_{(1-x)} = y(\pi - \alpha\pi_L - \varepsilon R_L - P_L + C_L) + (1-y)(\pi - \alpha\pi_L + C_L)$ can be obtained, so:

$$E_{(1-x)} = -y(\varepsilon R_L + P_L) + \pi - \alpha\pi_L + C_L \tag{2}$$

The average expected return of the construction unit is $\overline{E_x}$, then $\overline{E_x} = xE_x + (1\text{-}x)E_{(1-x)}$. The replication dynamic equation for the construction unit's strategy of providing high-quality services is $F(x) = x(E_x - \overline{E_x}) = x(1-x)(E_x - E_{(1-x)})$, then:

$$F(x) = x(1\text{-}x)\left[y(\delta R_H + P_H + \varepsilon R_L + P_L) + \alpha(\pi_H + \pi_L) - (C_H + C_L)\right] \tag{3}$$

The above payment matrix logic analysis leads to:

$$F(x) = x(1\text{-}x)\left[y(\Delta\pi_1 + \Delta\pi_2) + \alpha\Delta\pi - \Delta C\right] \tag{4}$$

Similarly, assume that the expected return of the design unit adopting the regulatory strategy is $E_y = x(G + \beta\pi_H + \gamma T_H - M) + (1-x)(G - \beta\pi_L - M)$, and the expected return of the non-regulatory strategy is $E_{(1-y)} = x(G + \beta\pi_H) + (1-x)(G - \beta\pi_L - Q)$, then:

$$E_y = x[\beta(\pi_H + \pi_L) + \gamma T_H] + G - \beta\pi_L - M \tag{5}$$

$$E_{(1-y)} = x[\beta(\pi_H + \pi_L) + Q] + G - \beta\pi_L - Q \tag{6}$$

The replication dynamic equation for the design unit's strategy of providing high-quality services is $F(y) = y(E_y - \overline{E_y}) = y(1-y)(E_y - E_{(1-y)})$.

$$F(y) = y(1\text{-}y)\left[x\left(\gamma T_H - Q\right) + Q - M\right] \tag{7}$$

## GAME ANALYSIS AND SIMULATION OF EPC CONSORTIUM COOPERATION EVOLUTION UNDER STATIC REWARD AND PUNISHMENT MECHANISM

When the design unit gives the construction unit economic incentives $P_H$ and economic penalties $P_L$ that are fixed values, it is regarded as a static reward and punishment mechanism. According to (4) and (7), the joint equation can be obtained:

$$\begin{cases} F(x) = x(1\text{-}x)\left[y(\Delta\pi_1 + \Delta\pi_2) + \alpha\Delta\pi - \Delta C\right] \\ F(y) = y(1\text{-}y)\left[x\left(\gamma T_H - Q\right) + Q - M\right] \end{cases} \tag{8}$$

When $\left(F(x), F(y)\right) = 0$, the five equilibrium points of the EPC consortium cooperation evolution game system under the static reward and punishment mechanism can be obtained as $E_1(0,0)$, $E_2(0,1)$, $E_3(1,0)$, $E_4(1,1)$ and $E_5(\frac{Q-M}{Q-\gamma T_H}, \frac{\Delta C\text{-}\alpha\Delta\pi}{\Delta\pi_1 + \Delta\pi_2})$ respectively.

Therefore, the Jacobin matrix of the EPC consortium cooperative evolution game is denoted as:

$$J=\begin{bmatrix}(1\text{-}2x)[y(\Delta\pi_1+\Delta\pi_2)+\alpha\Delta\pi\text{-}\Delta C] & x(1-x)(\Delta\pi_1+\Delta\pi_2)\\ y(1\text{-}y)\left(\gamma T_H\text{-}Q\right) & (1-2y)[x\left(\gamma T_H\text{-}Q\right)+Q-M]\end{bmatrix} \tag{9}$$

As a result, the value $\det(J)$ and trace value $\mathrm{tr}(J)$ of the matrix determinant for each equilibrium point can be obtained, as shown in Table 2.

When $\det(J)>0$ and $\mathrm{tr}(J)<0$, the equilibrium is a local asymptotic stabilization point, corresponding to the evolutionary stabilization strategy (Liu et al., 2017). Based on the logical analysis of the game payment matrices above, we can obtain $\det(J)<0$ for $E_1$, $E_2$, $E_3$ and $E_4$. The positive and negative magnitude of the trace value $\mathrm{tr}(J)$ is indeterminate. Therefore, $E_1$, $E_2$, $E_3$, and $E_4$ are unstable saddle points. At this point $E_5$ has $\det(J)>0$, but the trace value $\mathrm{tr}(J)=0$, which needs to be analyzed for eigenroots. Since $\lambda_{1,2}=\dfrac{(a+d)\pm\sqrt{(a+d)^2\text{-}4(ad\text{-}bc)}}{2}=\pm i\sqrt{\det(J)}$, $\lambda_1\lambda_2$ are pure imaginary roots when the system has no local steady state (Yang, 2021). At this time, $E_5$ is the center point, as shown in Table 2. Therefore, with fixed rewards and penalties, the EPC consortium cooperation game moves in a cyclic round-robin motion centered on $E_5$ in the decision space of (0,1) x (0,1).

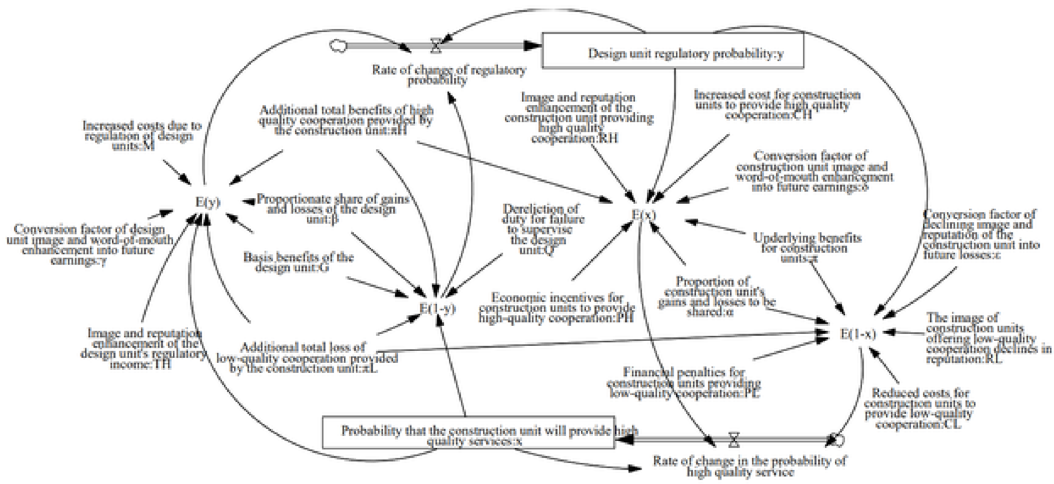
Since the game between the two sides of the EPC consortium is dynamically changing, this paper adopts Vensim PLE software to construct the System Dynamics(SD) model of the cooperative evolution game of the EPC consortium led by the design unit, as shown in Figure 1.

