Analysis of the Evolution of Construction-Designer Cooperation Behavior Based on Incentive Mechanism Under the IPD Model

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Abstract. Based on the IPD model and the premise of the distribution incentive mechanism [1] given by the owner to the construction and design parties, this paper analyzes the evolutionary game between the construction and design parties, so as to find out the positive strategy to maximize the benefits of cooperation and the balance state of cooperation between the two parties. The results show that: Under this mechanism, the slow input of the initial energy of both parties and the preference of the owner for the designer's reward in the cooperation between the two parties have a promoting effect on the overall positive collaboration. Meanwhile, the constructor tends to save costs while the designer tends to create benefits. In the case of losses for both parties, the constructor has a stronger risk-bearing capacity and plays an important role in maintaining the positive stability of the designer.

Keywords: IPD model · Evolutionary game · Incentive mechanism · Cooperation

1 Introduction

In recent years, the domestic engineering industry has stabilized and various engineering project management models have emerged, with increasing owner requirements and project complexity. With the emergence of challenges in the industry and the improvement of project efficiency by various stakeholders, various problems have erupted due to the conflict of interest among various participants [2]. In order to further improve the overall quality of the project, scholars in the industry have transformed the integrated product development process into Integrated Project Delivery (IPD) [3], which is based on the combination of Building Information Modeling (BIM) [10] and engineering construction and design, and effectively integrates the individual participants in the general contracting management mode, greatly improving the efficiency of information exchange and problem handling among them [4].

In a comprehensive view, many scholars have different entry points for engineering projects under IPD mode, but their ultimate goal is to solve and optimize the effectiveness

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of the implementation process, mainly focusing on organizational structure, team, management ideas, communication, goals, decision making, contractual relationship, etc. [10]. Due to the complex structure between relevant stakeholders, even though some scholars have analyzed the factors influencing the cooperation dynamics of design and construction parties and how to coordinate, but still lack the operation mode under the established mechanism, and few scholars can improve the operation route of the optimized mechanism [5]. In this paper, we assume that the owner introduces an incentive mechanism to combine the construction and designers to operate under the established mechanism and construct an evolutionary model of their cooperative behavior to analyze the cooperative benefits of each major participant under the mechanism, so as to better select evolutionary strategies and optimization suggestions [7].

2 The Construction of the Evolutionary Model

2.1 Basic Assumptions of the Model

Main assumptions:

- Based on the "economic man" hypothesis, assume that every participant is measured by interest size stability [9].
- Assume that when one side of the two sides is negative synergy, the degree of the designer accepting the optimized project volume is the same as the proportion of the negative optimization of the constructor, i.e. q = r
- assumes that the parts optimized in the design phase of this paper can all be realized in the construction phase from obtaining the benefit allocation

Based on the assumptions and the mechanism of cooperation between the two parties [6], we can assume the following variables in Table 1.

Table 1 Relevant parameters of the model and their meanings

Parameter	Meaning
α	Revenue sharing coefficient based on the optimized design part
β	Economic benefit coefficient after design optimization
E	Knowledge benefit bonus
K0	Effort cost coefficient of the constructor
K1	Effort cost coefficient of the designer
K2	Allocation coefficient of knowledge benefits
K3	Allocation coefficient of loss
m	The amount of optimization submitted by the constructor
r	The extent to which the designer accepts the optimized work
q	The proportion of negative optimization by the constructor

Strategy analysis:

Both of them, including the owner, are pursuing profit maximization and can adjust their strategy choices through constant observation, comparison, trial and error under the situation of incomplete information. The proportion of "positive synergy" and "negative synergy" is X, and the proportion of "negative synergy" is X. The proportion of "positive synergy" strategy is X, and the proportion of "negative synergy" strategy is (1−X), where $0 \le X \le 1$. The designer also chooses "positive synergy" and "negative synergy", and the proportion of "positive synergy" strategy is Y. The proportion of "positive synergy" strategy is Y, and the proportion of "negative synergy" strategy is (1−Y), where $0 \le Y \le 1$ [8].

