Hindawi
Complexity
Volume 2018, Article ID 5698170, 11 pages
https://doi.org/10.1155/2018/5698170

Research Article

The Complexity and Simulation of Revenue Sharing Negotiation Based on Construction Stakeholders

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Received 22 May 2018; Accepted 12 July 2018; Published 2 August 2018

Academic Editor: Shoujun Huang

This paper focuses on the complexity characteristics of a stakeholder's revenue sharing for time compression in construction projects, such as adopting a life cycle perspective, the preferences of stakeholders, and the adaptability behaviors in the negotiation process. We build an agent-based model on revenue sharing negotiation. Considering that the agents who are in a weak position not only care about their own benefits but also compare their benefits to others, we design an experimental scenario where a contractor has fairness preference based on China's reality. According to different sympathy and envy coefficients, we can divide the inequity aversion preference into three typical types, and we research how a contractor's different types of inequity aversion preferences impact revenue sharing coefficient of agreements, results of successful negotiations, and efficiency in negotiations. Results are as follows: it is advantageous for a contractor to maintain a modest inequity aversion for their own earnings and the degree of sympathy preference in inequity aversion has an important impact on the time to reach consensus while the degree of jealousy preference has no obvious effect. If contractors' sympathy preference is maintained within a moderate range, it will achieve a higher success rate of negotiations in the negotiation process; the success rate of negotiation is affected largely by the agents' sympathy preference, though it is also influenced by the jealousy preference, but it is not very sensitive.

1. Introduction

The multiobjective optimization of construction projects, such as time, cost, and quality, has always been an important topic in the field of project management. The length of the construction period has a significant influence on economic, social, and ecological benefits of the project. It is well known that there are a strong interdependence and constraint among construction time, cost, and quality. The revenue of the system will be improved through investing a reasonable capital to cut down construction time, which puts the project into operation as soon as possible. In this process, if multiple objectives which included construction time compression, project quality, construction costs, and maintenance costs cannot be coordinated well, some problems such as quality accidents, engineering waste, and cost overrun will be happen. For example, the third Qiantang River Bridge in China was built fast and was complicated due to a shortage of funds, leading to an expensive repair after 8 years and a collapse accident in 2011. In addition, because of unreasonable compression in construction time, "the shortest lifetime" road in Yunnan Province, the "protection room demolition incident" in China, and the "11.15 fire incident" in Shanghai apartment are bringing immeasurable loss.

In the construction process, there are many complex challenges that make the decision to have a reasonable construction time scheme difficult. For example, the owner may provide an optimization scheme in an administrative and commanding manner. On the one hand, the owner does not have the professional ability to evaluate the technology, difficulty, and environment of the construction, so this sometimes perhaps leads to an unreasonable scheme of construction optimization time. On the other hand, the owner has serious asymmetric information about the cost and quality of the construction, and the contractor may employ this asymmetric information to produce the corresponding moral hazard. Thus, how the owner should encourage the contractor to make a reasonable construction compression time scheme on the basis of ensuring the quality of the project is an important and urgent problem that needs to be solved during the process of construction management.

In order to coordinate the complex conflicts of interests among stakeholders, in current construction practice, the decision mode of construction time compression is changing from the traditional administrative control to the negotiation based on revenue sharing. The revenue sharing ideas are widely introduced into the construction management practice and theoretical research. These ideas try to gain high benefits through the joint effort of both parties (principle-agent) and then distribute benefits through negotiating between the owner and the contractor, so as to eliminate the contractor's moral hazard and improper motives. It is different from the traditional passive control or command and other incentives and is more concentrated on "win-win" cooperation. Therefore, the negotiation result of the owner and the contractor on the increasing system benefits from construction time compression will be one of the most important factors that affect the decision quality of construction time compression.

However, during the process of time compression negotiation, the stakeholders all have very complex behavioral preferences. Behavioral science research shows that the subjects tend to show greater concern about fairness, that is, the characteristics of fair concern. Under the fairness concern influence, the subjects may punish the other parties even at the expense of their own benefits when they feel unfair. Many empirical or experimental studies have proved that people have this irrational behavior. In the negotiation process about construction time compression, the distribution and comparison of benefits will trigger the perceptions of fairness between the owner and the contractor, which will have a significant impact on the negotiation process and results. In addition, many scholars found that the subjects who are in a weak position not only care about their own benefits but also compare their benefits to others [1, 2]. In the construction practice of China, the contractor is in a weak position generally compared with the owner. Therefore, if the owner hopes to motivate the contractor to compress the construction time effectively on the basis of guaranteeing the quality of the project, so as to increase its own benefits, the owner must not ignore the impact of the contractor's inequity aversion behavior on the result of the negotiations.

Based on these, this paper is based on the view of the whole life cycle of the project, considering the unfairness aversion of the contractor, the revenue sharing negotiation process, and the results about construction time compression. Further, we subdivided unfairness aversion preference into sympathy preference and jealous preference and analyzed the impact of different combination degrees of the sympathy preference and jealous preference on the revenue sharing coefficient, the success rate, and the time of the negotiation. It is aimed at clarifying the influence mechanism of unfairness aversion preference of the contractor on the negotiation process and results about construction time compression. So it is of great importance to make the causes of negotiation results clear, control and encourage the contractor to carry out some related actions, and then make scientific and reasonable decisions on construction time compression and realize the multiple-objective coordination of construction time, cost, and quality of the project.

The subjects are with independent decision-making ability and the heterogeneity characteristic that they can adjust their behavior according to the strategy change of the opponent and their own fairness perception. As a result, the interaction among subjects often shows a nonlinear, dynamic relationship. In addition, because the negotiation process has multiple stages and uncertainties, we adopt a multiagent modeling method to build the negotiation model for construction time compression. Various system behaviors and phenomena will "emerge" from bottom to top through the interaction of agents who negotiate with each other. By constructing a controllable and reproducible computational model, we analyze the influence of the changing parameters which we are interested in on the strategy selections and performance of subjects. At last, we obtain some positive management implications through the comparative analysis of experimental results.