As this paper mainly focuses on the EPC consortium cooperation evolution game trend and stability, reasonably accurate parameter assignment is not the focus of the study. Therefore, after logically analyzing each parameter in the simulation model, combined with the actual situation and our own experience, we determine these to be reasonably assigned values. The value of each parameter is assigned as follows: $\pi=8$, $C_H=5$, $C_L=1$, $\pi_H=4$, $\pi_L=4$, $\alpha=0.3$, $R_H=2$, $\delta=0.2$, $R_L=2$, $\varepsilon=0.2$, $P_H=2.5$, $P_L=4$, $G=3$, $M=1.5$, $\beta=0.7$, $T_H=2$, $\gamma=0.2$, $Q=6$. Due to the large amount of money involved in EPC projects, the above assumptions are expressed in millions of dollars. To fully and

**Table 2. Stability Judgment of Each Equilibrium Point Under Static Reward and Punishment Mechanism**

| | **Expressions and Values of** $\det(J)$ | | **Expressions and Values of** $\mathrm{tr}(J)$ | | **Stability** |
|---|---|---|---|---|---|
| $E_1$ | $(\alpha\Delta\pi\text{-}\Delta C)(Q-M)$ | - | $\alpha\Delta\pi\text{-}\Delta C+Q-M$ | ± | Saddle Point |
| $E_2$ | $-(\Delta\pi_1+\Delta\pi_2+\alpha\Delta\pi\text{-}\Delta C)(Q-M)$ | - | $\Delta\pi_1+\Delta\pi_2+\alpha\Delta\pi\text{-}\Delta C-Q+M$ | ± | Saddle Point |
| $E_3$ | $-(\alpha\Delta\pi-\Delta C)(\gamma T_H-M)$ | - | $-(\alpha\Delta\pi-\Delta C)+(\gamma T_H-M)$ | ± | Saddle Point |
| $E_4$ | $(\Delta\pi_1+\Delta\pi_2+\alpha\Delta\pi\text{-}\Delta C)(\gamma T_H-M)$ | - | $-(\Delta\pi_1+\Delta\pi_2+\alpha\Delta\pi\text{-}\Delta C)-(\gamma T_H-M)$ | ± | Saddle Point |
| $E_5$ | $-\dfrac{(Q-M)(M-\gamma T_H)(\Delta C\text{-}\alpha\Delta\pi)(\Delta\pi_1+\Delta\pi_2\text{-}\Delta C+\alpha\Delta\pi)}{(\Delta\pi_1+\Delta\pi_2)\left(Q-\gamma T_H\right)}$ | + | 0 | 0 | Center Point |

**Figure 1. SD Model of EPC Consortium Cooperation Evolution Game Under Static Reward and Punishment Mechanism**



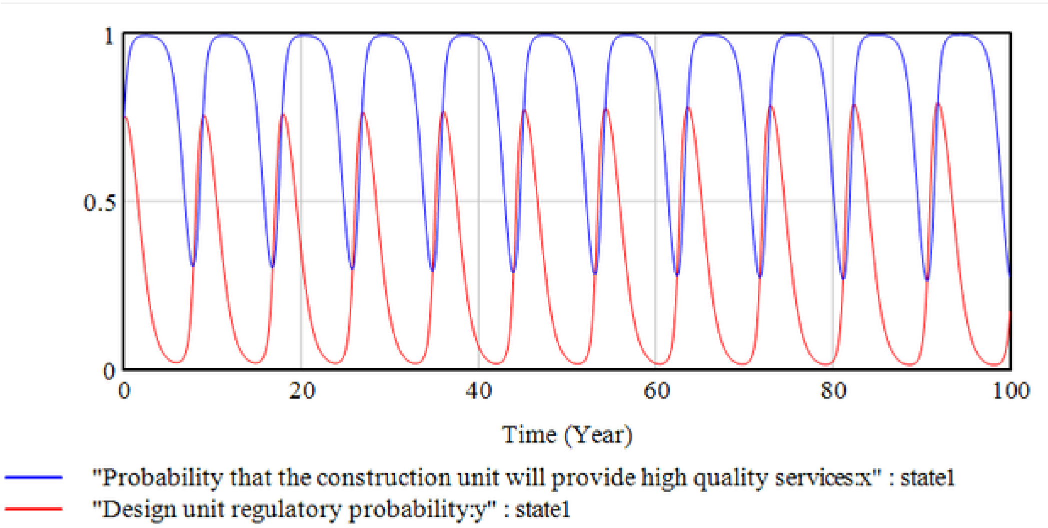

realistically respond to the simulation situation, the initial probability $x$ and $y$ are set to the following four states, State 1 (0.75,0.75), State 2 (0.25,0.75), State 3 (0.75,0.25), and State 4 (0.25,0.25), which represent the initial probability of decision-making for the behavior of the construction unit and the design unit, respectively. In addition, because of the long EPC project development cycle, a longer simulation time can be a more realistic and comprehensive response to the behavioral strategy choices of all parties in the EPC consortium. When the simulation time is 100 years, the system closely detects the stability of the two parties' cooperation with a frequency of once a day.

Taking State 1 as an example, the two main bodies of the game present a cyclical behavior pattern, as shown in Figure 2. That is, when the construction unit provides high-quality cooperation, the design unit reduces the cost of supervision considerations and choose not to regulate the behavior strategy. But when the construction unit knows that the design unit is not regulated, out of opportunistic considerations, it chooses a low-quality cooperation behavior strategy. At this point, the design unit, due to revenue, reputation, word-of-mouth, and other factors, strengthens the supervision, which means the construction unit again provides high-quality cooperation behavior strategy. As a result, the construction unit and the design unit are caught in a stalemate, and the two main players cannot come up with a stabilizing strategy.

To truly react to the behavioral strategies of the two main game subjects, the four state simulation trends are displayed, as shown in Figure 3. Under the static reward and punishment mechanism, the cooperation evolution process of the two main game players in the EPC consortium is a cyclic movement, and they make their own behavioral choices according to each other's behavioral strategies so that they can never evolve a stable behavioral strategy. In addition, whether it is the design unit or the construction unit, in the face of the change of the strategy of the other game party, there is always a certain delay and lag, which is also consistent with real life. Because the construction unit's brief strategy change may only be due to the influence of some external reasons, it may produce only a small shift, after which there is a shift back to the original strategy. Only when the construction unit makes strategy changes on a long-term basis, can the design unit dare to boldly change its strategy.

From a comprehensive view, the design unit's supervision of the construction unit is key to providing high-quality service. Therefore, in this case, the design unit needs to give the construction unit a deterrent. It must operate in a high--frequency supervision mode from the beginning and for a long period of time to ensure that the construction unit provides service stability. However, this also invariably brings a certain regulatory pressure on the design unit and increases the regulatory

Figure 2. Simulation of Design Unit and Construction Unit in State 1




cost. Therefore, the static reward and punishment mechanism is not conducive to the stability of EPC consortium cooperation.

