

Research on Knowledge Sharing Strategy of EPC Consortium Based on Fairness Concern

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Abstract

Knowledge sharing is the foundation of EPC consortium cooperation, this paper focuses on the problem of knowledge sharing strategy selection of EPC consortium members, constructs the EPC consortium knowledge sharing game model based on fairness perception, and analyzes the factors influencing the decision-making of EPC consortium's knowledge sharing behavior through data simulation. The research results show that: the size of the initial probability of knowledge sharing of the gamers has a certain relationship with the system evolution; the evolution of knowledge sharing behavior is positively related to the proportion of knowledge complementarity and the coefficient of synergistic benefit; and negatively related to the coefficient of fairness perception, fixed cost, risk cost coefficient, and the coefficient of direct benefit. Suggestions for building a knowledge sharing platform and strengthening contract management are also put forward to provide support for EPC consortium behavioral decision-making research.

Keywords

EPC Consortium; Fairness Concern; knowledge sharing; Strategic Research.

1. Introduction

Traditional contracting mode due to the design, construction, procurement and other phases of the split, resulting in a long construction cycle and cost waste and other shortcomings, while the EPC general contracting mode perfect integration of the three phases, to make up for the shortcomings of the traditional contracting mode, so the EPC general contracting mode by the government and the owners of the favor. At this stage, there are fewer enterprises with the dual qualification of design and construction, so it is a big trend to form an EPC consortium through the design unit and the construction unit to jointly contract the project, so as to realize the complementary advantages and risk-sharing. However, in the knowledge economy today, talent and knowledge and other intellectual resources to become the first element of resource allocation, but also the enterprise to achieve the strategic resources of innovation. A construction project can only succeed in a more complex environment by continuously absorbing and applying new knowledge for innovation. However, in the current EPC project contracting process, members of the consortium for the protection of their own interests, there will be reluctant to share knowledge or even deliberately cover up knowledge, so that the knowledge and information in the consortium members can not be effective flow and sharing. And consortium cooperation has independence and one-time, members are in the dual role of cooperation and competition, worrying about their loss of monopoly advantage in knowledge sharing, so that they will be in a disadvantageous position in the future competition, resulting in knowledge sharing in the cooperation is difficult to be transformed into conscious behavior.

Therefore, this paper mainly focuses on the control and maintenance of the stability of knowledge alliance among EPC consortium members, and researches the behavioral strategy selection and mutual influence mechanism of EPC consortium members in knowledge cooperation.

Research on EPC projects at home and abroad focuses on the following aspects. In terms of risk allocation, Wan SY [1] developed an operational three-phase risk allocation model for EPC, discussed the application of the model to commercial buildings in China, and proposed a new methodology for allocating EPC project risks in a dynamic and phased manner. In the context of collaborative management, Fan ZL [2] established a network model to explore the relationship between design and construction management of EPC projects by combining the social network analysis method and the Wuli-Shili-Renli (WSR) system approach. It was concluded that coordination and communication mechanism, organizational construction, interface management system and design management system are the core network elements affecting the collaborative management of railroad EPC. Jiang WP [3-4] used Structural Equation Modeling (SEM) and a large-scale questionnaire survey to study the influential relationship between trust and project success in construction projects, and concluded that relational trust has a greater impact on project success than calculative trust. It also analyzed that calculated trust and relational trust have a facilitating effect on contractors' intention to cooperate in EPC projects, and concluded that reputation, reciprocity and communication are important factors in generating trust. In terms of earnings distribution, Yue YM [5] addressed the limitations of Shapley value, introduced input factors, technical factors and management factors, and developed an improved profit distribution model based on entropy-weighted TOPSIS and Shapley value, which balanced earnings and actual contributions to achieve fair and reasonable earnings distribution. Sun CS [6] combined BIM technology with EPC projects to analyze the interaction behavior among government, owner and general contractor, and established a ternary evolutionary game model, which concluded that the choice of BIM application strategy is affected by the interaction behavior of the participants' game, reasonable subsidies contribute to the evolution of the ideal stable strategy, and the owner's high incentive standard for the general contractor can accelerate the promotion of BIM. In terms of partnerships, Wang TF [7] quantified the relationship between good partnering and improved contracting capabilities and risk management of contractors, contributing to enhanced design management and improved project outcomes. Du L [8] revealed that partnerships not only contribute directly to organizational capacity and risk management, but also have an impact on risk management by enhancing organizational capacity, thus improving project performance. In terms of behavioral decision-making, Hu JD [9] considered the impact of different reward and punishment mechanisms on the cooperation strategies of EPC consortium members, and compared four scenarios of static reward, static punishment, dynamic reward, and dynamic punishment in a comparative study, which explored the behavioral interaction mechanism of stable cooperation in EPC consortiums. Wang HP [10] constructed a tripartite evolutionary game model of government, EPC general contractor and supervision unit. And the influence of reward and punishment mechanism, cost and other factors on the strategy selection of the three parties was analyzed through simulation.

In the aspect of knowledge management, Song YQ [11] deeply analyzes the knowledge characteristics of EPC projects, clarifies the path of project knowledge transfer between organizations in the knowledge chain and the obstacles of knowledge transfer, and constructs a synergistic mechanism and role model of the interface of organizations in the knowledge chain of EPC projects, so as to improve the efficiency of knowledge transfer. Chang T [12] establishes the knowledge sharing game model of design unit and construction unit of EPC consortium members under the regulatory mechanism, and verifies the influence path of the model parameters on the strategy selection of the main body of the game through Matlab.

Zhang ZY[13]analyzed the factors and barriers affecting knowledge flow, proposed a cooperative network model of knowledge flow participants in each stage of EPC projects, and came up with three research methods of knowledge management that are beneficial to EPC projects. She JJ[14] applies BIM technology to project knowledge management activities, proposes a knowledge integration management model for EPC projects based on BIM, and analyzes in detail the contents of knowledge management in each stage of EPC projects and the application of BIM technology in the knowledge management activities of design, procurement, and construction phases, so as to order and systematize the project knowledge and provide new ideas for the knowledge management of construction enterprises.Olsen AO [15] introduced stakeholder theory to consortia and concluded that groups can benefit from consortia, especially when the consortium's technical knowledge is highly dispersed and inexperienced.