Compared with the existing research, this paper has the following contributions and innovations:

First of all, decision-making for construction period compression is generally translated into the trade-off mathematical optimization problem, and few researches focus on the process and results of revenue sharing negotiation between the owner and contractor.

Second, it is assumed that both parties are the rational economic man, who seek to maximize their economic benefits, and did not consider the impact of fairness preference on the negotiation behavior. At present, researches of fairness preferences are mainly of concern in the field of operation management, and few literatures have introduced fairness preference into the field of construction project management, especially in the process of revenue sharing negotiation for the time compression in construction projects.

In addition, there is no subdivision of a particular preference in current researches. In this paper, we subdivide the inequity aversion preference into the sympathy preference and envy preference and divide the inequity aversion preference into three typical types according to different sympathy and envy coefficients, and we research how the contractor's different types of inequity aversion preferences impact results of negotiations.

The remainder of this paper is structured as follows. Section 2 presents a brief review of the literature on time-cost optimization in construction, negotiation in construction, and fairness preference. Section 3 describes our simulation model and experiment design in detail. Section 4 presents the results of the simulation studies. Section 5 summarizes the insights gained from this study.

2. Literature Review

The importance of construction time compression has been widely recognized by the construction industry. Scholars have studied this problem generally based on time-cost trade-off analysis, so a variety of optimization algorithms have been developed to find the optimal solution [3]. For example, Liu and Rahbar presented an innovative technique that can be used to automate and optimize the time-cost trade-off process [4]. Ghoddousi et al. considered a multi-mode resource-constrained project scheduling problem, discrete time-cost trade-off problem, and also resource allocation and resource leveling problem simultaneously [5]. Li and Wu addressed a time-cost trade-off problem under uncertainty, in which activities in projects can be executed in different construction modes corresponding to the specified time and cost with interval uncertainty [6]. Zhang et al. improved the traditional cost-time model by taking reward and punishment into consideration [7]. Jeang adopted an approach that uses computer simulation and statistical analysis of uncertain activity time, activity cost, due date, and project budget to address the quality and learning process with regard to project scheduling [8]. Ashuri and Tavakolan presented a shuffled frog-leaping model to solve complex time-cost-resource optimization problems in construction project planning and considered the simultaneous optimization of three important objective functions [9]. Liu et al. proposed a method based on PRT-net for time performance optimization, which is a Petri net-based formulism tailored for a kind of project constrained by resource and time [10].

The studies mentioned above about construction period optimization require the centralized decision-making and seek the optimal scheme under the multiobjective constraint, and few researches focus on the process and results of revenue sharing negotiation for construction period optimization. However, in current construction practice, the decision mode of construction time compression is changing from the traditional administrative control to the negotiation based on revenue sharing. Negotiation has become one of the important decision-making modes for construction time compression, and some scholars have studied the problem of negotiation in construction projects.

For example, Liou and Huang incorporated risk attributes of the BOT project into the formulation of a contractual negotiation model, and the proposed model allows the government and the sponsor to reach a consensus on the terms should the financial return as well as the risk of the project be determined [11]. Koskinen and Makinen addressed the question of what sort of role do boundary objects play in negotiations of contracts in the project business context [12]; Yousefi et al. presented an innovative negotiation methodology for managing conflicts in construction projects where multiple decision-makers are involved [13]. Cheung and Chow uncovered the underlying factors affecting withdrawal in construction project dispute negotiation from a behavioral perspective [14]. Kang et al. developed a royalty negotiation model for BOT projects [15]. Chow et al. studied the behavioral primers that trigger the sudden withdrawal in construction project dispute negotiation [16]. Lu and Liu explored the moderating effects of progress and quality performance on the relationship between bargaining power and its critical factors [17]. Wang et al. proposed a risky project negotiation framework, comprising fuzzy real options, ordered weighted averaging, and the graph model of conflict resolution [18]. Zhu et al. developed a bargaining model of agent-based debt terms that simulates the negotiation process and improves the negotiation inefficiency [19].

The abovementioned research on project negotiations involves few revenue sharing negotiations for construction time compression, and it is assumed that both parties in negotiation are the rational economic man and less consider that the agents have a fairness preference. Therefore, few literatures have introduced fairness preference into the field of construction project management, especially in the process of revenue sharing negotiation for the time compression in construction projects. Now, researches of fairness preferences are mainly of concern in the field of supply chain management.

For example, Cui et al. showed that when channel members are concerned about fairness, the manufacturer can use a simple wholesale price above their marginal cost to coordinate this channel [1]. De Bruyn and Bolton deemed that the strength of bargainers' preferences for fair settlements has important implications for predicting negotiation outcomes and guiding bargaining strategy [20]. Katok et al. found that inequality aversion has by far the most explanatory power regarding retailers' behavior [21]. Yang et al. considered a distribution channel consisting of a single manufacturer and a single retailer and investigated the effect of the retailer's fairness concerns [22]. Du et al. investigated the newsvendor problem for a dyadic supply chain in which both the supplier and the retailer have the preference of status seeking with fairness concerns [23]. Wu and Niederhoff studied the impact of fairness concerns on supply chain performance in the two-party newsvendor setting [24]. Li and Jain studied the impact of consumers' fairness concerns on firms' behavior-based pricing strategy, profits, consumer surplus, and social welfare [25]. Qin et al. investigated how fairness concerns influence supply chain decision-making, while examining the effect of private production cost information and touching on issues related to bounded rationality [26]. Choi and Messinger found the significant role of fairness in competitive supply chain relationships, even in a scenario that is designed to favor one supply chain member over the others [27].