## GAME ANALYSIS AND SIMULATION OF EPC CONSORTIUM COOPERATION EVOLUTION UNDER DYNAMIC REWARD AND PUNISHMENT MECHANISM

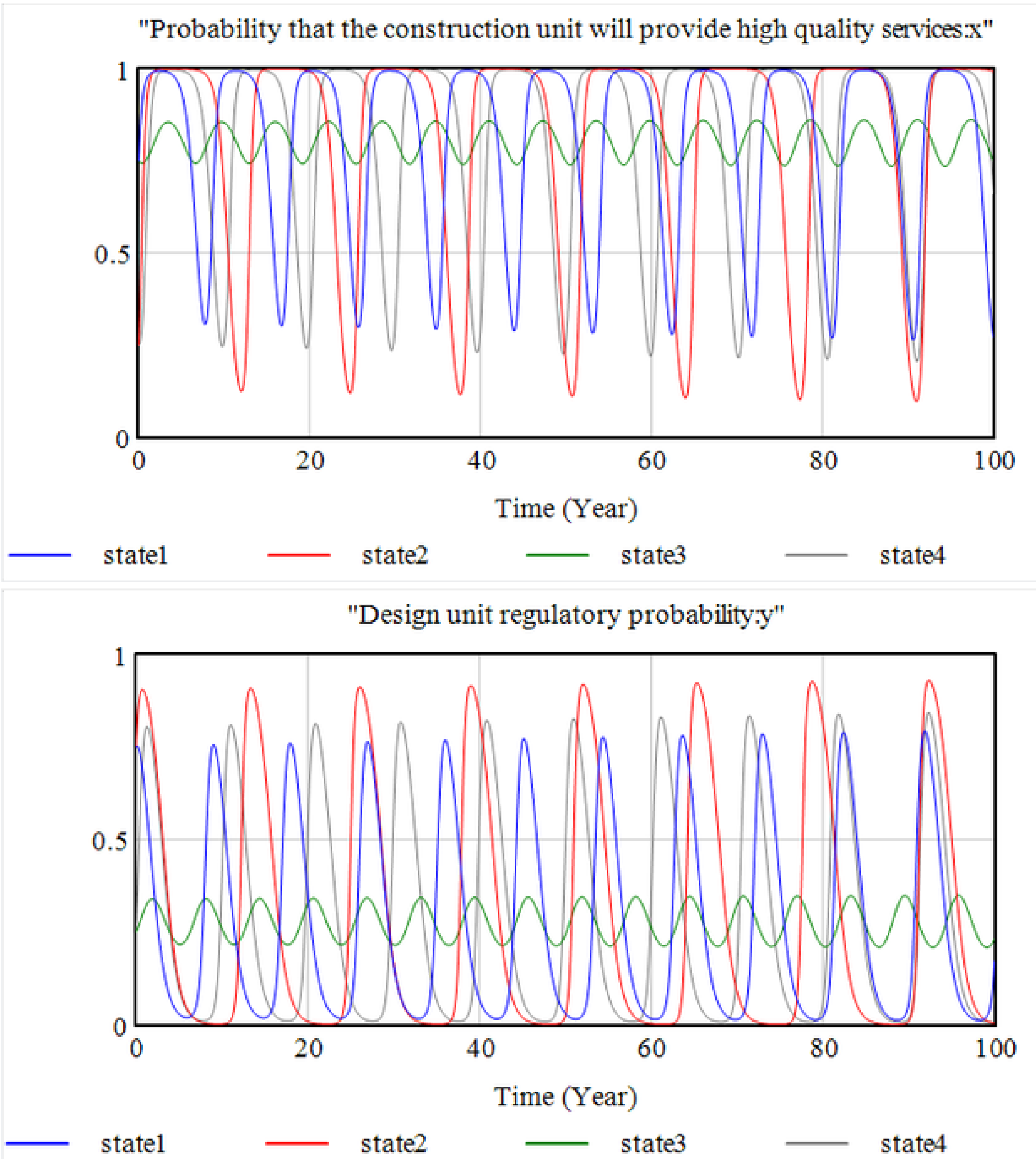
Often rewards and penalties vary with the performance of the construction unit cooperation. The dynamic reward and punishment mechanism studied in this paper is divided into three cases. The first is a dynamic incentive mechanism, where the financial penalty $P_L$ is a fixed value and the financial incentive $P_H$ varies with the quality of cooperation provided by the constructor. The second is a dynamic penalty mechanism, where the financial incentive $P_H$ is a fixed value and the financial penalty $P_L$ varies with the realization of the construction unit. The third is a dynamic incentive and penalty mechanism, in which the reward $P_H$ and the penalty $P_L$ simultaneously vary with the performance of the construction unit.

### Dynamic Reward Mechanism

Assume that $P_H = P_H(x) = P_{H0}x$, $P_{H0}$ denotes the maximum amount of incentive given to the construction unit. When $x = 0$ and $P_H = 0$, which means that the probability of the constructor providing high-quality cooperation is 0, no financial incentives are available. When $x = 1$ and $P_H = P_{H0}$, the constructor receives the highest economic reward for providing high-quality cooperation with probability 1. Constructing the dynamic replication equation under dynamic incentives leads to:

$$\begin{cases} F(\mathrm{x}) = x(1\text{-}x)\left[y(\delta R_H + P_H(\mathrm{x}) + \Delta\pi_2) + \alpha\Delta\pi - \Delta C\right] \\ F(y) = y(1\text{-}y)\left[x\left(\gamma T_H - Q\right) + Q - M\right] \end{cases} \tag{10}$$

**Figure 3. Simulation of Both Sides of EPC Consortium Under Static Reward and Punishment Mechanism**




Similarly, five equilibrium points can be also obtained as $E_1(0,0)$, $E_2(0,1)$, $E_3(1,0)$, $E_4(1,1)$, $E_5(\frac{Q-M}{Q-\gamma T_H},\frac{\Delta C\text{-}\alpha\Delta\pi}{\delta R_H+P_H(x^*)+\Delta\pi_2})$, where $x=\frac{Q-M}{Q-\gamma T_H}$.

Now, the Jacobin matrix of the evolutionary game system is:

$$J=\begin{bmatrix}(1\text{-}2x)[y(P_H(x)+\delta R_H+\Delta\pi_2)+\alpha\Delta\pi\text{-}\Delta C]+xy(1\text{-}x)P_{H0} & x(1-x)(P_H(x)+\delta R_H+\Delta\pi_2)\\ y(1\text{-}y)\left(\gamma T_H\text{-}Q\right) & (1-2y)[x\left(\gamma T_H\text{-}Q\right)+Q-M]\end{bmatrix} \tag{11}$$

The determinant $\det(J)$ and trace value $\mathrm{tr}(J)$ of each equilibrium point, as shown in Table 3.

When a design organization chooses to supervise, the construction organization tends to choose high-quality cooperation, so that $\pi + \alpha\pi_H + \delta R_H + P_H(x) - C_H > \pi - \alpha\pi_L - \varepsilon R_L - P_L + C_L$, i.e. $P_H(x)+\delta R_H+\Delta\pi_2 > \Delta C\text{-}\alpha\Delta\pi$. The relationships derived above show that $\det(J)$ <0 for $E_1$, $E_2$, $E_3$ and $E_4$, and $\det(J)$ >0 for $E_5$, but $\mathrm{tr}(J)$ >0. That is, $E_1$, $E_2$, $E_3$, $E_4$ and $E_5$ are all unstable saddle points, as shown in Table 3. It indicates that under the dynamic reward mechanism, the EPC consortium will also not have evolutionary equilibrium points in the cooperative evolutionary game.

According to the replicated dynamic equations under the dynamic reward mechanism, the economic rewards from the design unit to the construction unit are linked to the quality of the provided cooperation, and the newly added dynamic reward relationship is represented by a red dashed line in VENSIM PLE software to construct the corresponding SD model, as shown in Figure 4.