All of the above research subjects are fully rational human beings, but it is difficult to idealize and undisturbed fully rational human beings in the process of real project occurrence. Li HM [16] established a profit sharing model for EPC projects based on fairness concern, and concluded that the project optimization profit and its sharing are not only related to the efforts and the cost coefficient, but also related to the fairness concern behaviors of both parties.Hu JD [17] constructed a game model for the evolution of design, construction and procurement cooperation strategy based on prospect theory to analyze the behavioral interaction mechanism of the three parties and provide theoretical basis and decision support for the cooperation of EPC consortium members. Chen ZY [18] similarly used prospect theory to analyze the security behavior among EPC consortium members.Lee CY [19] combined the factors of perceived fairness, calculated trust, relational trust and distrust and analyzed them using Partial Least Squares Structural Equation Modeling (PLS-SEM). It was concluded that the joint contracting function has no direct effect on BIM-enabled EPC project performance, but there are significant total and indirect relational effects, which are strongly influenced by perceived fairness and relational trust.Yan L [20] used eye-tracking techniques to explore the degree of attention paid by contractors to the allocation clause and the change procedure clause in reading construction project contracts, and then verified the connotation and structure of contractors' fairness perception.Li YD [21] constructed a public-government agent game model considering the perception of fairness, tried to abstract the negotiation between the public and the government in the process of neighbor avoidance as a multi-stage game process in which the agents of each subject benefit, and sought the coordination between the public's optimal expectation of periodic compensation and the government's optimal actual periodic compensation strategy.

Through the analysis of the above literature, it can be seen that EPC projects want to realize mutual benefit and win-win situation, not only related to its reasonable risk sharing and benefit distribution, but also related to the willingness of EPC consortium members to share knowledge. The research on knowledge sharing of EPC consortium mainly focuses on the analysis of knowledge dissemination barriers and paths, and there are fewer studies on the decision-making of knowledge sharing behaviors of EPC consortium members, and there is no good knowledge sharing habit in the traditional construction engineering field itself. In addition, EPC consortium members' knowledge sharing willingness and adopted behavioral strategies are related to whether consortium members perceive fairness. Therefore, this study stands from the perspective of imperfect rational person, starts from the internal EPC consortium members, considers the influence of fairness perception, constructs the game model of knowledge sharing behavioral strategy evolution of EPC consortium members based on fairness perception, and analyzes the influencing factors of knowledge sharing behavioral strategy of EPC consortium members through numerical simulation, so as to provide reference for the future knowledge

alliance and stability cooperation within EPC consortiums. The model provides a reference for future knowledge alliance and stability cooperation within EPC consortium.

2. Model Description and Assumptions

2.1. Model Description

As EPC projects have one-time characteristics, the knowledge sharing among the members of the EPC consortium is also one-time and temporary. However, in order to maximize their own interests and achieve a stable evolutionary strategy, the main body of the game will constantly adjust its own strategy according to the changes in the strategy of the other player. In order to better reveal the knowledge sharing behavior and knowledge sharing process among the consortium members, this paper is constructed under the background of no external regulation, only studying the dynamic evolution process of the strategy behavior of the two main game players, namely design and construction units, and their stability, revealing the mechanism of the evolution of the main knowledge sharing strategy.

2.2. Parameterization

Assumption 1: Only the design unit and the construction company form the EPC consortium. Both are finite rationality and subject to fairness perception factors.

Assumption 2: In the project cooperation, both the design unit and the construction company have two strategy choices of knowledge “sharing” and “not sharing”. At the same time, the strategies of both parties will affect each other, that is, both parties will predict and adjust according to their respective strategies, and the choice of strategies of both parties will be changed due to changes in each other's strategies, therefore, the strategies of the EPC consortium members are in a state of long-term dynamic evolution. It is assumed that the probability of the design unit choosing the knowledge sharing strategy is x ($0 < x < 1$) and the probability of choosing the knowledge not sharing strategy is $1-x$. Similarly, the probability that the construction company chooses the knowledge sharing strategy is y ($0 < y < 1$) and the probability that it chooses the knowledge not sharing strategy is $1-y$.

Assumption 3: The design and construction units in an EPC consortium consider the costs and benefits when making a choice of knowledge sharing or no sharing strategy. This is an imperfect information game because neither unit can fully understand its partner's payoff function and options for knowledge sharing, so it is an imperfect information game. The unit itself can only decide on the basis of the amount of knowledge sharing k , the ratio of knowledge complementarity μ , the direct benefit coefficient α , the synergistic benefit coefficient β , and the risk-cost coefficient of knowledge sharing r . Therefore, its decision on knowledge sharing will be based on the total return, and the firm's payoff function depends on the knowledge sharing behavior of its trading partners.

(1) Direct benefits M . The ability of the subject to transform the knowledge shared by the partner into its own gain based on its own learning ability and knowledge level. Its size is affected by the amount of knowledge sharing, the proportion of knowledge complementarity and the direct gain coefficient of knowledge sharing, then the direct gain of the design unit is $M_D = k_C \mu_C \alpha_D$, and the direct gain of the construction company is $M_C = k_D \mu_D \alpha_C$.

(2) Synergy Gain N . The size of the gains generated by the integration of proprietary knowledge between the subject parties is affected by the amount of knowledge shared, the proportion of complementary knowledge and the coefficient of synergistic gains from knowledge sharing. Then the synergy gain for the design unit is $N_D = k_C \mu_C \beta_D$, and the synergy gain for the construction company is $N_C = k_D \mu_D \beta_C$.

(3) Knowledge sharing costs T . Including fixed costs G and risk costs F . Fixed costs refer to various resource costs such as human and material resources incurred in the process of

knowledge exchange, dissemination and transformation, while risk costs refer to the leakage of core knowledge and the reduction of knowledge competitiveness. The greater the amount of knowledge sharing and the more complementary knowledge sharing, the higher the risk cost. Therefore risk cost is expressed in terms of knowledge sharing quantity and cost coefficient. Then the knowledge sharing cost of the design unit is $T_D = G_D + k_D \mu_D r_D$, and the knowledge sharing cost of the construction company is $T_C = G_C + k_C \mu_C r_C$.

Assumption 4: Fairness concern refers to the fairness perception of both design and construction parties regarding their own and each other's benefits. According to Rabin [22] proposed the use of profit difference to indicate the degree of fair concern, the larger the value of profit difference, the higher the fairness perception. In this paper, we use the reference point dependence to characterize the fair concern utility function, λ is the fairness concern coefficient of the firm, the return of the firm i is $X_i = M_i + N_i - T_i$, and the utility function of firm B is $U_i = X_i - \lambda_i(X_j - X_i) = (1 + \lambda_i) - \lambda_i X_j$, where $i, j = (D, C)$.

3. Model Construction and Analysis

3.1. Model Construction

According to the parameter assumptions above, the game utility matrix of EPC consortium design and construction units is established by comprehensive consideration from four aspects: direct benefits, indirect benefits, costs, and fairness concern, as shown in Table 1.