In summary, there is no subdivision of a particular preference in current researches. In this paper, we subdivide the inequity aversion preference into the sympathy preference and envy preference and divide the inequity aversion preference into three typical types according to different sympathy and envy coefficients, and we research how the contractor's different types of inequity aversion preferences impact results of negotiations.

3. Revenue Sharing Negotiation Model for Time Compression

We summarize all the symbols and abbreviations and put them in Table 1, so as to make it easier for readers to get a better understanding of their meaning.

3.1. The Agents' Revenue and the Time Compression Model. Optimization of construction time can bring the project into operation as soon as possible, thereby increasing operating income. Figure 1 shows the logical relationship between time compression and system revenue.

The increased system revenue (π_t) is calculated in (1), in which p_o represents the unit time income for operations of construction, t_p represents the planned construction period, and t_t represents the optimized construction period ($t_t < t_p$).

$$\pi_t = p_o\left(t_p - t_t\right). \tag{1}$$

The π_t will be assigned by the owner and the contractor through the revenue sharing contract, and the allocation results depend on the negotiation game between two bodies. We assumed that the contractor derives Φ proportional revenue from the π_t and the owner obtains the remaining portion. The owner's profit π_o and the contractor's profit π_c are calculated in (2) and (3), where c_o and c_c represent the costs of the owner and the contractor to optimize the time limit for a project, respectively.

$$\pi_o = (1 - \Phi) \cdot \pi_t - c_o, \tag{2}$$

$$\pi_c = \Phi \cdot \pi_t - c_c. \tag{3}$$

The negotiation for construction time optimization between the owner and contractor should be considered in certain constraint conditions. Firstly, time compression must ensure the quality of the project. Assume that the minimum quality standard required for the project is Q_l, the planned quality standard is Q_p, the project quality after time optimization is Q_t, and $Q_t \geq Q_l$ needs to be met. To a certain extent, time optimization may affect the quality of the project and then affect maintenance costs during the project operation. Suppose that the increased owners' maintenance cost ratio due to the quality of project is γ_t; according to the literature [28], $\gamma_t = (1 - Q_t)/Q_t$, that is, the maintenance cost ratio is closely related to the project quality. Assume that the planned project operation cycle is L and the owner's maintenance coefficient of quality cost is μ_o; thus, the impact of different options of time optimization on the owners' postmaintenance costs (c_o) has a difference effect, as shown in

$$c_o = \mu_o \gamma_t \left(L + t_p - t_t\right) - \mu_o \cdot \left(\frac{1 - Q_p}{Q_p}\right) \cdot L. \tag{4}$$

In addition to reducing the quality of the project and thereby affecting the owners' maintenance cost, time optimization also affects the construction cost of contractors, generally considering that the shortening of construction time will lead to an increase in construction cost. And according to the literature [29], the relationship between the time limit for a project (t_t) and cost (c) is $c = m \cdot e^{-\lambda t_t}$, in which $m, \lambda > 0$ indicate the influencing factor of the duration of the project under the corresponding characteristics of the project; thus,

Table 1: The meaning of the parameters in the model.

Parameter	Description
π_t	The increase in system revenue
p_o	The per unit of time revenue of the project operation
t_p	The planned construction period
t_t	The optimized operation period
π_o	The owner's profits
π_c	The contractor's profits
Φ	The contractor obtains the proportional benefit from the π_t
c_o	The cost that the owner must pay to optimize the timescale of a project
c_c	The cost that the contractor must pay to optimize the timescale of a project
Q_l	The minimum required quality standard for the project
Q_p	The planned quality standard
Q_t	The project quality after construction period optimization
γ_t	The owner's increasing maintenance expense ratio due to the quality factor
L	The original planned project operation cycle
μ_o	The maintenance coefficient of the owner's quality cost
m, λ	The impact factor of construction time on cost
η, δ	The impact factor of construction time on quality
t_l	The shortest construction time corresponding to the minimum quality requirements
π_c	The contractor's profit in the time optimization process
t_t^*	The optimal construction period
α	The weight parameters when the contractor's profit is greater than the owner's
β	The weight parameters when the contractor's profit is smaller than the owner's
v	The change magnitude of Φ
$N(t)$	The experience weight
ρ	The historical experience discount factor
$A_i^s(t)$	The attractiveness index of strategy s to agent i
ω	The discount factor of $A_i^s(t)$
$U_i^s(t)$	The expected utility of strategy s adopted by agent i at time t
∂	The weight of the subject's emphasis on the strategy
$I(s)$	It shows whether agent i adopts strategy s
ψ	The sensitivity of $A_i^s(t)$ in strategy selection

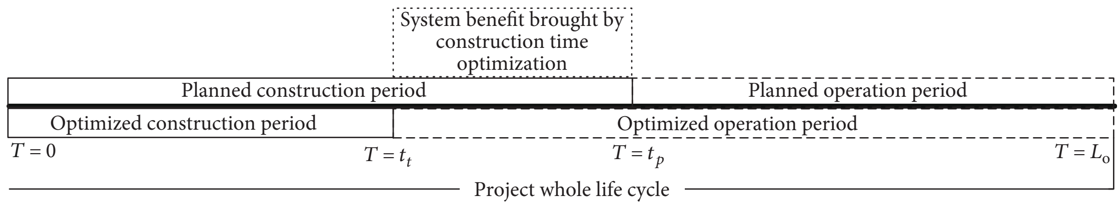


Figure 1: The impact of construction time compression on the system revenue.