If the maximum economic reward $P_{H0}$ =2.5 is set, other parameter settings remain unchanged while simulating the simulation scenarios under different initial states in VENSIM PLE software, as shown in Figure 5.

**Table 3. Stability Judgment of Each Equilibrium Point Under Dynamic Reward Mechanism**

| | Expressions and Values of $\det(J)$ | | Expressions and Values of $\mathrm{tr}(J)$ | | Stability |
|---|---|---|---|---|---|
| $E_1$ | $(\alpha\Delta\pi\text{-}\Delta C)(Q-M)$ | - | $\alpha\Delta\pi\text{-}\Delta C+Q-M$ | ± | Saddle Point |
| $E_2$ | $-(\delta R_H+\Delta\pi_2+\alpha\Delta\pi\text{-}\Delta C)(Q-M)$ | - | $\delta R_H+\Delta\pi_2+\alpha\Delta\pi\text{-}\Delta C-Q+M$ | ± | Saddle Point |
| $E_3$ | $-(\alpha\Delta\pi-\Delta C)(\gamma T_H-M)$ | - | $-(\alpha\Delta\pi-\Delta C)+(\gamma T_H-M)$ | ± | Saddle Point |
| $E_4$ | $(P_{H0}+\delta R_H+\Delta\pi_2+\alpha\Delta\pi\text{-}\Delta C)(\gamma T_H-M)$ | - | $-(P_{H0}+\delta R_H+\Delta\pi_2+\alpha\Delta\pi\text{-}\Delta C)-(\gamma T_H-M)$ | ± | Saddle Point |
| $E_5$ | $\frac{(Q-M)(M-\gamma T_H)(\Delta C\text{-}\alpha\Delta\pi)[(P_{H0}(Q-M)+(Q-\gamma T_H)(\delta R_H+\Delta\pi_2\text{-}\Delta C+\alpha\Delta\pi)]}{(Q-\gamma T_H)[(\delta R_H+\Delta\pi_2)(Q-\gamma T_H)+P_{H0}(Q-M)]}$ | + | $\frac{(Q-M)(M-\gamma T_H)(\Delta C\text{-}\alpha\Delta\pi)P_{H0}}{(Q-\gamma T_H)[(\delta R_H+\Delta\pi_2)(Q-\gamma T_H)+P_{H0}(Q-M)]}$ | + | Saddle Point |

**Figure 4. SD Model of EPC Consortium Cooperation Evolution Game Under Dynamic Reward Mechanism**

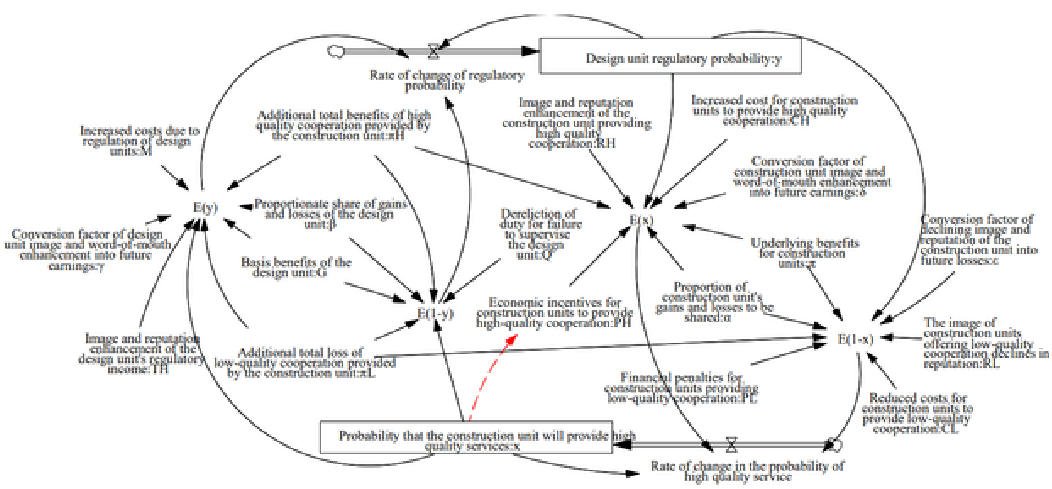
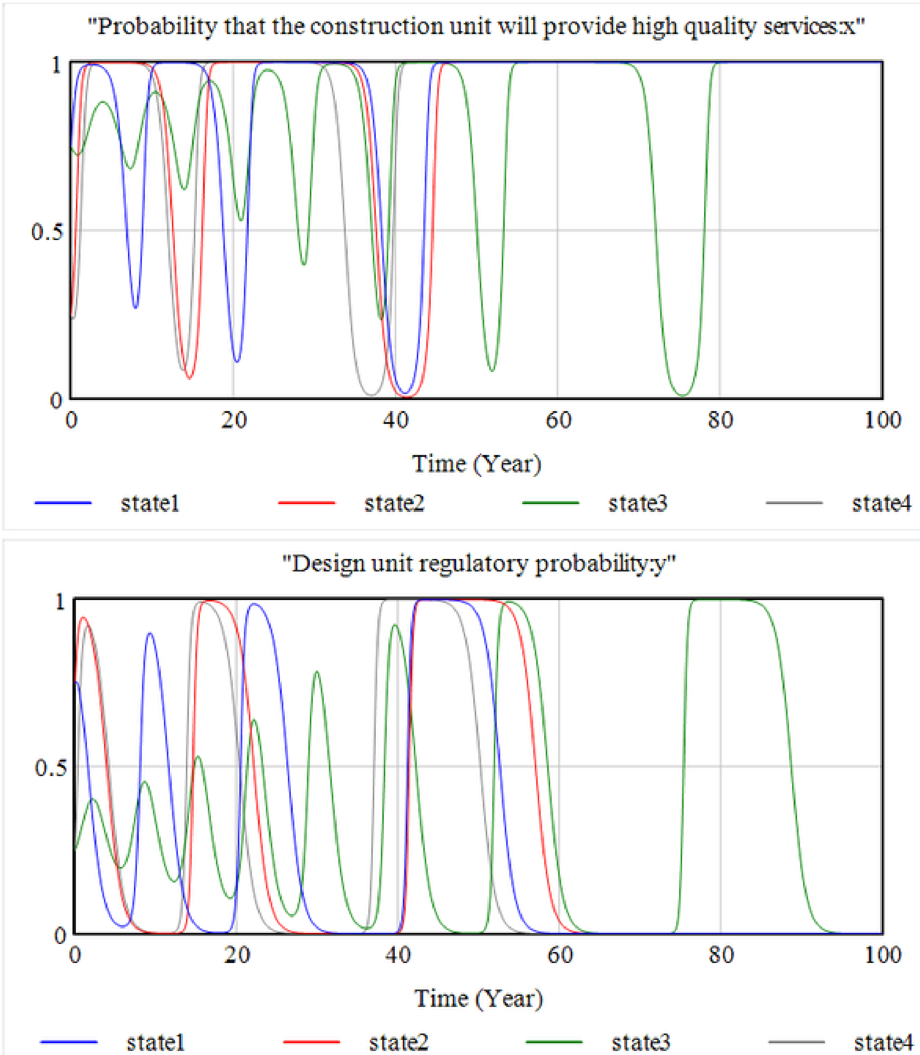


**Figure 5. Simulation of Both Sides of EPC Consortium Under Dynamic Reward Mechanism**




Similar to the static reward and punishment mechanism, both parties will also make their own behavioral choices based on each other's behavioral strategies, and there is a certain lag in the making of behavioral decisions. In addition, under the dynamic reward mechanism, although the probability of the construction unit providing high-quality services over a long period is cyclic, through a long period of strategic cooperation, the construction unit will eventually choose to provide high-quality services, which is also in line with the principle of maximizing the interests of the construction unit to maximize the principle of profit-seeking behavior. This behavioral strategy has nothing to do with the probability of the construction unit providing high-quality services at the beginning. The design unit is also driven by its own interests, and ultimately takes the strategy of non-supervision, to save the cost of supervision. Although both sides will eventually make behavioral strategies in line with their own interests, this strategy is dependent on each other's behavior becaise the EPC consortium of the two main games does not have system stability. Therefore, setting only dynamic financial rewards falls short of the desired effect of incentives.