Table 1. Game Utility Matrix with Introduction of Fairness Concern

		Construction Company	
		Sharing y	Not Sharing $1-y$
Design Unit	Sharing x	$(1 + \lambda_D)(M_D + N_D - T_D) - \lambda_D(M_C + N_C - T_C)$ $(1 + \lambda_C)(M_C + N_C - T_C) - \lambda_C(M_D + N_D - T_D)$	$-(1 + \lambda_D)T_D - \lambda_D M_C$ $(1 + \lambda_C)M_C + \lambda_C T_D$
	Not Sharing $1-x$	$(1 + \lambda_D)M_D + \lambda_D T_C$ $-(1 + \lambda_C)T_C - \lambda_C M_D$	0 0

According to the game utility matrix, the expected utility of the design unit adopting a sharing strategy and adopting a non-sharing strategy are respectively:

$$E(x) = y[(1 + \lambda_D)(M_D + N_D) - \lambda_D(N_C - T_C)] - (1 + \lambda_D)T_D - \lambda_D M_C$$

$$E(1-x) = y[(1 + \lambda_D)M_D + \lambda_D T_C]$$

Then the expected utility of the design unit adopting a mixed strategy is:

$$F(x) = x(1-x)\{y[(1 + \lambda_D)N_D - \lambda_D N_C] - (1 + \lambda_D)T_D - \lambda_D M_C\}$$

Similarly, the expected utility of a construction company adopting a sharing strategy and adopting a non-sharing strategy are respectively:

$$E(y) = x[(1 + \lambda_C)(M_C + N_C) - \lambda_C(N_D - T_D)] - (1 + \lambda_C)T_C - \lambda_C M_D$$

$$E(1-y) = x[(1 + \lambda_C)M_C + \lambda_C T_D]$$

Then the expected utility of the construction company's mixed strategy is:

$$F(y) = y(1-y)\{x[(1 + \lambda_C)N_C - \lambda_C N_D] - (1 + \lambda_C)T_C - \lambda_C M_D\}$$

3.2. Stability Analysis

Associating the mixed-strategy expected utility established above, such that $F(x)=0, F(y)=0$, yields five local equilibria, namely $E_1(0,0)$, $E_2(0,1)$, $E_3(1,0)$, $E_4(1,1)$, $E_5(x^*, y^*)$, where

$x^* = \frac{(1+\lambda_c)T_c + \lambda_c M_D}{(1+\lambda_c)N_c - \lambda_c N_D}$, $y^* = \frac{(1+\lambda_D)T_D + \lambda_D M_C}{(1+\lambda_D)N_D - \lambda_D N_C}$. The Jacobin matrix of the knowledge sharing evolution game for EPC consortium members is denoted as:

$$J = \begin{bmatrix} (1-2x)\{y[(1+\lambda_D)N_D - \lambda_D N_C] - (1+\lambda_D)T_D - \lambda_D M_C\} & x(1-x)[(1+\lambda_D)N_D - \lambda_D N_C] \\ y(1-y)[(1+\lambda_c)N_c - \lambda_c N_D] & (1-2y)\{x[(1+\lambda_c)N_c - \lambda_c N_D] - (1+\lambda_c)T_c - \lambda_c M_D\} \end{bmatrix}$$

Assumptions are made to simplify the calculations: $U_1 = (1+\lambda_D)N_D - \lambda_D N_C$, $U_2 = (1+\lambda_D)T_D + \lambda_D M_C$, $U_3 = (1+\lambda_c)N_c - \lambda_c N_D$, $U_4 = (1+\lambda_c)T_c + \lambda_c M_D$, then $J = \begin{bmatrix} (1-2x)[U_1 y - U_2] & x(1-x)U_1 \\ y(1-y)U_3 & (1-2y)[xU_3 - U_4] \end{bmatrix}$. The value $\det(J)$ and trace value $\text{tr}(J)$ of each equilibrium point matrix determinant are shown in Table 2.

Table 2. $\det(J)$ and $\text{tr}(J)$ for each equilibrium

Equilibrium	$\det(J)$	$\text{tr}(J)$
$E_1(0,0)$	$U_2 U_4$	$-(U_2 + U_4)$
$E_2(0,1)$	$(U_1 + U_2)U_4$	$U_1 + U_2 + U_4$
$E_3(1,0)$	$U_2(U_3 - U_4)$	$U_2 + U_3 - U_4$
$E_4(1,1)$	$(U_1 + U_2)(U_3 + U_4)$	$-(U_1 + U_2) - (U_3 + U_4)$
$E_5(x^*, y^*)$	$-\frac{U_2 U_4 (U_1 - U_2)(U_3 - U_4)}{U_1 U_3}$	0

Since the construction company is profit-seeking, if the design unit adopts a non-sharing strategy, the construction company is likewise adopting a non-sharing strategy, which means that the benefit of adopting a non-sharing strategy is greater than the benefit of a sharing strategy, i.e., $-(1+\lambda_c)T_c - \lambda_c M_D < 0$, then $U_4 > 0$. In turn, if the design unit adopts a sharing strategy, the construction company will also adopt a sharing strategy considering the overlapping benefits of the consortium, i.e., $(1+\lambda_c)(M_c + N_c - T_c) - \lambda_c(M_D + N_D - T_D) > (1+\lambda_c)M_c + \lambda_c T_D$, then $U_3 - U_4 > 0$. It can be obtained that $U_3 > U_4 > 0$.

Similarly, if the construction company adopts the non-sharing strategy, the design unit will still choose not to share in order to eliminate the “free-rider” behavior, then $(1+\lambda_D)M_D + \lambda_D T_c > 0$, i.e., $U_2 > 0$. If the construction company adopts the sharing strategy, the design unit will consider the principle of maximizing the benefit and choose the sharing strategy, then $(1+\lambda_D)(M_D + N_D - T_D) - \lambda_D(M_c + N_c - T_c) > (1+\lambda_D)M_D + \lambda_D T_c$, i.e., $U_1 - U_2 > 0$. It can be obtained that $U_1 > U_4 > 0$. The results of the stability analysis of each equilibrium point can be obtained by bringing the obtained conclusions into Table 2. As shown in Table 3, there are two stable points in the EPC consortium knowledge sharing system, $E_1(0,0)$ and $E_4(1,1)$, while $E_5(x^*, y^*)$ is the center point of the system. When the initial probability falls within the region $E_1 E_2 E_5 E_3$, the system will converge to $(0,0)$, and the two main players of the game will eventually adopt the non-sharing strategy. When the initial probability falls within region $E_2 E_5 E_3 E_4$, the system will converge to $(1,1)$, and the two main players will eventually adopt the sharing strategy.