From the Table 2, it can be seen that the expected benefits of a positive synergy strategy for the construction unit U_1 are:

$$\begin{aligned} U_1 &= y(\alpha\beta m - \frac{1}{2}k_0 m^2 + k_2 E) + (1-y)(\alpha\beta mr - \frac{1}{2}k_0 m^2) \\ &= y[\alpha\beta m(1-r) + k_2 E] + \alpha\beta mr - \frac{1}{2}k_0 m^2 \end{aligned}$$

The expected benefits of a negative synergy strategy for the constructor U_2 are:

$$\begin{aligned} U_2 &= y[\alpha\beta mr - \frac{1}{2}k_0(mr)^2] + (y-1)k_3\beta m \\ &= -k_3\beta m + y[k_3\beta m + \alpha\beta mr - \frac{1}{2}k_0(mr)^2] \end{aligned}$$

From the two equations above, we know that the combined expected return of the construction unit is: $\overline{U} = xU_1 + (1-x)U_2$

Also further the replication dynamic equation for the constructor to adopt the synergistic strategy can be obtained as:

$$\begin{aligned} F(x) &= \frac{dx}{dt} = x(U_1 - \overline{U}) = x(1-x)(U_1 - U_2) \\ &= x(1-x)\{y[\beta m(\alpha - 2\alpha r - k_3) + \frac{1}{2}k_0(mr)^2 + k_2 E] + \beta m(\alpha r + k_3) - \frac{1}{2}k_0 m^2\} \end{aligned}$$

Table 2. Game gain-loss matrix

constructor	Designer	
	Positive synergy	Negative synergy
Positive synergy	$\alpha\beta m - \frac{1}{2}k_0 m^2 + k_2 E$, $(1-\alpha)\beta m - \frac{1}{2}k_1 m^2 + (1-k_2)E$	$\alpha\beta mr - \frac{1}{2}k_0 m^2$ $(1-\alpha)\beta mr - \frac{1}{2}k_1(mr)^2$
Negative synergy	$\alpha\beta mr - \frac{1}{2}k_0(mr)^2$, $(1-\alpha)\beta mr - \frac{1}{2}k_1(mr)^2$	$-k_3\beta m$, $(k_3-1)\beta m$

Similarly, the expected benefits of a positive synergy strategy for the designer $U_2^{'}$ are:

$$U_2^{'} = x[(1-\alpha)\beta mr - \frac{1}{2}k_1(mr)^2] + (1-x)[(k_3-1)\beta m]$$
$$(k_3-1)\beta m - x[(k_3-1)\beta m + (1-\alpha)\beta mr - \frac{1}{2}k_1(mr)^2]$$

In turn, the combined expected return of the design unit is obtained as:

$$\overline{U}^{'} = yU_1^{'} + (1-y)U_2^{'}$$

The replication dynamics equation for the design of the single-take synergistic strategy is:

$$F(y) = \frac{dy}{dt} = y(U_1^{'} - \overline{U}^{'}) = y(1-y)(U_1^{'} - U_2^{'})$$
$$= y(1-y)\{\beta m[(1-\alpha)r - k_3 + 1] - \frac{1}{2}k_1(mr)^2$$
$$+ x[\beta m(k_3-\alpha) - \frac{1}{2}k_1 m^2 + (k_3-1)E]\}$$

2.2 Equilibrium Point Stability and Strategy Analysis

Let F(x) = 0, F(y) = 0, we can get 5 local equilibrium points (0,0), (1,0), (1,1), (0,1),(x*,y*),

$$x^* = \frac{\frac{1}{2}k_1(mr)^2 - \beta m[(1-\alpha)r - k_3 + 1]}{\beta m(k_3-\alpha) - \frac{1}{2}k_1 m^2 + (k_3-1)E}$$
$$y^* = \frac{\frac{1}{2}k_0 m^2 - \beta m(\alpha r + k_3)}{\beta m(\alpha - 2\alpha r - k_3) + \frac{1}{2}k_0(mr)^2 + k_2 E}$$

The five equilibrium points of the construction and designers in the evolutionary game system of incentives will be divided into four regions, as shown in Fig. 1, respectively, I, II, III, IV

In the I area, there are 0<x<x*, 0<y<y*, $\frac{dx}{dt} < 0$, $\frac{dy}{dt} < 0$ which means that both x and y decrease in this area, in the II area, there are x*<x<1,0<y<y*, $\frac{dx}{dt} < 0$, $\frac{dy}{dt} > 0$ which means that x decreases and y increases, in the III area, there are x*<x<1,y*<y<1, $\frac{dx}{dt} > 0$, $\frac{dy}{dt} > 0$ which means that x increases and y increases, in the IV area, there are 0<x<x*,y*<y<1, $\frac{dx}{dt} > 0$, $\frac{dy}{dt} < 0$ which means that x increases and y decreases. In summary, the evolutionary trend of this cooperative game is shown in Fig. 2: from the Fig, we can find that the system eventually tends to (0,0) as well as (1,1) two points, that is, the constructor and the designer eventually choose positive synergy or negative synergy at the same time.