## Dynamic Punishment Mechanism

Assume that $P_L$=$P_L$(x)=$P_{L0}(1\text{-}x)$, $P_{L0}$ denote the maximum penalties given to the construction unit. When $x$ =0, $P_L = P_{L0}$, indicating that when the probability that the constructor provides high-quality cooperation is 0, the highest amount of financial penalty is received. And when $x$ =1, $P_L$ =0, indicating that when the probability of the constructor providing high-quality cooperation is 1, no financial penalty is applied. Constructing the dynamic replication equation under the dynamic penalization mechanism yields:

$$\begin{cases} F(\mathrm{x}) = x(1\text{-}x)\left[y(\Delta\pi_1 + \varepsilon R_L + P_L(x)) + \alpha\Delta\pi - \Delta C\right] \\ F(y) = y(1\text{-}y)\left[x\left(\gamma T_H - Q\right) + Q - M\right] \end{cases} \tag{12}$$

Similarly, five equilibrium points can be obtained as $E_1(0,0)$, $E_2(0,1)$, $E_3(1,0)$, $E_4(1,1)$ and $E_5(\frac{Q-M}{Q-\gamma T_H}, \frac{\Delta C\text{-}\alpha\Delta\pi}{\varepsilon R_L + P_L(\mathrm{x}^*) + \Delta\pi_1})$, where $x$= $\frac{Q-M}{Q-\gamma T_H}$. At this moment, the Jacobin matrix of the evolutionary game system is as follows, with determinant $\det(J)$ and trace value $\mathrm{tr}(J)$ for each equilibrium, as shown in Table 4.

$$J = \begin{bmatrix} (1\text{-}2x)[y(P_L(x) + \varepsilon R_L + \Delta\pi_1) + \alpha\Delta\pi\text{-}\Delta C] - xy(1\text{-}x)P_{L0} & x(1-x)(P_L(x) + \varepsilon R_L + \Delta\pi_1) \\ y(1\text{-}y)\left(\gamma T_H\text{-}Q\right) & (1-2y)[x\left(\gamma T_H\text{-}Q\right) + Q - M] \end{bmatrix} \tag{13}$$

Similarly, when a design organization chooses to supervise, the construction organization tends to choose high-quality cooperation, at this moment, $\pi + \alpha\pi_H + \delta R_H + P_H - C_H > \pi - \alpha\pi_L - \varepsilon R_L - P_L(x) + C_L$, i.e. $P_L(\mathrm{x}) + \varepsilon R_L + \Delta\pi_1 > \Delta C\text{-}\alpha\Delta\pi$. The stability of each equilibrium point is shown in Table 4, which shows that under the dynamic penalty mechanism, the design unit-led EPC consortium cooperation evolution has asymptotic stability.

Similarly, according to the replicated dynamic equations under the dynamic penalty mechanism, the economic penalties imposed by the design unit on the construction unit are linked to the quality of the cooperation provided, and the newly added dynamic penalty relationship is represented by

**Table 4. Stability Judgment of Each Equilibrium Point Under Dynamic Punishment Mechanism**

| | **Expressions and Values of** $\det(J)$ | | **Expressions and Values of** $\mathrm{tr}(J)$ | | **Stability** |
|---|---|---|---|---|---|
| $E_1$ | $(\alpha\Delta\pi\text{-}\Delta C)(Q-M)$ | - | $\alpha\Delta\pi\text{-}\Delta C + Q - M$ | ± | Saddle Point |
| $E_2$ | $-(P_{L0} + \varepsilon R_L + \Delta\pi_1 + \alpha\Delta\pi\text{-}\Delta C)(Q-M)$ | - | $P_{L0} + \varepsilon R_L + \Delta\pi_1 + \alpha\Delta\pi\text{-}\Delta C - Q + M$ | ± | Saddle Point |
| $E_3$ | $-(\alpha\Delta\pi - \Delta C)(\gamma T_H - M)$ | - | $-(\alpha\Delta\pi - \Delta C) + (\gamma T_H - M)$ | ± | Saddle Point |
| $E_4$ | $(\varepsilon R_L + \Delta\pi_1 + \alpha\Delta\pi\text{-}\Delta C)(\gamma T_H - M)$ | - | $-(\varepsilon R_L + \Delta\pi_1 + \alpha\Delta\pi\text{-}\Delta C) - (\gamma T_H - M)$ | ± | Saddle Point |
| $E_5$ | $\frac{(Q-M)(M-\gamma T_H)(\Delta C\text{-}\alpha\Delta\pi)[(P_{L0}(M-\gamma T_H) + (Q-\gamma T_H)(\varepsilon R_L + \Delta\pi_1\text{-}\Delta C + \alpha\Delta\pi)]}{(Q-\gamma T_H)[(\varepsilon R_L + \Delta\pi_1)(Q-\gamma T_H) + P_{L0}(M-\gamma T_H)]}$ | + | $-\frac{(Q-M)(M-\gamma T_H)(\Delta C\text{-}\alpha\Delta\pi)P_{L0}}{(Q-\gamma T_H)[(\varepsilon R_L + \Delta\pi_1)(Q-\gamma T_H) + P_{L0}(M-\gamma T_H)]}$ | - | ESS |

a red dashed line in the VENSIM PLE software to construct the corresponding system dynamics model, as shown in Figure 6.

If the maximum economic penalty set $P_{L0}$ =2.5 and other parameter settings remain unchanged, the simulation scenarios under the above four initial states are simulated in the VENSIM PLE software, and Figure 7 can be obtained. From the waveform of the simulation curve, the behavioral strategy of the design and construction unit also has a certain time lag. This means the two sides cannot predict each other's actions in advance, and cannot make changes in the strategy at the same time, but gradually evolve their own strategy. With the repetition of the game of the two main bodies of the EPC consortium, the fluctuation of the strategies of both sides is gradually reduced, the evolutionary trend is gradually converging, and the cooperation between the two tends to stabilize. This stable evolution strategy is independent of the initial probability of $x$ and $y$ . Therefore, under the setting of a dynamic punishment mechanism, the construction unit is forced to take corresponding strategies passively and actively under the pressure of punishment, which is conducive to the stability of cooperation.