Table 3. Analysis of Local Stability Results for Each Equilibrium Point

Conditions	Equilibrium	$\det(J)$	$\text{tr}(J)$	Stability
$U_1 > U_2 > 0$ $U_3 > U_4 > 0$	$E_1(0,0)$	+	-	ESS
	$E_2(0,1)$	+	+	Instability
	$E_3(1,0)$	+	+	Instability
	$E_4(1,1)$	+	-	ESS
	$E_5(x^*, y^*)$	-	0	centerpoint

4. Simulation

4.1. Construction of Knowledge Sharing Game Model for EPC Consortium Based on Fairness Concern

Considering the dynamic changeability of EPC consortium members' choice of knowledge sharing strategy, this paper adopts VENSIM PLE software to construct EPC consortium knowledge sharing evolution game SD model, as shown in Figure 1. As this paper studies the selection trend of the two main game subjects of design and construction on knowledge sharing strategy in EPC projects, how to accurately assign is not the focus of the study, the parameter assignment involved in the model refer to the real-life EPC project related data, but not exactly the real data in reality, and only represents a kind of relationship reaction. In the range of constraints $U_1 > U_2 > 0, U_3 > U_4 > 0$, the parameters take the values of $k_D = 120, k_C = 100, \mu_D = 0.5, \mu_C = 0.3, \alpha_D = 0.5, \alpha_C = 0.3, \beta_D = 2, \beta_C = 2, G_D = 10, G_C = 12, r_D = 0.3, r_C = 0.2, \lambda_D = 0.1, \lambda_C = 0.1$. The system was simulated for 1 year and the stability of the cooperation between the two parties was closely tested at a frequency of once a day.

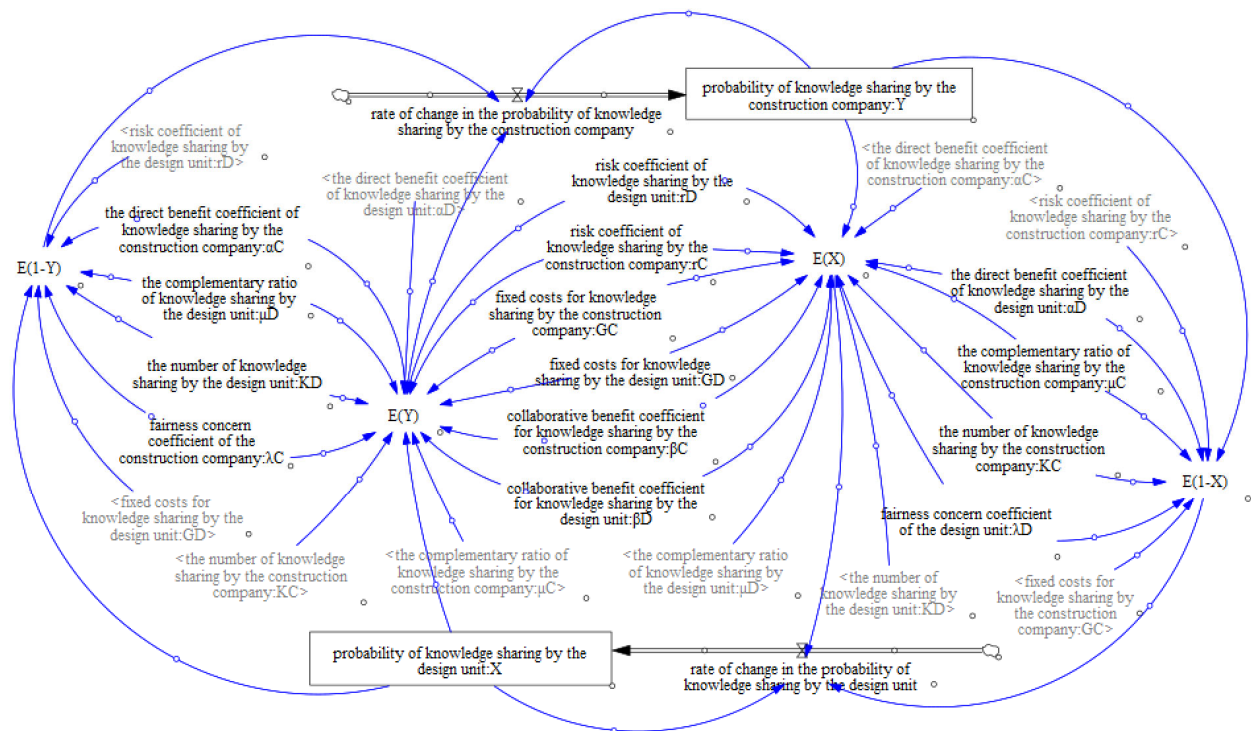


Figure 1. SD model of knowledge sharing evolution game for EPC consortia

4.2. Analysis of Factors Influencing Knowledge Sharing Strategies of EPC Consortia

(1) Initial Behavior Selection

In order to comprehensively and realistically react to the simulation situation, the initial probability of the design unit and the construction company selecting the knowledge sharing strategy is considered in the following four scenarios, respectively, state1(0.25,0.25), state2 (0.25,0.75), state3 (0.75,0.25), state4 (0.75,0.75), and the behavioral selection shown in Fig. 2 is obtained through the model simulation Strategy diagram.

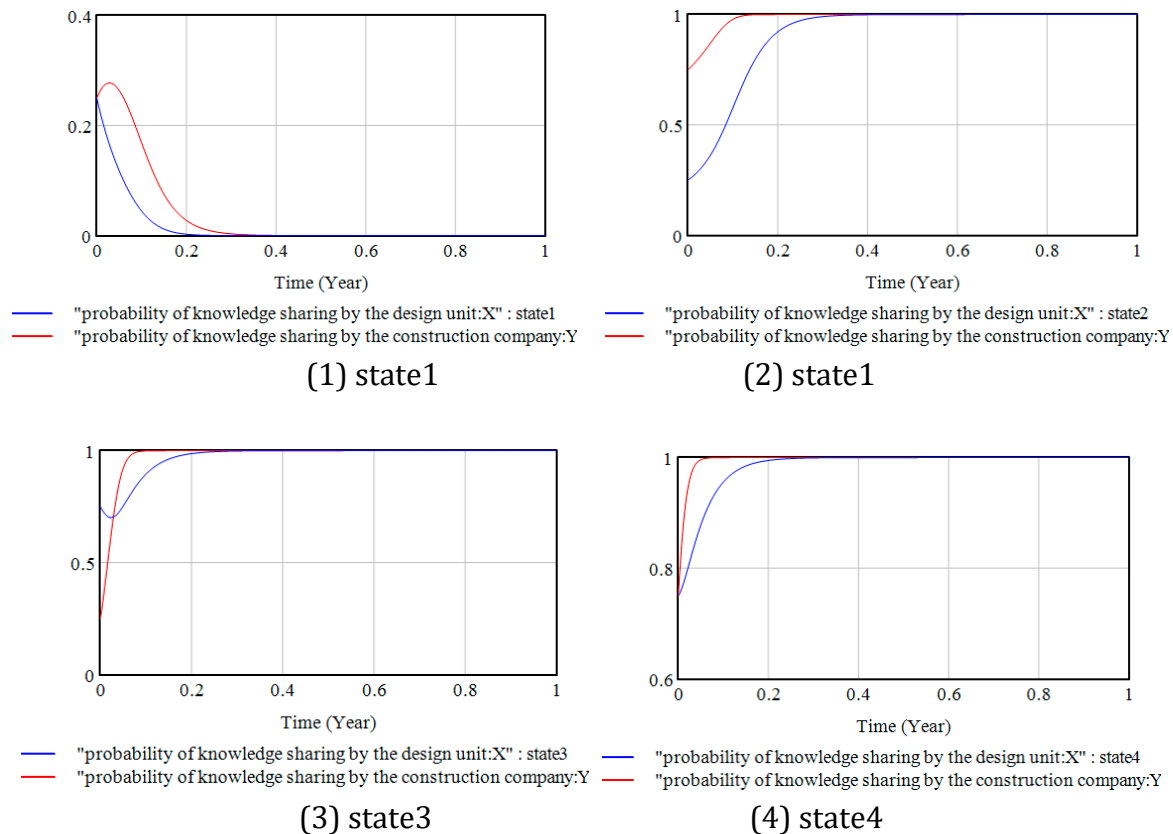


Figure 2. Effect of EPC consortium initial strategy on knowledge sharing behavior

