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Research Article

Negotiation for Time Optimization in Construction Projects with Competitive and Social Welfare Preferences

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Construction time optimization is affected greatly by the negotiation between owners and contractors, whose progress is dictated by their desire to maximize system revenues. This paper builds an agent-based model and designs an experimental scenario in which the contractor has competitive and social welfare preferences relevant to the Chinese context; we subdivide competitive preference into greed and jealousy components and subdivide social welfare preference into generosity and sympathy components. We analyze the impacts of these different contractor preferences on the revenue-sharing coefficient, negotiation success rate, and negotiation time when negotiation reaches agreement. The results show that the jealousy component of competitive preference has an important influence on improving the income of the subject, while the greed component does not significantly enhance the revenue-sharing coefficient. The sympathy component of social welfare preference does not have an influence on the revenue-sharing coefficient no matter the strength of the generosity component. Increasing the greed component of competitive preference will lead to the extension of negotiation time and, to a certain extent, to the reduction of the negotiation success rate; the sympathy component of social welfare preference does not have an influence on negotiation time no matter the strength of the generosity preference.

1. Introduction

The time taken to complete construction projects has significant implications for the economic, social, and ecological benefits of the project. Time optimization has therefore always been an important issue in the field of construction project management [1, 2]. For owners, a reasonable compression of the construction period on the basis of ensuring the quality of the project can make sure they are put into operation as soon as possible and thus increase operating revenues and social benefits [3, 4].

Uncertainties and particular requirements by the owner can cause the construction period of the project to change. In recent years, construction accidents related to time optimization in China have been frequent, largely because the relationships between time compression, construction costs, the quality of the project, and maintenance costs are neglected in the process [5, 6]. For example, the third Qiantang River Bridge was completed ahead of schedule leading to expensive repairs and a collapse in 2011. In addition, "the shortest lifetime" road in Yunnan Province and "protection room demolitions" are typical examples of projects in which the owners did not take the life cycle of the project into consideration when making time optimization decisions. Optimizing construction time based on the whole life cycle of the project can effectively avoid certain "shorted-sighted" behaviors, such as "considering construction time to be more important than the quality of the project" and "neglecting the cost of maintenance." So owners should undertake a comprehensive consideration of multiple goals from the perspective of the life cycle of the project during time optimization.

Owner and contractor may get better system benefits through making the projects put into operation ahead of schedule. Revenue sharing provides a feasible way to allocate system benefits between owner and contractor to optimize construction time [7]. By revenue sharing, the contractor's moral hazard and opportunistic behavior can be reduced or eliminated. The allocation of system benefits is often concluded by the negotiation between owner and contractor, because of information asymmetry between owner and contractor about construction cost and many more. In practice, whether revenue sharing can be implemented smoothly or achieve the best outcome for owner and contractor will depend on the outcome of the negotiation.

Both sides of the negotiation game are regarded as rational economic individuals, both of whom seek to maximize their profits [8]. However, research in the field of behavioral decision-making shows that describing or predicting human behavior based on an assumption of rationality may cause systematic error [9]. Scholars have found a large number of prosocial behaviors in behavioral game experiments which offer a strong rebuttal to the economic individual hypothesis. Examples are the responder rejection behaviors in ultimatum games [10], the giving behavior in dictator experiments [11], and the reciprocity behavior in gift exchange games [12]. The results of many studies which contradict the self-interest hypothesis promoted the emergence of social preference theory. At its core is the idea that people care not only about their own interests but also about the interests and motivations of others, it can be seen that conclusions will be more realistic if we consider social preference theory when studying subjects' game bargaining behavior.

There are several typical social preferences which have important impacts on the results of negotiation and subsequent behaviors during the negotiation process for time optimizing, such as competitive preference and social welfare preference. Competitive preferences mean that Player B always prefers to do as well as possible in comparison to A, while also caring directly about her payoff. That is, people like their payoffs to be high relative to others' payoffs. Social welfare preferences mean subjects always prefer more for themselves and the other person but are more in favor of getting payoffs for themselves when they are behind than when they are ahead [13]. So if the contractor has a competitive preference, because he is responsible for the specific implementation of the time compression for which he pays a certain cost, it means that he wants to get greater benefits than the owner, and there may be negative effects if this is not the case. There may be social welfare preference if the contractor wants to maintain a good relationship with the owner. In such circumstances, the contractor cares less about his own benefits and hopes that the owner achieves good benefits. Some literatures have found that the agents in weaker position pay more attention to their own benefits and are more inclined to compare their benefits to the stronger agents [14, 15]. Particularly compared with the owners the contractors in China are in weaker position. Thus we can see that contractors' competitive and social welfare preferences have great importance for the results of the time optimization negotiation in the construction context.

In summary, it is important to clarify the mechanism by which the contractor's competitive and social welfare preference impact on the time optimization negotiation. It is also significant for clarifying the causes of negotiation results. As a result, we can make rational and reasonable decisions to control and encourage relevant revenue-sharing negotiation behaviors under constraints of time, cost, quality, and other objectives. This paper concentrates on the process and results of the time optimization negotiation in construction and analyzes the impacts of different contractor preferences on the revenue-sharing coefficient, negotiation success rate, and negotiation time when negotiation reaches agreement. Finally, we compare the influences of contractors' competitive, social welfare, and self-interest preferences.