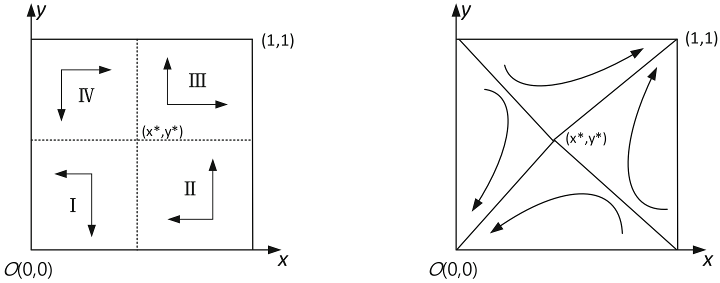

Fig. 1. Evolutionary trend diagram

3 Numerical Simulation and Analysis

The proportion of both sides choosing the initial behavior and the change of related parameters as the analysis of system evolution is explored, in order to meet the saddle point (x*,y*) falls on the interval (0,1) while ensuring that the trend line and phase diagram remain consistent, and combined with Professor Wei Guang Xing's research on complex projects [7] can set the relevant parameters as:

$$m = 1000, \beta = 0.3, \alpha = 0.5, q = r = 0.7, k_0 = 5 \times 10^{-4},$$

$$k_1 = 4 \times 10^{-4}, k_2 = 0.4, k_3 = 0.5, E = 200$$

Bringing the relevant parameters into the replicated dynamic equations F(X), F(Y) in MATLAB2022b gives

$$dydt(1) = y(1) * (1 - y(1)) * (-7.5 * y(2) + 5)$$
$$dydt(2) = y(2) * (1 - y(2)) * (-300 * y(1) + 157)$$

3.1 Effect of the Initial Behavioral Strategy

The willingness of constructors and designers to choose positive synergy is represented by x,y. The x-axis of this simulation is the time t, and the y-axis is the ratio y of the synergy strategy of the designer. Let x be 0.1, 0.3, 0.5, 0.7, 0.9, which form five different strategy combinations with y = 0.2, y = 0.3, respectively [11].

During the simulation, it is found that when $0.3 \leq y < 1$, the intention of the constructor and the designer for collaborative cooperation remains basically the same, when $x \leq 0.5$, i.e., when the probability of the constructor choosing positive collaboration is less than half, the designer is more willing to cooperate and reach agreement quickly, and when $x \geq 0.5$, i.e., the more the constructor tends to choose positive collaboration, the more the designer chooses negative collaboration. The evolutionary results are shown in the following Fig. 2.

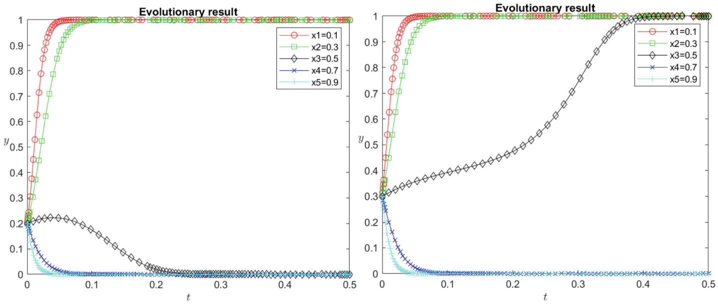

Fig. 2. Initial behavioral strategy

3.2 Effect of Effort Cost and Benefit Coefficients

As the effort cost coefficient increases, the cost of design and construction increases, and thus the more benefits should be obtained from the allocation. At this time, it is assumed that the larger the effort cost coefficient is, the larger the benefit coefficient is, so as to ensure that both sides can maintain positive synergy. The evolution of the effort cost coefficient and benefit coefficient are shown in Fig. 3.

In Fig. 3, the second and third one show that only $k_0 \geq 6 \times 10^{-4}$ when β increases, the builder changes from tending to negatively collaborate to slowly negatively collaborate or even to positively collaborate, while $k_0 \leq 6 \times 10^{-4}$ when β increases, it does not have as much impact on the builder as the cost factor decreases. This shows that the