State 1: Compared to the construction company, the design unit's dominant force in EPC projects becomes more and more obvious due to the design-first nature of EPC projects. If the design unit is worried about the public exposure of its own proprietary tacit knowledge and experience, the willingness to actively share is not high. In this case, the construction company fully understands that it is not enough to rely only on its own understanding of the construction or its own knowledge to understand the design intent. Therefore, the construction company has the will to adopt the sharing strategy at the beginning, but as the design unit's willingness not to share is strengthened, the construction company also adopts the “bad” strategy, and both sides have the mentality of “if you don't ask, I don't answer”, and do not actively share their personal knowledge resources, the knowledge sharing system will eventually converge to zero.

State 2: Although the design unit is unwilling to share resources at the beginning, but the construction company knowledge sharing willingness is very strong, in this case, the design unit to see the construction unit's positive initiative, but also in the spirit of win-win cooperation concept, will eventually take the sharing strategy, and sharing strategy rate faster than the construction company sharing strategy.

State 3: The design unit shows sharing behavior at the beginning, while the construction company is thinking about whether it can try to reduce sharing costs and get more benefits by adopting speculative or “free-riding” behavior, so the willingness to share knowledge is low at the beginning. In this case, the design unit's willingness to share starts to decline in order to avoid “free-riding” behavior. However, as the construction company realizes that only sharing and cooperation can lead to a win-win situation, it can only make the other party change its willingness to share by changing its own strategy. Therefore, even if the initial probability of sharing willingness of the construction company is low, but ultimately will still take the sharing strategy, and the rate of sharing strategy is faster than the rate of sharing strategy of the design unit.

State 4: Both parties have a strong willingness to choose the knowledge sharing strategy, and both parties have the awareness of risk-sharing and benefit-sharing, and pay for the actual sharing actions. The probability of both parties to choose the sharing strategy finally converges to 1, and the speed of convergence accelerates with the increase of the initial probability. In order to analyze the impact of different influencing factors on the knowledge sharing strategy of EPC consortium members, this paper is based on the discussion and analysis of state 4.

(2) Fairness Concern

In the cooperative knowledge sharing behavior of EPC consortium, the fairness concern coefficient is a quantification of the fairness concern willingness of both sides of the EPC consortium, i.e., the larger the fairness concern coefficient is, the more sensitive the subject's fairness concern utility is. In the case of keeping other parameters unchanged, change the value of λ_D and λ_C to simulate the SD model, the results are shown in Fig.3.

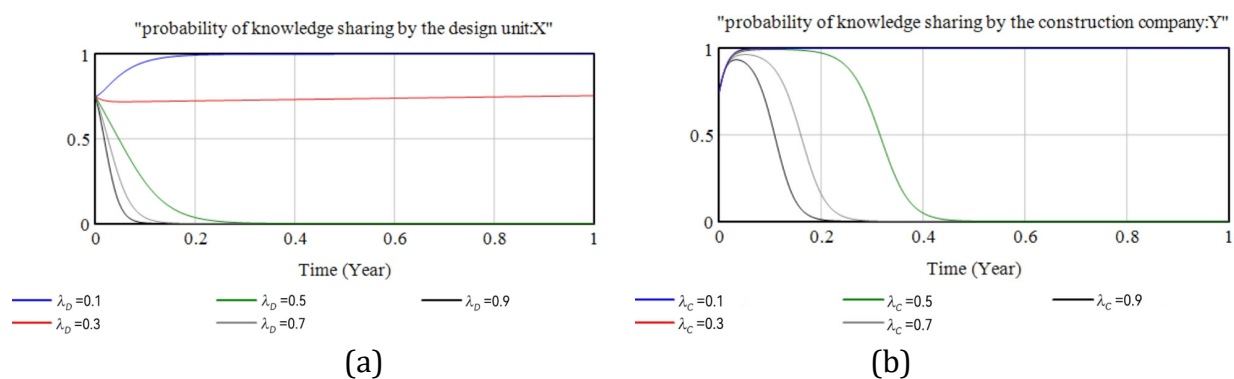


Figure 3. Impact of Fairness Perception on Knowledge Sharing Strategies of EPC Consortia

As can be seen from the above figure, as the values of λ_D and λ_C increase, the willingness of the design unit and the construction company to share knowledge gradually decreases, but the initial stage of the system also tends to a stable state of (1, 1). However, as the values of λ_D and λ_C continue to increase, the willingness of both parties to share will decline rapidly, and the system will eventually tend to (no sharing, no sharing) stable state.

This shows that the fairness concern coefficient has a specific threshold for both subjects of the EPC consortium, and the knowledge sharing willingness of the design unit is always weaker than that of the construction company, which is due to the influence of the dominant position of the participation, which is dominated by the design unit at the beginning, and the construction company can only play a supporting role, and the design unit has a fuzzy feeling about the knowledge sharing willingness of the construction company. When the fairness concern coefficient is smaller than the subject's own strategy selection threshold, the system evolution stable state tends to (1,1) point, i.e., the design unit and the construction company will share the cooperation. On the contrary, the stable state of system evolution tends to point (0,0), and both parties will not share knowledge. Therefore, the subjective strategy selection of both EPC parties will be influenced by the fairness concern behavior, and both parties will pay attention to the benefits gained by themselves and their partners at the same time. With the enhancement of the role of fairness concern, the subject is more and more dissatisfied with the current payoffs and benefits, and will refuse to cooperate at the cost of the damage to their own interests, in order to achieve the purpose of punishing the other party.