At this time, the probability of the construction unit providing high-quality services is related to the equilibrium point, i.e., related to $\dfrac{Q-M}{Q-\gamma T_H}$ . The simulation results are consistent with the results of the dynamic equation analysis of the EPC consortium game replication. So, the probability of the construction unit providing high-quality services can be improved by adopting the measures to reduce the cost of supervision of the design unit $M$ , to decrease the design unit's supervision of the dereliction of duty to pursue responsibility $Q$ , and the conversion factor of the design unit's image and reputation to enhance the construction unit's image and reputation to improve the probability of providing high-quality services, and to ensure that the construction unit provides reliably high-quality cooperation.

And the design unit regulatory probability is related to $\dfrac{(\Delta C\text{-}\alpha\Delta\pi)(Q-\gamma T_H)}{(\varepsilon R_L+\Delta\pi_1)(Q-\gamma T_H)+P_{L0}(M-\gamma T_H)}$ . Because of the many factors involved, and this paper stands in the perspective of the design unit, the main purpose of the study is to take corresponding measures to the construction unit to promote the construction unit and its stable cooperation. In addition, whether the design unit provides supervision and construction unit provides high-quality services has nothing to do with the behavioral strategy, and EPC consortium revenue is also through the construction unit to provide specific construction

**Figure 6. SD model of EPC Consortium Cooperation Evolution Game Under Dynamic Punishment Mechanism**

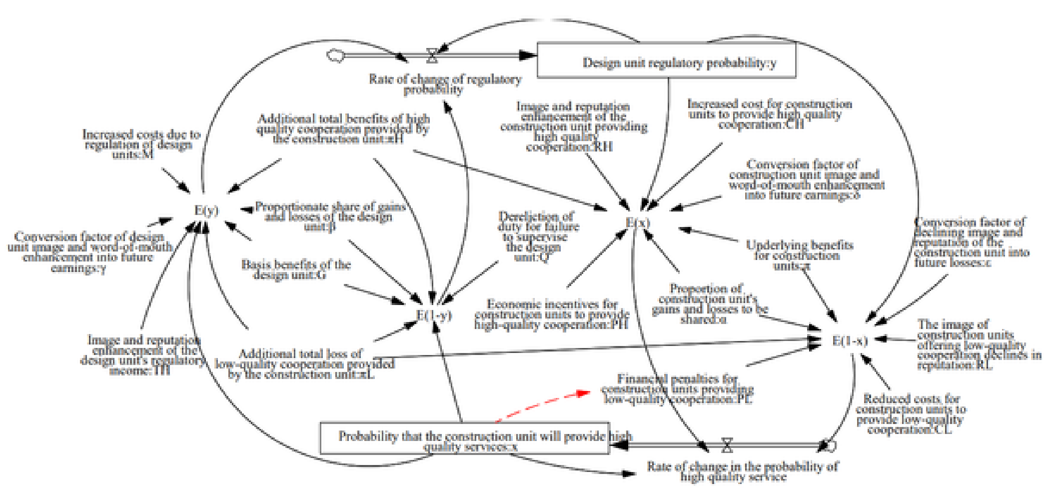
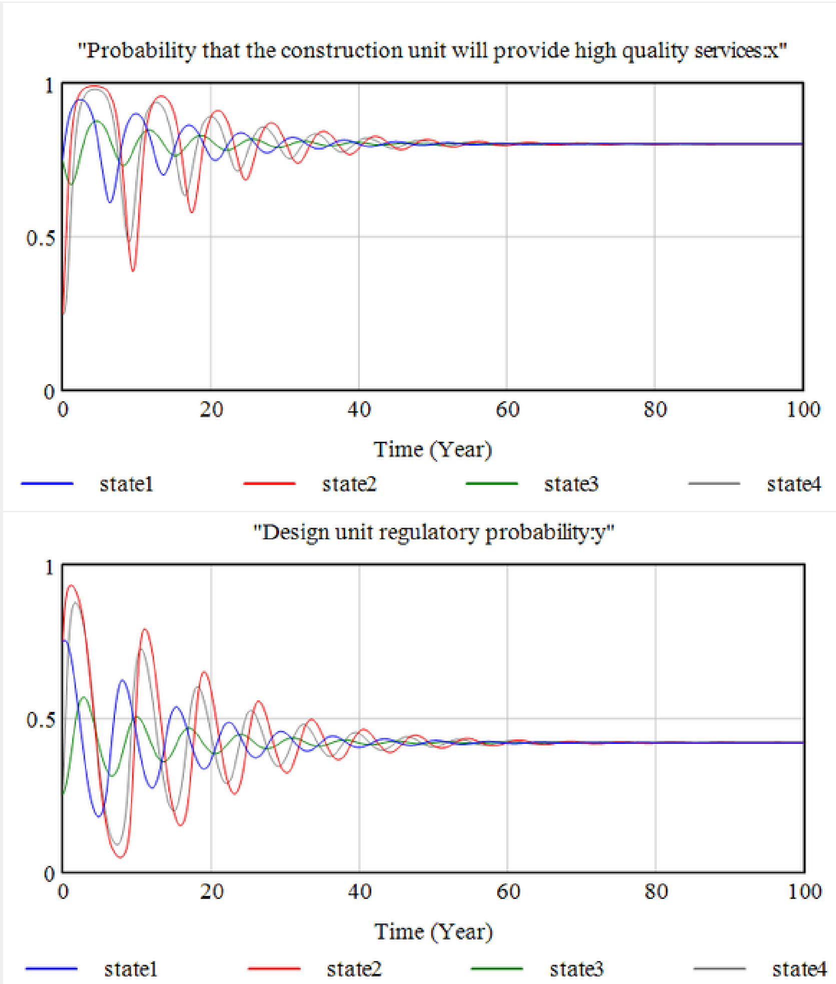


**Figure 7. Simulation of Both Sides of EPC Consortium Under Dynamic Punishment Mechanism**




services to reflect, therefore, this paper does not discuss the probability of the impact of design unit supervision factors.

## Dynamic Reward and Punishment Mechanism

By considering both $P_H = P_H(x) = P_{H0}x$ and $P_L = P_L(\mathrm{x}) = P_{L0}(1\text{-}x)$ is obtained:

$$\begin{cases} F(\mathrm{x}) = x(1\text{-}x)\left[y(\delta R_H + P_H(x) + \varepsilon R_L + P_L(x)) + \alpha\Delta\pi - \Delta C\right] \\ F(y) = y(1\text{-}y)\left[x\left(\gamma T_H - Q\right) + Q - M\right] \end{cases} \tag{14}$$

Similarly, five equilibrium points $E_1(0,0)$, $E_2(0,1)$, $E_3(1,0)$, $E_4(1,1)$ and $E_5(\frac{Q-M}{Q-\gamma T_H}, \frac{\Delta C\text{-}\alpha\Delta\pi}{P_H(\mathrm{x}^*) + P_L(x^*) + \varepsilon R_L + \delta R_H})$ are obtained, where $x = \frac{Q-M}{Q-\gamma T_H}$, and the Jacobin matrix and the determinant $\det(J)$ and trace value $\mathrm{tr}(J)$ of each equalization point, as shown in Table 5.