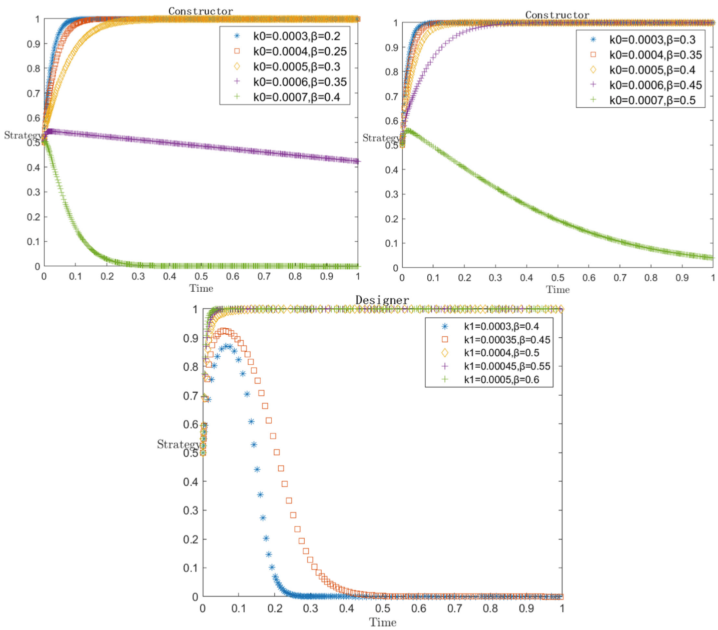

Fig. 3. Effort cost and benefit coefficients

constructors are more motivated to reduce the cost rather than share the benefit. As can be seen from Fig. 3, when β ≥ 0.5, the increase of k1 does not change the designer's attitude of choosing positive collaboration, while when β ≤ 0.5, the designer is still inclined to positive collaboration rather than negative at first, and gradually tends to y = 0 as t increases, which shows that the designer's motivation is more inclined to gaining benefits rather than saving costs. Therefore, under the premise that the parameters are reasonable based on the assumption that $k_0 = 6 \times 10^{-4}$, $k_1 = 4 \times 10^{-4}$, $\beta \in [0.4, 0.5]$ is the best choice.

3.3 Effect of Allocation Coefficient and Negativity

Under the established mechanism, the additional benefits and losses obtained by both parties from the project are shared, and the stability of the synergy is further improved by judging the negative degree of both parties and the evolution of the benefit distribution coefficient. Without considering the knowledge benefit (i.e., the owner's incentive) the change of the benefit sharing coefficient also affects the loss allocation coefficient to a certain extent, so the trend of co-evolution of the two is shown in Fig. 4.

From the Fig. 4, even when the gain coefficient is smaller than the loss coefficient, with the simultaneous increase of both, the constructor gradually approaches the direction of y = 1. When k3 = 0.6 and α equals to 0.45, the constructor completely tends to actively collaborate. For the designer, the lower α and the higher k3, the greatest benefit can be obtained, as can be seen from Fig. 5, when α ≥ 0.5, the designer completely tends to y = 0, i.e., negative synergy, and when α ≤ 0.5, with the simultaneous reduction of k3 of the simultaneous decrease, the probability of the designer choosing positive synergy shows a fluctuating distribution and cannot reach a steady state. From the above comparative analysis of construction and design, we can see that the constructor has a stronger ability to bear losses compared with the designer, which is more convenient for both sides to reach stability.

When there is a negative synergy between one of the design and construction parties, as the degree of negativity changes the two parties show an evolutionary trend as shown in Fig. 5.

For the designer, the smaller the value of r, the more cost the designer can reduce is greater than the income from distribution, so the designer tends to actively cooperate. For the construction side, the higher the R-value, the more efforts to submit the

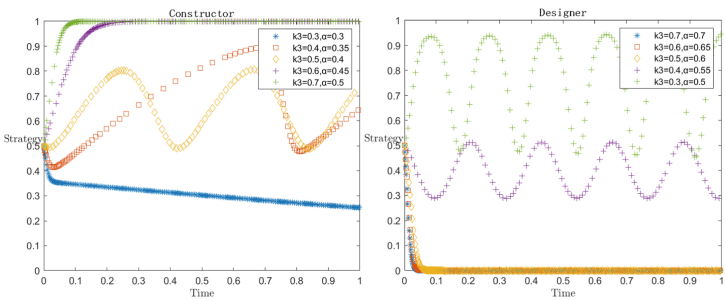

Fig. 4. Allocation coefficient

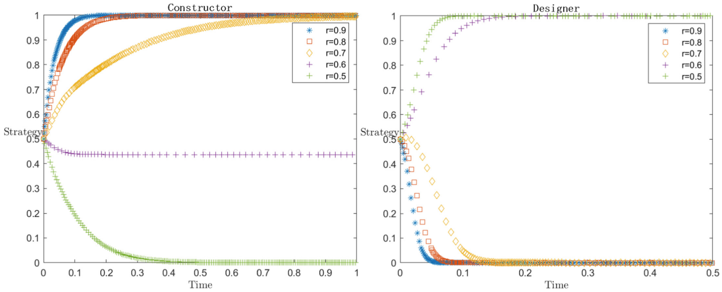

Fig. 5. Negative degree

complete optimization engineering quantity and the designer actively cooperate with the optimization design, the benefits can be far more than the optimization cost, so tend to actively cooperate. In order to ensure the stability of cooperation, it is necessary to properly adjust the knowledge benefit distribution of the designer.