(3) Risk Cost Factor

Knowledge sharing risk coefficient reflects the risk of core knowledge leakage in the process of knowledge sharing, as shown in Fig.4, the larger the values of risk cost coefficients r_D and r_C are, the weaker the willingness of the design and construction units to choose the sharing strategy,

and the knowledge sharing risk coefficient is negatively correlated with the system evolution. The reason for this is that knowledge sharing is constantly sharing their own important core knowledge and technology, which often has a certain degree of relevance and complementarity, and is very likely to lead to the leakage of knowledge in the process of knowledge sharing, thus increasing the probability of knowledge sharing cost risk, resulting in an increase in the cost of sharing, and making the EPC two parties to the knowledge sharing behavior to obtain a reduction in the total benefits, thus reducing the willingness to share knowledge. In addition, once a party's competitive unique resources are leaked to the outside world, it will reduce the probability of winning the construction project later, making its own interests damaged. Therefore, when the risk cost coefficient exceeds a certain threshold, both EPC parties choose not to share. Only when the risk of knowledge sharing is reduced, the core competitiveness of the enterprise will not be affected, and the motivation of the enterprise to adopt knowledge sharing strategy will increase.

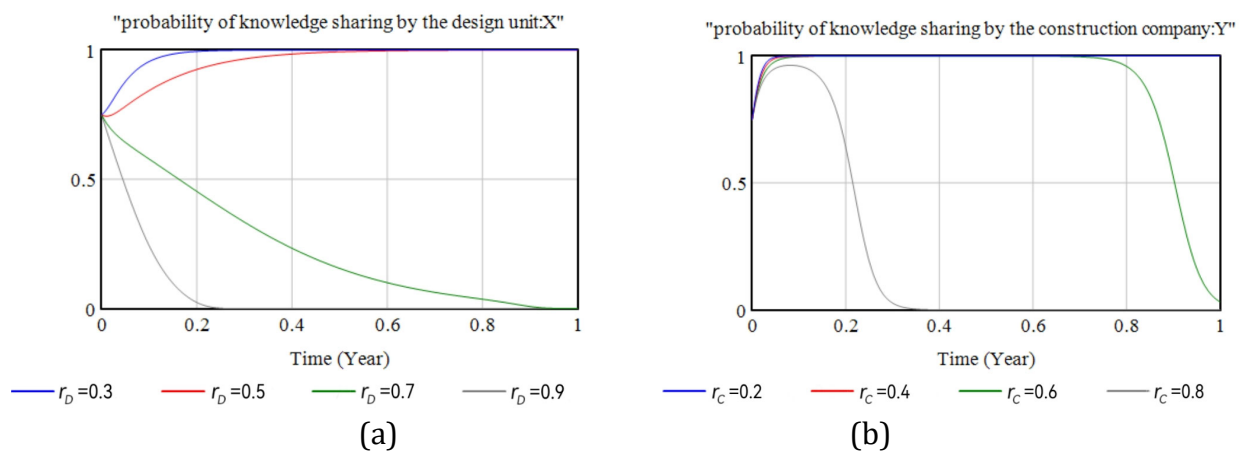


Figure 4. Influence of risk-cost coefficient on knowledge sharing strategies of EPC consortia

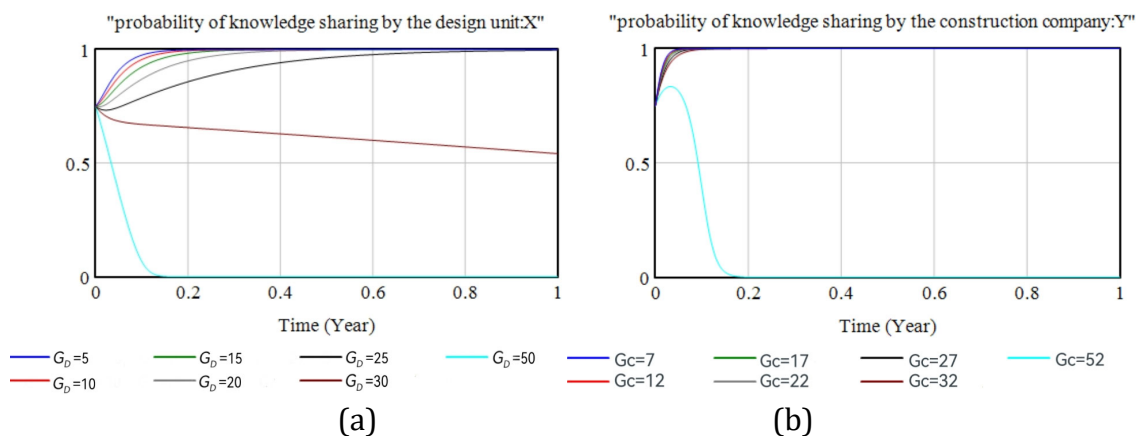


Figure 5. Impact of fixed cost on knowledge sharing strategy of EPC consortia

(4) Fixed Cost

The evolution of the fixed cost is consistent with the evolution of the cost risk factor, as shown in Figure 5, when the fixed cost G_D and G_C of knowledge sharing of EPC consortium members is higher, the enthusiasm of adopting knowledge sharing will be lower. According to the transaction cost theory, as the cost of knowledge increases, the benefit objectives of members' participation in knowledge cooperation cannot be compensated by the loss. In addition, the payback period of knowledge sharing in EPC projects is already long, and the design unit and the construction company not only need to send relevant technicians to share relevant

knowledge, but also need to cooperate with the optimization of on-site construction in the knowledge sharing cooperation. If for various reasons the increasing costs are not compensated by the improved project benefits, both parties will not take the initiative to implement the knowledge cooperation behavior again.

(5) Knowledge Complementarity Ratio

The complementary knowledge ratio represents the level of shared complementary knowledge and has a great influence on knowledge sharing behavior. As shown in Fi.6, when the value of the complementary knowledge ratio μ_D and μ_C is low, both EPC parties have a weak willingness to cooperate and even adopt a non-sharing strategy. This is because the knowledge provided by both parties does not have much impact on their own revenue, and it also leads to an increase in the sharing cost. When the value of the ratio of complementary knowledge μ_D and μ_C gradually increases, the willingness of both parties to cooperate increases. Because the proportion of complementary knowledge increases, both sides can get complementary resources from each other, that is, the design unit from the construction company to get the actual construction and management experience, the construction company can also be from the design unit to get the design expertise, the two strong combination, complement each other, not only to increase the revenue of the EPC project, but also enhance the probability of winning the bidding of the future project, to create new value. As the proportion of complementary knowledge increases steadily, the speed of system convergence to the stability point (1,1) is significantly accelerated, because the differentiated complementary knowledge creates higher synergy value, and the knowledge sharing model is more competitive for the EPC consortium partner companies, which also motivates the EPC consortium partners to carry out the cooperative sharing strategy. And from the slope of the graph, it can be seen that the construction company is more likely to be influenced by complementary knowledge than the design unit. As long as the ratio of complementary knowledge increases, the construction company is able to make sharing strategies more quickly. This is due to the fact that design is dominant in EPC projects, and studies have shown that design can affect costs by as much as 70%-95%, but design costs are much lower than construction costs. Therefore, the design unit is more dominant, and its willingness to share is weaker than that of the construction company when faced with a decision.