it can be seen that the cost to be paid by the contractor in the optimization process is shown in

$$c_c = m \cdot \left(e^{-\lambda t_t} - e^{-\lambda t_p} \right). \tag{5}$$

According to the literature [30], there is a positive correlation between project quality and construction period. Generally, the project quality level is expressed by $[0, 1]$. Under the same conditions, the longer the construction period, the higher the quality of the project, infinitely close to 1. In the process of optimization, the time cannot be infinitely compressed due to the constraints, such as project quality, cost, and other factors. The relationship between project quality (Q_t) and construction time (t_t) is shown in

$$Q_t = \eta \cdot \ln\left(\delta \cdot t_t\right). \tag{6}$$

In (6), $\eta, \delta > 0$ represent the factors of the impact of project time on the quality, which can be solved by two sets of variables $(1, t_p)$ and (Q_l, t_l) into the equations, in which t_l represents the shortest construction time corresponding to the minimum quality requirements Q_l of the project. Substituting (6) into (4), we can further refine the owner's maintenance cost. By combining (1), (3), and (5), the contractor's profit (π_c) can be obtained during the optimization of the construction period, as shown in

$$\pi_c = \Phi p_o \left(t_p - t_t\right) - m\left(e^{-\lambda t_t} - e^{-\lambda t_p}\right). \tag{7}$$

In summary, the system-increased profits π can be expressed as $\pi = p_o(t_p - t_t) - c_o - c_c$. The first derivative of t_t is

$$\frac{d\pi}{dt_t} = -p_o - \mu_o \cdot \left[\frac{t_t - L - t_p}{t_t \cdot \eta \cdot \ln^2(\delta \cdot t_t)} - \frac{1}{\eta \cdot \ln\left(\delta \cdot t_t\right)} + 1 \right] + m \cdot \lambda \cdot e^{-\lambda t_t}. \tag{8}$$

The second derivative of t_t is

$$\frac{d^2\pi}{d{t_t}^2} = -\mu_o \cdot \frac{2\left(L + t_p - t_t\right) + \left(L + t_p\right) \ln\left(\delta \cdot t_t\right)}{t_t^2 \cdot \eta \cdot \ln^3(\delta \cdot t_t)} - \mu_o \cdot \frac{1}{t_t \cdot \eta \cdot \ln^2(\delta \cdot t_t)} - m \cdot \lambda^2 \cdot e^{-\lambda t_t}. \tag{9}$$

Since $Q_t = \eta \cdot \ln\left(\delta \cdot t_t\right) > 0$, $\eta > 0$, and $\ln\left(\delta \cdot t_t\right) > 0$, therefore $(d^2\pi/d{t_t}^2) < 0$; the system has the optimal solution of time optimization t_t^*, making $m \cdot \lambda \cdot e^{-\lambda t_t} - p_o - \mu_o \cdot [(((t_t - L - t_p)/(t_t \cdot \eta \cdot \ln^2(\delta \cdot t_t))) - (1/(\eta \cdot \ln\left(\delta \cdot t_t\right))) + 1] = 0$. Thus, as shown in (10), the value of time optimization t_t can be further analyzed.

$$t_t = \begin{cases} t_l, & \text{if } (t_t^* \le t_l), \\ t_t^*, & \text{if } \left(t_l < t_t^* < t_p\right), \\ t_p, & \text{if } \left(t_t^* \ge t_p\right). \end{cases} \tag{10}$$

When $t_t^* \le t_l$, the optimized time cannot be less than t_l, and at this time, $t_t = t_l$ due to the constraint Q_l of the lowest standard of project quality. When $t_t^* \ge t_p$, there are no optimization for the time and no increased profits for the system. When $t_l < t_t^* < t_p$, the time optimization scheme could make the system profit maximize, and with a centralized decision-making, the owner and contractor select the construction period which can make the π maximize; thus, this means $t_t = t_t^*$.

3.2. Inequity Aversion Model. Under the influence of unfairness aversion, the agents not only care about their own profits but also care about differences in income from other agents' profits. In this paper, we characterize the agent's unfairness aversion preference based on the utility function proposed in literature [31]. Numerous scholars found that agents in a weak position, in addition to paying more attention to their own profits, are much willing to compare with other agents [2, 32]. In China's project practice, compared to the owner, the contractor generally is in a weak position. Therefore, this paper considers a more realistic situation; that is, it considers the effects on negotiation for time optimization when the contractor has inequity aversion preference. The contractor's utility function is shown in

$$U_c(\pi_c) = \begin{cases} \pi_c + \alpha \cdot (\pi_o - \pi_c), & \pi_o < \pi_c, \\ \pi_c + \beta \cdot (\pi_o - \pi_c), & \pi_o > \pi_c. \end{cases} \tag{11}$$

It can be seen that the contractor's utility is the weighted average of their own income and differences in profit distribution, while in reality, the owner occupies a strong position and is only concern about their own income; thus, $U_o(\pi_o) = \pi_o$. According to Charness and Rabin [33], they proposed the types of inequity aversion, and [33] assumed that the weight parameter α when the contractor's profit is greater than the owner's profit and the weight parameter β when the contractor's profit is less than the owner's income are both within the interval $[-1, 1]$; $-1 < \beta < 0 < \alpha < 1$, in which α represents the "sympathy" coefficient (the contractor's revenue is higher than the owner's; this will bring a higher negative effect for the contractor, i.e., "get