Table 5. Stability Judgment of Each Equilibrium Point Under Dynamic Reward and Punishment Mechanism

| | Expressions and Values of $\det(J)$ | | Expressions and values of $\mathrm{tr}(J)$ | | conditions | Stability |
|---|---|---|---|---|---|---|
| $E_1$ | $(\alpha\Delta\pi\text{-}\Delta C)(Q-M)$ | - | $\alpha\Delta\pi\text{-}\Delta C+Q-M$ | ± | / | Saddle Point |
| $E_2$ | $-(\delta R_H+\varepsilon R_L+P_{L0}+\alpha\Delta\pi\text{-}\Delta C)(Q-M)$ | - | $\delta R_H+\varepsilon R_L+P_{L0}+\alpha\Delta\pi\text{-}\Delta C-Q+M$ | ± | / | Saddle Point |
| $E_3$ | $-(\alpha\Delta\pi-\Delta C)(\Delta G_1-\Delta M)$ | - | $-(\alpha\Delta\pi-\Delta C)+(\gamma T_H-M)$ | ± | / | Saddle Point |
| $E_4$ | $(P_{H0}+\delta R_H+\varepsilon R_L+\alpha\Delta\pi\text{-}\Delta C)(\gamma T_H-M)$ | - | $-(P_{H0}+\delta R_H+\varepsilon R_L+\alpha\Delta\pi\text{-}\Delta C)-(\gamma T_H-M)$ | ± | / | Saddle Point |
| $E_5$ | $\frac{(Q-M)(M-\gamma T_H)(\Delta C\text{-}\alpha\Delta\pi)[(P_{H0}(Q-M)+P_{L0}(M-\gamma T_H)+(Q-\gamma T_H)(\varepsilon R_L+\delta R_H\text{-}\Delta C+\alpha\Delta\pi)]}{(Q-\gamma T_H)[(\varepsilon R_L+\delta R_H)(Q-\gamma T_H)+P_{H0}(Q-M)+P_{L0}(M-\gamma T_H)]}$ | + | $\frac{(Q-M)(M-\gamma T_H)(\Delta C\text{-}\alpha\Delta\pi)(P_{H0}-P_{L0})}{(Q-\gamma T_H)[(\delta R_H+\varepsilon R_L)(Q-\gamma T_H)+P_{H0}(Q-M)+P_{L0}(M-\gamma T_H)]}$ | - | $P_{H0}<P_{L0}$ | ESS |

$$J=\begin{bmatrix}(1\text{-}2x)[y(P_H(\mathrm{x})+P_L(x)+\varepsilon R_L+\delta R_H)+\alpha\Delta\pi\text{-}\Delta C]+xy(1\text{-}x)(P_{H0}-P_{L0}) & x(1-x)(P_H(\mathrm{x})+P_L(x)+\varepsilon R_L+\delta R_H) \\ y(1\text{-}y)\left(\gamma T_H\text{-}Q\right) & (1-2y)[x\left(\gamma T_H\text{-}Q\right)+Q-M]\end{bmatrix} \tag{15}$$

The same reasoning still exists $\pi+\alpha\pi_H+\delta R_H+P_H(x)-C_H>\pi-\alpha\pi_L-\varepsilon R_L-P_L(x)+C_L$ i.e., no matter when $x$ takes any value, there is a constant $P_H(x)+P_L(\mathrm{x})+\delta R_H+\varepsilon R_L>\Delta C\text{-}\alpha\Delta\pi$. The stability of each equilibrium point is shown in Table 5. Therefore, when the maximum penalty for the construction unit $P_{L0}$ is greater than the maximum reward for the construction unit $P_{H0}$, the EPC consortium cooperation tends to be stabilized and forced to provide high-quality cooperation voluntarily due to the financial penalty.

Similarly, the newly added dynamic reward/punishment relationship is represented by a red dashed line in the VENSIM PLE software, and the corresponding system dynamics model is constructed, as shown in Figure 8.

Other things being equal, the values of 2.5 and 4 are assigned to $P_{H0}$ and $P_{L0}$, respectively, under satisfying the condition $P_{H0}$ - $P_{L0}$ <0, the simulation is shown in Figure 9. In this case, the two EPC game cooperation tends to be stable. Similar to the game strategy under the dynamic punishment mechanism, both behavioral decisions do not rely on the interference of each other's behavior; the system performs out of consistency. The simulation results are consistent with the results of the dynamic equation analysis of the consortium game replication. The construction unit to makes behavioral strategies in line with the principle of maximizing their own interests, but probability of the construction unit providing high-quality cooperation has nothing to do with the economic incentives and economic penalties, the same with $\dfrac{Q-M}{Q-\gamma T_H}$. The probability of the design unit's supervision is related to $\dfrac{(\Delta C\text{-}\alpha\Delta\pi)(Q-\gamma T_H)}{(\varepsilon R_L+\delta R_H)(Q-\gamma T_H)+P_{H0}(Q-M)+P_{L0}(M-\gamma T_H)}$.

This paper mainly discusses the stability of EPC consortium cooperation relationship, which has nothing to do with the initial probability of construction unit to provide high-quality cooperation and the initial probability of design unit to supervise. Under the dynamic reward and punishment mechanism, the EPC consortium evolution strategy can reach consistency, and the cooperative relationship can be stabilized, which provides theoretical support for the lead unit to formulate the corresponding

**Figure 8. SD Model of EPC Consortium Cooperation Evolution Game Under Dynamic Reward and Punishment Mechanism**

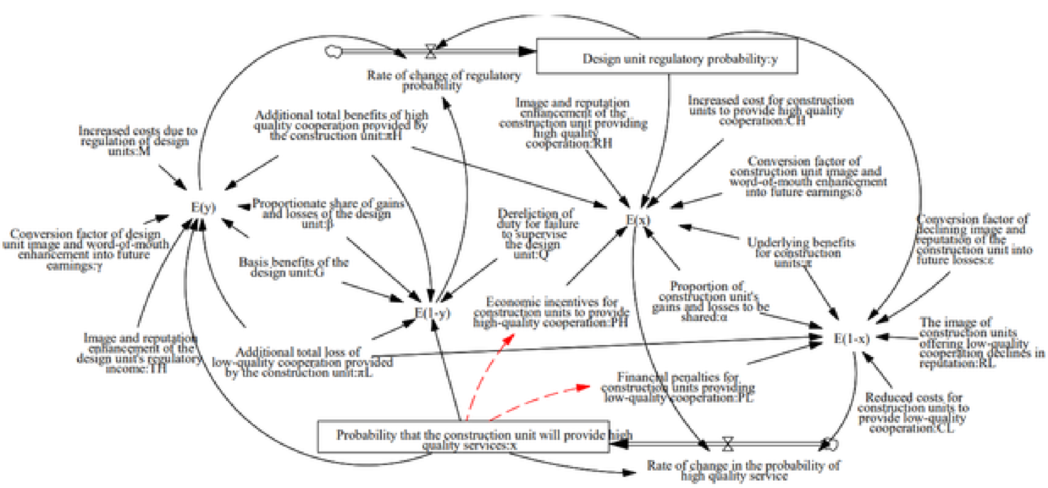
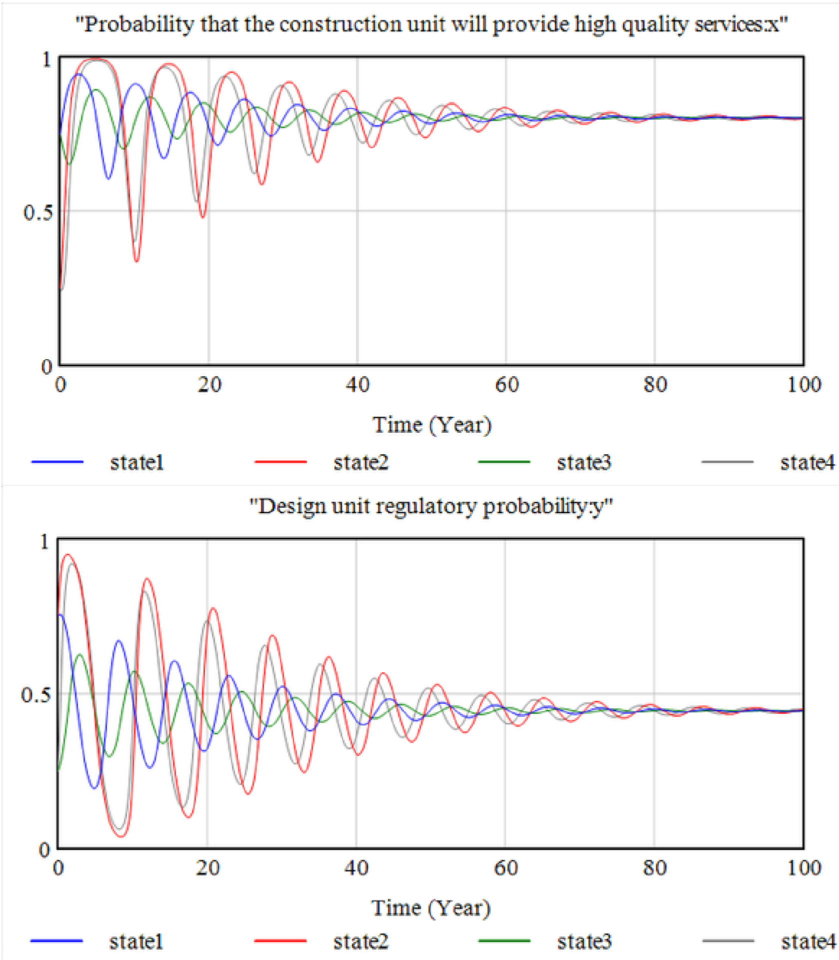