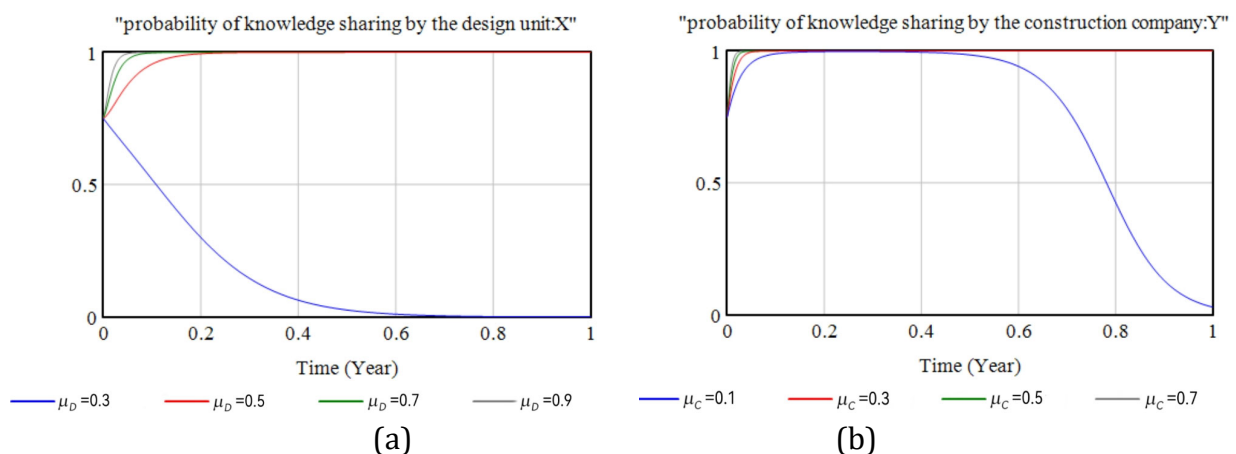


Figure 6. Influence of knowledge complementarity ratio on knowledge sharing strategy of EPC consortia

(6) Direct Benefit Coefficient

The direct gain coefficient is the embodiment of one enterprise's ability to absorb another enterprise's knowledge sharing. As shown in Fig.7, with the increase in the value of the direct

gain coefficient α_D and α_C , the knowledge transformation ability of the EPC consortium members also increases, and the knowledge sharing willingness of the design unit and the construction company is gradually weakened, but at this time the system still tends to be in a stable state of evolution of knowledge sharing. However, when the values of direct gain coefficients α_D and α_C continue to increase, the knowledge transformation ability is getting stronger and stronger, the knowledge sharing willingness of both parties decreases sharply, and the system eventually tends to the evolution of the stable state of non-sharing. This indicates that there is a specific threshold value for the direct benefit coefficient of the EPC consortium, and when the direct benefit coefficient is smaller than this threshold value, the evolutionary stable state of the system tends to (1,1) point, i.e., the design unit and the construction company will carry out knowledge sharing cooperation. On the contrary, the system evolution stable state tends to the point (0,0), and the two parties will not share cooperation. This is because knowledge, as a new type of factor of production, has been integrated into the economic value creation process along with other factors of production. Knowledge, as an important asset of an enterprise, has a certain spillover effect. If the partner's knowledge transformation ability is too strong, it will pose a potential risk to the knowledge sharer, which will most likely lead to the loss of the sharer's proprietary data advantage. In addition, if the former cooperative relationship breaks down and becomes a competitor, thus causing a loss of benefits to the knowledge provider. Therefore, the larger the direct benefit coefficient is, the weaker the willingness to share knowledge is under the effect of fairness perception.

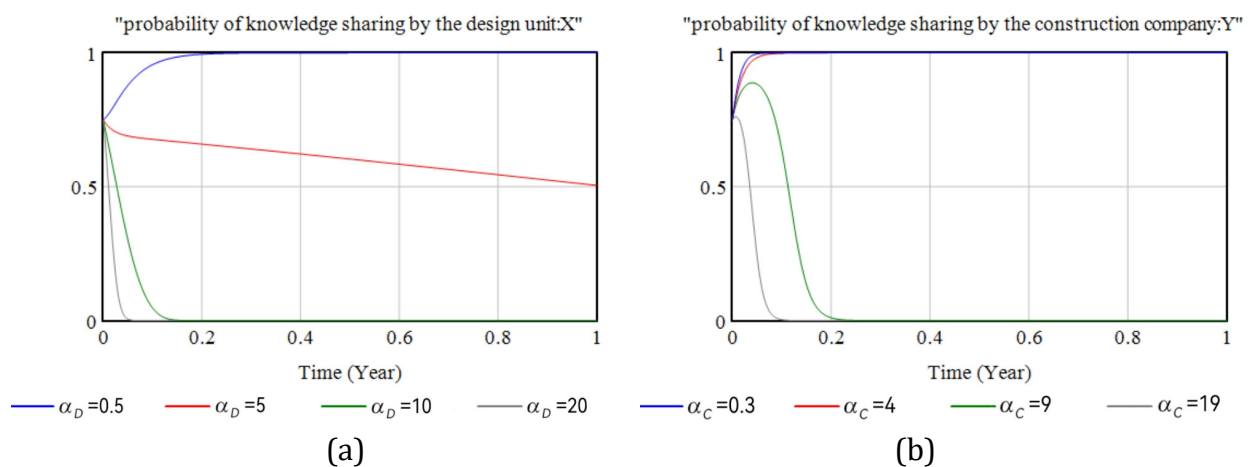


Figure 7. Effect of direct benefit coefficient on knowledge sharing strategy of EPC consortia

(7) Coefficient of Synergy Gains

The synergy gain of knowledge sharing reflects the degree of knowledge complementarity and trust between enterprises. As the values of synergy gain coefficients β_D and β_C increase, the willingness of both parties to share knowledge gradually increases, and finally reaches a stable state of knowledge sharing, as shown in Fig.8. This is due to the fact that in the process of EPC consortium cooperation, through knowledge sharing, both parties can learn new and creative things from each other, which is the performance of win-win cooperation, i.e., the knowledge provider not only makes the other party's interests improve, but also makes its own interests improve. Based on the principle of fairness perception, knowledge providers pay more attention to whether their own interests are enhanced, which is because when the collaborative benefits of enterprises are higher than the basic standard, improving the credibility of enterprise sharing behavior will play a positive role in the dynamic evolution of the whole network system. When the synergistic gain of knowledge sharing is high, enterprises will

generate more knowledge and new benefits through cooperative behavior, which will be conducive to improving the enthusiasm of enterprise knowledge sharing behavior. On the contrary, even though the initial probability of the design unit and the construction company is high, the enterprise synergy gain fails to reach the basic standard that meets the psychological expectation of the enterprise, and one of the two sides of the game fails to reach the expected total gain of knowledge sharing, and the system will inevitably evolve to (0,0). As a result, the cooperative state of knowledge sharing will collapse. Therefore, the stronger the learning ability of EPC consortium members' organizations, the more skillful they are in transforming and applying the absorbed external knowledge, the higher the internalization into commercial value, and the faster they adopt knowledge sharing strategies.