Since this paper assumes q = r for the sake of simplifying the model and at this time, in order to ensure the stability of the synergy between the two sides, we should ensure that the incentive amount is allocated more reasonably as much as possible, at this time, for the benefit function of the designer, when q < r, we can get $\frac{1}{2}k_1(mq)^2\langle\langle(1-\alpha)\beta mq$, which saves the cost for the designer, so when the degree of negative synergy of the constructor is smaller than that of the designer, the value of k2 can be increased appropriately to balance the incentive.

4 Conclusion

This paper is based on IPD engineering model as the background, and uses the theory and method of the evolutionary game to analyze the cooperation strategy choice of the main stakeholders in Chinese general engineering under the established mechanism, as well as the specific factors affecting the positive or negative cooperation between the two parties, and the parameter range of each factor is roughly determined through simulation analysis [12].

The analysis proves that strengthening the active cooperative cooperation between the constructor and the designer under the incentive mechanism has a positive effect on promoting the project benefit, and can maintain the cooperative stability of both sides through a dynamic adjustment strategy. The analysis results show that under this mechanism, both parties should strive towards the direction of positive collaboration, but it should be gradual in the early stage of the project, and the dynamic adjustment of the enthusiasm of both parties in the whole life cycle can improve the stability of the collaboration. The initial cooperative enthusiasm of the constructor determines the subsequent cooperative trend to a large extent. The risk of construction cooperation lies in that the optimization design investment is greater than the gain, while the enthusiasm of the designer cooperation is not in the design investment, but in the optimization of benefit distribution. The higher the degree of negative optimization of the constructor, the less the effort cost, and the higher the enthusiasm of the constructor, while the higher the degree of negativity of the designer, the higher the process tends to be negative collaboration, and the stronger the ability of the constructor to bear the loss compared with the designer, when the degree of negative optimization of the constructor.

References

1. Wang Yujie, Su Zhenmin, She Xiaojie. Design and Analysis of Project team Incentive Mechanism under IPD model [J]. Journal of Engineering Management, 2013, 27(04):72–76.
2. Chang Tao, Jiang Fengcheng. Research on the Evolution Game of Cooperative Innovation between General Contractor and Subcontractor in large complex engineering [J]. Heilongjiang institute of engineering journal, 2022, 4 (02): 37–44, https://doi.org/10.19352/j.cnki.issn1671-4679.2022.02.007
3. Liu Kai. Evolutionary Game Study on Collaborative Behavior of Project Stakeholders under IPD Model [D]. Shandong university of science and technology, 2020. https://doi.org/10.27275/dcnki.Gsdku.2020.000861
4. Ouyang Jing. Evolutionary Game Analysis of IPD project stakeholder cooperation relationship [D]. Lanzhou Jiaotong University, 2018.
5. Ma Zhiliang, Ma Jiankun. Eliminating quantitative incentive mechanism of architectural engineering design change [J]. Journal of Tongji University (Natural Science), 2016, 44(08):1280–1285.
6. GAO Binkai. Research on Collaborative Management of Engineering Projects Based on BIM Technology and IPD Model [D]. Xi 'an Technological University.
7. Wei Guangxing, Wan Xinyi. Interactive Optimization of complex Transportation Project Design and construction based on Equity Concerns [J]. Journal of Wuhan University of Technology (Information and Management Engineering Edition), 2022, 44(01):84–90.
8. Yan Hongyan, Guo Ruitao, Zhou Chunmei. IPD project team trust model and the dynamic evolution mechanism structure [J]. Journal of building economy, 2020, 9(5):104–108. https://doi.org/10.14181/j.cnki.1002-851x.202005104
9. EL Mounla Karim, eladjine Djaoued, eddiar Karim, azari Bélahcène. Lean-BIM Approach for Improving the Performance of a Construction Project in the Design Phase [J]. Buildings, 2023, 13(3).
10. Mesa H A, Molenaar K R, Alarcon L F. Exploring performance of the integrated project delivery process on complex building projects [J]. International Journal of Project Management, 2016, 34(7):1089–1101.
11. Kai L, Yl B, Hza B, et al. Evolutionary game and numerical simulation of participants' collaborative behavior in integrated project delivery project [J]. Alexandria Engineering Journal, 2020.
12. Du Y, Zhou H, Yuan Y, et al. Exploring the Moral Hazard Evolutionary Mechanism for BIM Implementation in an Integrated Project Team [J]. Sustainability, 2019, 11.