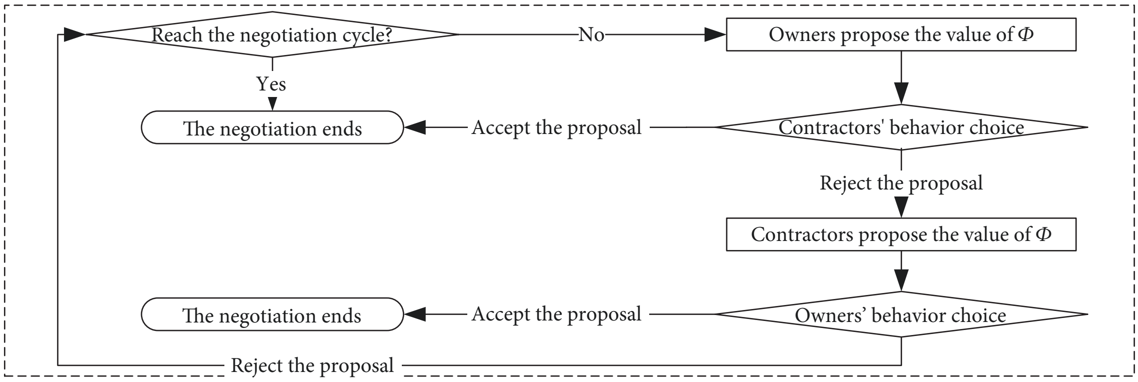


FIGURE 2: Negotiation processes between the owner and contractor.

more also upset") and β stands for the "jealous" coefficient (when its absolute value is greater, the more jealous preference is observed if the owner's income is higher than the contractor's; this will provide a greater negative effect).

3.3. Agent Negotiation Process and Learning Model. The negotiation between the owner and contractor will follow the sequential negotiation rule, which is one of the most common bargaining in practice. Due to some constraints, such as $Q_o \geq Q_l$, $t_t < t_p$, $\pi_o > 0$, and $\pi_c > 0$, it will result in a negotiable feasible domain interval for the revenue sharing coefficient; that is, $\Phi \in [\Phi_{min}, \Phi_{max}]$. For different behavioral preference types corresponding to Φ_{min}, Φ_{max}, they are to be analyzed in detail in Section 3.2.

In the negotiation process for time optimization, the owner puts forward a value of Φ first and then the contractor decides whether to accept it or not. If the contractor refuses, the contractor will put forward a new one and then the owner decides whether to accept it or not. The owner and the contractor start the proposal from Φ_{min} and Φ_{max}, respectively, and for each proposal, the owner increases the value of Φ by the magnitude of v; on the other hand, the contractor reduces the Φ by the magnitude of v. The negotiation is a success when one party accepts the other party's proposal. This paper assumes that the negotiation process is limited; actually, the negotiation cycle involves a certain cost of negotiations, so it is assumed that the negotiation fails when one party quits or the negotiation lasts over a certain period. So $v = (\Phi_{max} - \Phi_{min})/T$, in which T is the negotiated fixed period, and the negotiation fails if both parties fail to reach an agreement in the cycle T. The negotiation process is shown in Figure 2.

In the negotiation process, the owner and the contractor both have three kinds of behavior strategies:

Strategy 1. Accept the value of Φ proposed by the other party, this Φ determines the expected utility of the agent, and then the negotiation reaches an agreement.

Strategy 2. Reject the value of Φ put forward by the other party and then propose a new one. At this time, the expected utility is the one corresponding to the new value of Φ.

Strategy 3. Exit negotiations. In this case, the expected utility is zero.

In reality, both parties of the negotiation show the characteristics of learning and intelligence and so on; that is, agents can adjust their decision and behavior according to the situation, their experience, and the expectations of strategies. In this paper, the EWA learning algorithm [34] is adopted to characterize the learning and intelligence of the agents. Each of the three behavioral strategies above is assigned an attractive index, and the probability of each strategy being selected is computed based on certain rules. Therefore, based on the EWA algorithm, we can describe the experience accumulation process of the agents, as shown in (12), where $N(t)$ denotes the experience weight, ρ is the historical experience discount factor, $A_i^s(t)$ is the attractiveness index of the strategy s to the agent i, ω represents the discount factor of $A_i^s(t)$, $U_i^s(t)$ expresses the expected utility of the strategy s adopted by the agent i at time t, ∂ is the weight of the subject's emphasis on the strategy, and $I(s)$ means that the agent i whether adopts the strategy s or not.

$$\begin{aligned} N(t) &= \rho N(t-1) + 1, \\ A_i^s(t) &= \frac{\{N(t-1)\omega A_i^s(t-1) + [\partial + (1-\partial)I(s)]U_i^s(t)\}}{N(t)}. \end{aligned} \tag{12}$$

$I(s) = 1$ or $I(s) = 0$, respectively, represents the situation where the strategy s is adopted or not at the time t, and the corresponding attraction is calculated in

$$\begin{aligned} A_i^s(t) &= \frac{\{N(t-1)\omega A_i^s(t-1) + U_i^s(t)\}}{N(t)}, \\ A_i^s(t) &= \frac{\{N(t-1)\omega A_i^s(t-1) + \partial U_i^s(t)\}}{N(t)}. \end{aligned} \tag{13}$$

$A_i^s(t)$ will determine the probability where the agent chooses strategy s. In this paper, the probability is calculated based on logit reaction function [33], as shown in (14). ψ is used to characterize the sensitivity of $A_i^s(t)$ in the strategy selection, and the reciprocal $1/\psi$ of which can be interpreted as noise. The negotiators will choose a strategy randomly based on this probability.

$$\text{Prob}_i^s(t+1) = \frac{e^{\psi A_i^s(t)}}{\sum_{s=1}^{3} e^{\psi A_i^s(t)}}. \quad (14)$$

4. Experimental Results and Analysis

4.1. Initial Parameter Setting. This research adopts the Recursive Porous Agent Simulation Toolkit (Repast) and Eclipse 3.2 to implement the agent-based modelling and simulation. We subdivide the inequity aversion preference of the contractor into the sympathy preference (α) and jealousy preference (β) and set α and β to select different values. According to the range of values ($-1 < \beta < 0 < \alpha < 1$, $|\beta| \geq |\alpha|$), we set the absolute value of α and β to be 0.0001, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.99 (11 sets of data, resp.). During the experiment, take α to be a positive value and take β to be a negative value. According to different combinations with sympathy and envy coefficients, we further divide the inequity aversion preference into several typical types and research how the contractor's different types of inequity aversion preferences impact the revenue sharing coefficient of agreements, the time to reach consensus, and the success rate of negotiation.