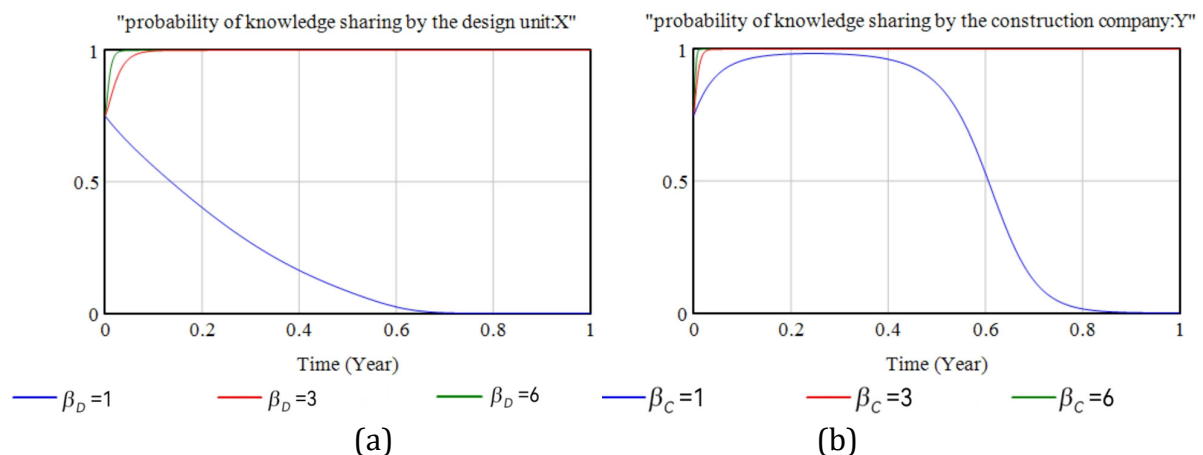


Figure 8. Effect of synergy gain coefficient on knowledge sharing strategy of EPC consortia

5. Results

The results of the study are shown below:

(1) The size of the initial probability of knowledge sharing between the two main players of the EPC consortium has a certain relationship with the evolution of the system. When the initial probability of knowledge sharing is low, both parties will not take the initiative to actively share their personal resources based on the attitude of "if you don't ask, I won't answer", and both of them will eventually choose the strategy of not sharing knowledge. When one party has a low initial probability of knowledge sharing but the other party has a high initial probability of knowledge sharing, the party with a low initial probability tries to adopt the behavior of "free-riding", which reduces the sharing cost and obtains more benefits, but the other party will also consider the leakage of the core knowledge and reduce the willingness to share the knowledge, thus failing to achieve the purpose of the formation of the consortium; however, the two parties will ultimately select the strategy of sharing the knowledge through the long-term decision-making and strategic adjustments. When the initial probability of knowledge sharing is high, it means that both sides of the consortium keep an open mind of mutual trust at the beginning, which is conducive to the development of the system in a favorable direction, and both sides will choose the knowledge sharing strategy more quickly, and the rate of convergence will increase with the increase of the initial probability.

(2) Combined with the numerical simulation of VENSIM PLE software, there exists a threshold value for the influence of fairness perception behavior on the selection of cooperation strategy of EPC consortium, and when the fairness perception coefficient of the subject is smaller than the threshold value of its own strategy selection, the system evolves a stable state of shared cooperation. However, with the enhancement of the role of fairness perception, the subject is more and more dissatisfied with the current distribution of benefits, and may destroy the

cooperation at the cost of damage to their own interests. The sharing cost will reduce the subject's willingness to cooperate, but the complementary proportion of knowledge provided by the other side of the EPC consortium will increase the subject's willingness to cooperate. With the improvement of the subject's knowledge transformation ability, the direct benefits of both sides of the EPC consortium will increase to different degrees, but due to the impact of the fairness perception behavior, comparing the increase in benefits and costs, both sides of the subject's perception of utility decreased, which also weakened the two sides of the willingness to cooperate. However, the increase in synergistic benefits brought by knowledge sharing has a facilitating effect on the adoption of knowledge sharing strategies by both sides of the EPC consortium.

6. Suggestions

(1) Focus on the construction of a big data sharing platform to improve the efficiency of knowledge integration. The higher the fixed cost and risk cost required by EPC consortium members for knowledge sharing, the weaker the willingness to share. By constructing a big data sharing platform, the transmission cost and knowledge mining cost in the process of data sharing can be reduced. At the same time, it improves its own heterogeneous knowledge stock and its ability to absorb and transform external knowledge, so as to cope with the risk of knowledge leakage and enhance the contracting ability of EPC consortium.

(2) Strengthen contract management and observe the spirit of contract. the level of initial willingness of EPC consortium members to share knowledge will affect the selection of subsequent cooperation strategies, so by formulating a reasonable prior contract to encourage members to maintain mutual trust and open-mindedness at an early stage, so as to avoid self-arbitrariness and opportunistic behavior in behavioral decision-making, which will be conducive to the development of the entire sharing system in a favorable direction.

7. Deficiencies

Each program is independent and individual, and this study relies heavily on specific situations, thus affecting the generalizability of the findings. The fairness concern coefficient is difficult to be accurately assigned and has certain limitations. The main body of the study only considers the two main game subjects of design and construction, and there are also more factors affecting the behavioral decisions of the limited rational person, such as reciprocal behavior, risk preference, etc., which limits the comprehensiveness of the analysis to a certain extent.

8. Deficiencies and Future Scope

Aiming at the problem of knowledge sharing behavioral strategy selection of EPC consortium members, this paper constructs a game model of EPC consortium knowledge sharing evolution based on fairness perception and performs numerical simulation with system dynamics, which concludes that the initial probability of knowledge sharing of EPC consortium members has a certain influence on the final selection of behavioral strategies. The influence of fairness perception, risk cost coefficient, fixed cost, knowledge complementary ratio, direct benefit coefficient and synergistic benefit coefficient on the choice of knowledge sharing behavioral strategies of EPC consortium members is analyzed, and suggestions for building a knowledge sharing platform and strengthening contract management are put forward. General engineering contracting is the key to the reform of the construction industry, which still needs to be studied more comprehensively, systematically and deeply. When expanding the research in the future, the influence of other stakeholders should be more comprehensively considered, and a multi-party game model close to the reality of life should be constructed. When assuming

a limited rational person, more consideration should be given to psychological and environmental factors to make the simulation results more convincing. When setting parameters, multi-context validation should be combined to make the research results more universal.

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