**Figure 9. Simulation of Both Sides of EPC Consortium Under Dynamic Reward and Punishment Mechanism**




cooperative mechanism. But in order to improve the reputation and profit of the consortium, the construction unit should also try to adopt the strategy of providing high-quality behaviors.

## RESULTS

Under the static reward and punishment mechanism, the EPC consortium cooperation relationship is centered on $E_5(\frac{Q-M}{Q-\gamma T_H}, \frac{\Delta C\text{-}\alpha\Delta\pi}{\Delta\pi_1+\Delta\pi_2})$, in a cyclic behavioral pattern, and there is no stable equilibrium strategy for the two main game players.

In the dynamic reward mechanism, the design unit and the construction unit game according to each other's behavioral strategy and make their own behavioral choices, both interdependent. Although the construction unit will eventually choose to provide high-quality service strategy, and the design unit choose to non-supervisory. But for gaming systems, the two partnerships are not stable.

Under the dynamic punishment mechanism, the EPC consortium cooperation relationship tends to stabilize, and both will eventually choose a certain fixed behavioral strategy, which is independent of the other party's behavioral strategy.

Under the dynamic penalty mechanism, the EPC consortium partnership tends to be stabilized only when the condition $P_{H0}$ - $P_{L0}$ <0 is satisfied, and this stabilization is similar to the system stability under the dynamic penalty mechanism.

When the behavioral strategies of the two main players of the EPC consortium tend to be stable, the probability of the construction unit providing high-quality cooperation is related to $\frac{Q-M}{Q-\gamma T_H}$, while the probability of the design unit's supervision is affected by different factors under different mechanisms.

## SUGGESTIONS

To establish a stable EPC consortium member cooperative relationship, and combined with the data simulation results, this paper puts forward several suggestions

### Establishment of a Rational Incentive and Punishment Mechanism

According to the simulation results above, the behavioral strategy evolution of both sides of the consortium only tends to converge when there is dynamic punishment, dynamic rewards and punishments, and the maximum reward amount is smaller than the maximum punishment amount. Therefore, for the construction unit, it is necessary to establish a reasonable reward and punishment mechanism to force the construction unit to provide high-quality cooperation out of its own interests. In addition, it is appropriate to increase the design unit due to non-supervision of the failure of the pursuit of responsibility, to force the design unit to take the supervision strategy, which in turn prompts the construction unit to take high-quality cooperation strategy.

### Build an Efficient Cooperation and Communication Platform

Strengthen the construction of enterprise office platform, for example, by linking building information modeling technology with the unit office platform enterprise resource planning or office automation to build an integrated office platform, breaking down professional communication barriers, and improving communication efficiency. This platform could help to supervise the work content of the construction unit, reduce the cost of supervision of the design unit, improve the willingness of the design unit to supervise, and force the construction unit to provide high-quality cooperation.

### Cultivate a Long-Cycle Culture of Strategic Cooperation of the Consortium and Improve the Image and Reputation of the Design Unit

A long-term strategic cooperative relationship can improve the fit between the members of the consortium and enhance the solidarity and cooperation between the partners. If the design unit takes the strategic cooperation approach, before the cooperation of the construction unit to establish a strategic partnership, it can make both sides continue to deepen the understanding, enhance the sense of shared identity, and promote the formation of the relationship of trust between the two sides. Cooperation will allow for support and cooperation with strategic partners. Having the design unit as the lead unit is conducive to its image and reputation enhancement, which promotes the two sides of the long-term stability of cooperation, to achieve long-term reciprocity.

## DEFICIENCIES

This paper relies heavily on simulation and theoretical modeling, and due to the uniqueness of each project, the assumptions made in this paper may not be applicable to all situations in the real world. The parameter settings in the simulation are based on my own experience combined with actual case data, which may affect the generalizability of the results of the study. In addition, only the two main players of EPC are considered in this study, and other potential stakeholders and their influence on the dynamics of the consortium are not considered, which may limit the comprehensiveness of the analysis. Some of the parameter assignments are vague and imprecise, such as the conversion factor of image and reputation on future gains or future losses, which fails to capture the subtle dynamics of actual EPC consortium interactions in a more comprehensive way.

## CONCLUSION AND FUTURE SCOPE

In this paper, for the EPC consortium cooperation stability problem led by the design unit, the EPC consortium cooperation stability game model under different reward and punishment mechanisms is constructed and the system dynamics are used to verify the consistency of the results with the consortium game replicating the analysis of dynamic equations. It is concluded that under the dynamic punishment mechanism and the dynamic reward and punishment mechanism where the maximum punishment amount is greater than the maximum reward amount, the design unit and the construction unit have the cooperation stability, and both of them evolve stable behavioral strategies.

According to the simulation results, the recommendations in favor of cooperation stability are put forward. However, general engineering contracting is still in the transition period, and more comprehensive, systematic, and in-depth research is needed. In future expansion research, the dynamic influence of other stakeholders on EPC consortium cooperation, such as procurement units, supply units, and even the government, should be more comprehensively considered. When setting the model parameters, the complex influencing factors in the actual project should be fully considered, so that the research results can be closer to the actual situation in the real world and be more universal. In parameter assignment, how to accurately assign values for vaguely defined parameters is also a major direction of research efforts, to provide more practical insights for the study of EPC consortium partnership stability.

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