In order to eliminate the randomness in the experiment process and improve the statistical stability and validity of the experimental results, the experiments were run 5000 times and repeated for each data set, and we have a statistical analysis of the results obtained. Initializations of the major parameters of the model are set as shown in Table 2.

Table 2: Initializations of the experimental parameters.

Parameters	Description	Value
Q_l	Minimum quality required	0.75
t_l	The shortest construction time	27 (month)
λ	Cost impact factor	0.06
δ	The factors of the impact of project time on the quality	0.1414
L_o	Operational period	30 (year)
μ_o	Maintenance cost factor	30
ρ	Experience discount factor	0.05
∂	Opportunity discount	0.5
m	Cost impact factor	46000
t_p	Planned construction time	36 (month)
η	The factor of the impact of project time on the quality	0.6146
p_o	Operating unit revenue	500 (million)
T	Negotiation periods	20
$N(0)$	Experience weight	1
ω	Attractive discount	0.1

4.2. Impact of Inequity Aversion on the Revenue Sharing Coefficient. Based on the different values of the sympathetic preference coefficient α and the jealous preference coefficient β of the contractor's inequity aversion preference, we can divide the inequity aversion preference into three typical types, namely, I, II, and III, as shown in Table 3.

As type II is called "light sympathy, heavy jealousy" type, whose sympathy coefficient α is smaller and jealous coefficient β is larger, the sense of unfairness is more sensitive when the profits of the contractor are less than those of the owner. Under the same conditions, it will bring greater negative effects to the contractor when the contractor's revenue is less than the owner's revenue. The same is true when α is smaller and β is smaller, that is, the "light sympathy, light jealousy" type (I), and when α is larger and β is larger, that is, the "heavy sympathy, heavy jealousy" type (III).

Figure 3 shows the contractor's revenue sharing coefficient under some scenarios with different combinations of the empathy coefficient and the jealous coefficient. As shown in Figure 3, corresponding to different sympathy and envy coefficient values of the contractor, the revenue sharing coefficient agreed in the negotiation will exhibit some characteristics, such as differences, hierarchy, nonlinearity, and regularity. When the contractor's unfairness aversion preference is of type I, II, and III, the outcome of the negotiation on the revenue sharing coefficient corresponds to the A, B, and C regions in Figure 3, respectively.

As can be seen from Figure 3, the revenue sharing coefficient in the B region is larger than that in other regions, followed by the revenue sharing coefficient in the A region, while the revenue sharing coefficient in the C region is smaller. With the contractor's sympathy coefficient α increasing and the jealousy coefficient β being given, even if β is larger ($\beta \in (0.5, 1)$), the revenue sharing coefficient will appear to have a progressively smaller trend.

Experimental results show that, if the contractor has inequity aversion, different degrees of sympathy and jealous preference combination will have different impacts on the outcome of revenue sharing negotiations for time optimization. Only from the perspective of economic benefits, it is most beneficial to their own income when the contractor belongs to type II. And compared with contractors belonging to types I and II, the contractor who belongs to type III will have a greater perception of unfairness about the differences in revenue between agents, which means that the idea that the contractor has more gains will lead to uneasiness and the contractor cannot accept that his own income is less than the owner's. In this situation, the revenue sharing coefficient of the contractor is lower than that of the contractor belonging to types I and II.

In further analysis, when $\alpha = \beta$ (i.e., to say, jealousy preference and sympathy preference are the same), the evolution trend of the revenue sharing coefficient is shown in Figure 4. As we can see in Figure 4, the revenue sharing coefficient shows a rising trend first and then a descending trend when α and β increase, and the revenue sharing coefficient becomes the largest when $\alpha = \beta = 0.3$. The experiment results show that it is advantageous for a contractor to maintain a

Table 3: Three typical types of the inequity aversion and revenue sharing coefficient area.

Types	I	II	III
Description	Light sympathy, light jealousy	Light sympathy, heavy jealousy	Heavy sympathy, Heavy jealousy
Revenue sharing coefficient area in Figure 3	A	B	C
Absolute value interval of α and β	$\alpha \in (0, 0.3)$, $\beta \in (0, 0.3)$	$\alpha \in (0, 0.3)$, $\beta \in (0.5, 1)$	$\alpha \in (0.7, 1)$, $\beta \in (0.7, 1)$

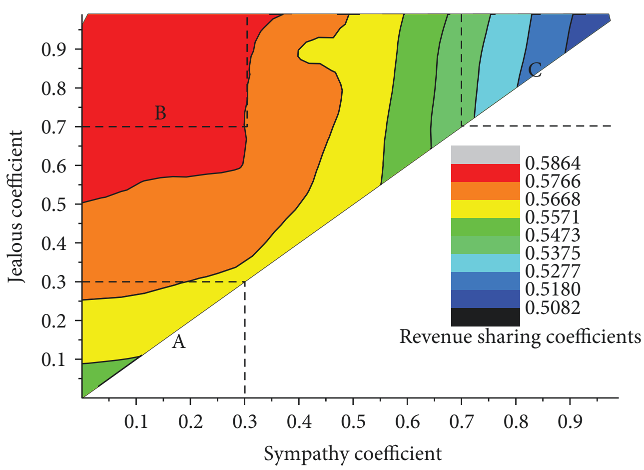


Figure 3: Revenue sharing coefficients under different combinations of sympathy and jealousy preference.

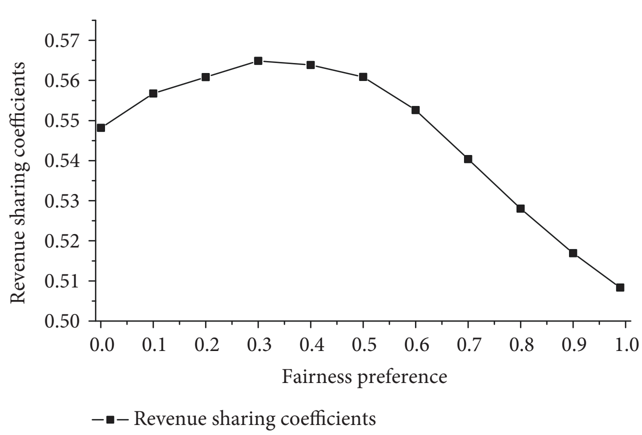


Figure 4: Revenue sharing coefficients when empathy preference and jealous preference are the same.

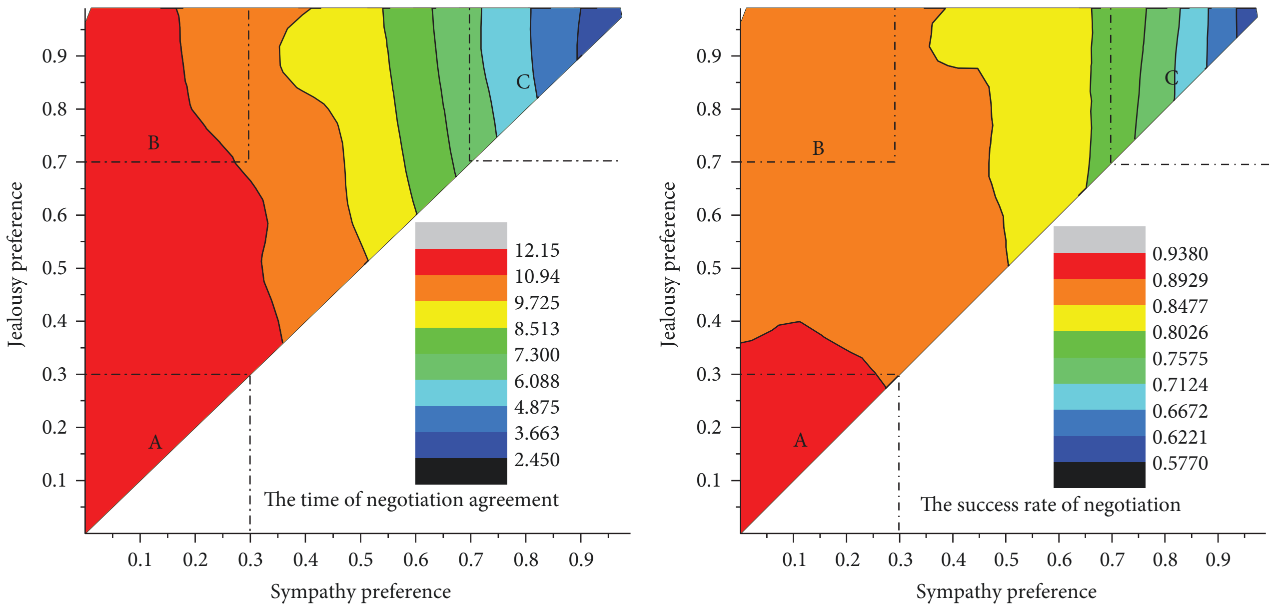
modest inequity aversion for their own earnings; greater inequity aversion means that the contractor cares much about the difference of earnings between his and the owner's which in fact is detrimental to their own earnings, while the owners show the "tolerance first, repression after" features for the contractor's behavior to squeeze his own profits in the negotiation process.

4.3. Impact of Inequity Aversion on the Negotiation Time and Negotiation Success Rate. Figure 5 shows the time of negotiation agreement (Figure 5(a)) and the success rate of negotiation (Figure 5(b)) in the case of different combinations of jealous preference and sympathetic preference. Similar to the experiment results of the revenue sharing coefficient, according to the different combinations of sympathy coefficient and jealous coefficient values, the negotiation time and success rate also show a certain degree of difference, hierarchy, nonlinearity, and regularity. As shown in Figure 5, when the jealousy coefficient is kept constant, the time to reach an agreement shows a downward trend when the sympathy preference increases, and when the degree of sympathy preference remains constant, there is not much difference in the time to reach an agreement with the increasing jealousy preference.

When the contractor belongs to types I, II, and III, respectively, the time of negotiation agreement corresponds to the areas A, B, and C in Figure 5(a); the time of negotiation agreement in area B when the contractor belongs to type II is the same as that in area A when the contractor belongs to type I. Besides, the time of negotiation agreement is all higher than that in area C when the contractor belongs to type III. Thus, the degree of sympathy preference in inequity aversion has an important impact on the time to reach a consensus; the higher the degree of sympathy preference, the shorter the time of negotiation agreement, while the degree of jealousy preference has no obvious impact on the time of negotiation agreement.

As shown in Figure 5(b), when the sympathy coefficient is kept within a certain range ($\alpha \in (0, 0.4)$), the success rate of negotiation is higher no matter how the jealousy coefficient changes, while when the contractor's jealousy coefficient is high ($\beta \in (0.6, 1)$) and kept constant, the success rate of negotiation shows a downward trend when the degree of sympathy preference increases. The negotiation success rate is the highest in the contractors belonging to type I in region A, respectively, and this negotiation success rate is higher than that in the contractors who belong to type II in area B and type III in area C. It is proved that if contractors' sympathy preference is maintained within a moderate range, it will achieve a higher success rate of negotiations in the negotiation process; the success rate of negotiation is affected largely by the agents' sympathy preference, though it is also influenced by the jealousy preference, but it is not very sensitive.

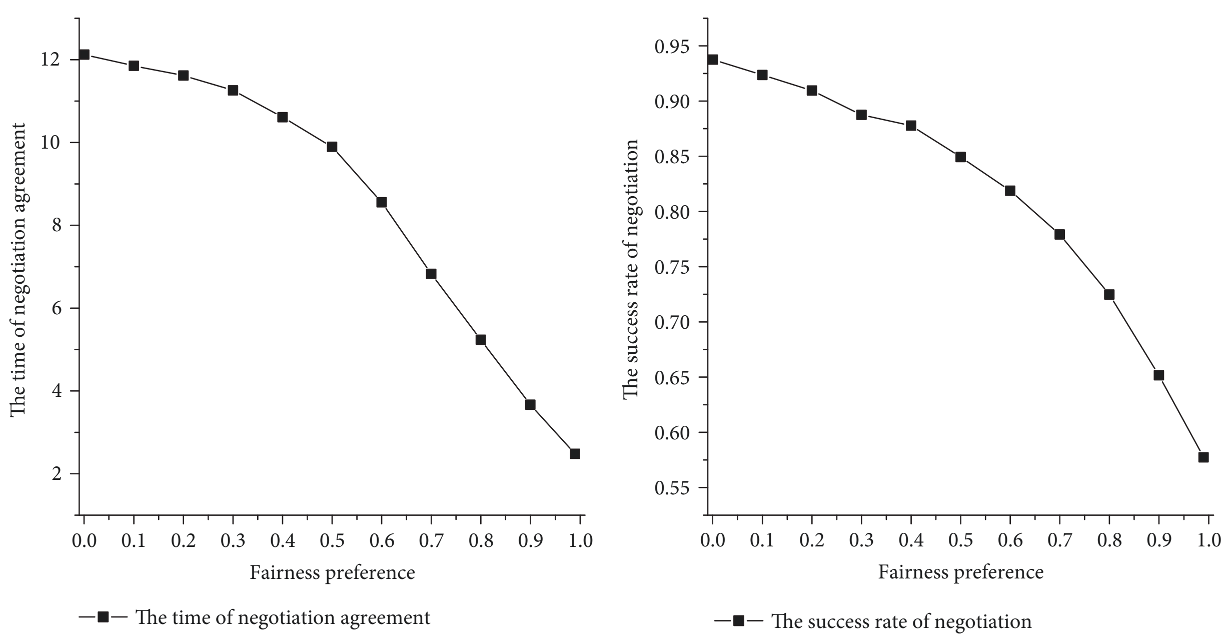
In further analysis, when $\alpha = \beta$, the evolutionary trends of negotiation agreement time and negotiation success rate are observed as shown in Figure 6. It can be seen in Figure 6 that the time to reach an agreement and the success rate of negotiation show a decreasing trend when the degree of inequity aversion increases, and the speed of decline is gradually increasing. When $\alpha = \beta \leq 0.5$, the decline rate of



(a) The time of negotiation agreement

(b) The success rate of negotiation

Figure 5: The negotiation results under different combinations of empathy and jealous preference.



(a) The time of negotiation agreement

(b) The success rate of negotiation

Figure 6: The negotiation results when empathy preference and jealous preference are the same.

the time to reach an agreement and the success rate of negotiation are relatively slow, while when $\alpha = \beta \geq 0.5$, the decline rate becomes faster.

From Figures 5 and 6, we can find that the time of negotiation agreement and the success rate of negotiation appear to be contrary to the evolutionary law to a certain extent. When the contractor's sympathy and jealousy preferences are kept at a low level, the success rate of negotiation is higher but the negotiation time is slightly longer. Thus, contractors need to maintain their inequity aversion (including sympathy preferences and jealousy preferences) to a low level if contractors and owners want to improve the success rate of negotiations in the process based on time optimization; contractors' inequity aversion is needed to be kept in a moderate range if they want to keep the cost of all about the negotiation in control.

5. Conclusions

By adopting a life cycle perspective, this paper focuses on time compression in construction projects and builds an agent-based model on revenue sharing negotiation. Considering that the agents who are in a weak position not only care about their own benefits but also compare their benefits to others, we design an experimental scenario where the contractor has fairness preference based on China's reality. According to different sympathy and envy coefficients, we can divide the inequity aversion preference into three typical types, and we research how the contractor's different types of inequity aversion preferences impact the revenue sharing coefficient of agreements, the results of successful negotiations, and the efficiency in negotiations.

Results are as follows: corresponding to different sympathy and envy coefficient values of the contractor, the revenue sharing coefficient agreed in the negotiation will exhibit some characteristics, such as differences, hierarchy, nonlinearity, and regularity. It is advantageous for a contractor to maintain a modest inequity aversion for their own earnings. The degree of sympathy preference in inequity aversion has an important impact on the time to reach a consensus; the higher the degree of sympathy preference, the shorter the time of negotiation agreement, while the degree of jealousy preference has no obvious impact on the time of negotiation agreement. If contractors' sympathy preference is maintained within a moderate range, it will achieve a higher success rate of negotiations in the negotiation process; the success rate of negotiation is affected largely by the agents' sympathy preference, though it is also influenced by the jealousy preference, but it is not very sensitive.

The model in this paper still has the following limitations: the subject in the model makes and adjusts the negotiation strategy based on the indicator of its utility and the utility function only contains the benefits as well as the utility changes caused by the preferences, where less factors are taken into consideration. However, in the process of actual negotiation, the contractor will take various factors into consideration, such as the relationship with the owner, the strong position of the owner, his own reputation, the socioeconomic situation, and other factors. Therefore, in future research, we may consider constructing a utility system that contains more complicated factors, adding more sophisticated intelligent algorithms, and enhancing the intelligence and behavior adaptability of negotiators.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (nos. 71501084, 71671078, 71390521, 71771127, 71602083, and 71301062) and the Youth Backbone Teacher Training Project of Jiangsu University.

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