The remainder of this paper is structured as follows: Section 2 presents a brief review of the literature; Section 3 describes our simulation model and experiment design in detail; Section 4 presents the results of the simulation studies; and Section 5 summarizes the insights gained.

2. Literature Review

The problem of construction time compression has been widely concerned by scholars, who generally study this problem based on time-cost trade-off analysis, so a variety of optimization algorithms have been developed to find optimal solutions. Cheng and Tran (2014) presented a two-phase differential evolution model to resolve the problems of trade-off optimization between project time and project cost which is necessary to maximize overall construction project benefit. This model is able to effectively consider both time-cost effects and resource constraints [16]; Zhang et al. (2014) improved the traditional cost-time model by taking reward and punishment into consideration [17]; Heravi and Faeghi (2014) presented a group decision-making framework to seek the optimal resource utilization, considering time, cost, and quality simultaneously [18]; Li and Wu (2014) addressed a time-cost trade-off problem under uncertainty, in which project activities can be executed in different construction modes corresponding to specified time and cost with interval uncertainty [19]; Jeang (2015) uses computer simulation and statistical analysis of uncertain activity time, activity cost, due date, and project budget to address quality and the learning process with regard to project scheduling [20]; Ashuri and Tavakolan (2015) presented a shuffled leapfrogging model to solve complex time-cost-resource optimization problems and considered the simultaneous optimization of three important objective functions [21]; Koo et al. (2015) conducted a study to develop an integrated Multiobjective Optimization model that provides the optimal solution set based on the concept of the Pareto front considering various factors such as time, cost, quality, environment, and safety [22].

Monghasemi et al. (2015) applied an evidential reasoning approach in the context of project scheduling to identify the best Pareto solution for discrete time-cost-quality trade-off problems [23]; Liu et al. (2016) proposed a method based on PRT-Net for time performance optimization, which is a Petri net-based formulism tailored for projects constrained by resources and time [24]; Khanzadi et al. (2016) presented a new hybrid model which integrated agent-based modeling with CPM and Genetic Algorithms to find out the best resource allocation combination for the construction project's activities [25]; Hou et al. (2017) formulated a feasible multiobject discrete firefly algorithm (MDFA) for optimizing scaffolding project resource and scheduling schemes [26]; Salimi et al. (2018) developed an integrated simulation-based optimization framework within one High Performance Computing (HPC) platform, and its performance is analyzed by carrying out a case study [27].

In summary, firstly, it can be seen that these studies all examine the optimization of cost, schedule and quality, or the contractor's mandatory arrangements for the contractor after its decision-making from the unilateral perspective of contractor. However, in practice such mandatory management not only can fail to play an adequate role in controlling the situation, but also sometimes may even lead to a confrontational attitude between the contractor and owner so that the plan cannot be effectively implemented and the goal cannot be achieved. Secondly, the above construction time optimization studies require centralized decision-making and seek the optimal scheme under the multiobjective constraint. However, the decision mode for construction time compression is changing, moving away from traditional administrative control to negotiation based on revenue sharing. Negotiation has become one of the most important decision-making modes for construction time compression, and some scholars have studied the problem of negotiation in construction projects [28–30].

Additionally, few studies consider the agents to have a social preference, yet social preferences are significant determinants of choice [31]. Studies of social preferences are mainly concerned with the field of supply chain management, and most of these focus on difference aversion preferences. For example, Yang et al. (2013) considered a distribution channel consisting of a single manufacturer and a single retailer and investigated the effect of the retailer's fairness concerns [32]; Du et al. (2014) investigated a newsvendor problem for a dyadic supply chain in which both supplier and retailer have status-seeking preference with fairness concerns [33]; Wu and Niederhoff (2014) studied the impact of fairness concerns on supply chain performance in a two-party newsvendor setting [34]; Li and Jain (2016) studied the impact of consumers' fairness concerns on firms' behavior-based pricing strategies, profits, consumer surplus, and social welfare [35]; Qin et al. (2016) 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 [36]; Choi and Messinger (2016) found that fairness has a significant role in competitive supply chain relationships, even in a scenario that is designed to favor one member of the supply chain over others [37]; Nie and Du (2017) considered dual fairness in a distribution channel with quantity discount contracts [38]; and Li et al. (2018) incorporated the members' fairness preference and bargaining power into the product quality and pricing decisions in a two-echelon supply chain [39].

In summary, firstly, research on social preferences is mainly concerned with the field of supply chain management at present. Few studies have introduced social preference into the field of construction project management, especially the process of revenue-sharing negotiation for time optimization. Secondly, most studies are conducted only on a single social preference type; there are few comparison studies of different types of social preference discussion. In addition, there is no subdivision of particular preferences in the extant research.

Compared with the above studies, this paper has the following innovations:

Firstly, this paper focuses on the negotiations on time optimization between the contractor and owner. We optimize the construction time on the perspective of the whole project life cycle, taking into account the impact of the multiple factors such as project quality, construction cost, and maintenance cost, thus providing theoretical support for improving the feasibility and validity of the time optimization schemes.

Secondly, the traditional time optimization method belongs to the deterministic passive management and passive feedback control, whose defect lies in ignoring the interaction between the contractor and owner. This paper introduces the revenue-sharing negotiation to transform the traditional incentives and uses the master-slave hierarchical game model to represent the decision-making process of time optimization, which is more in line with the reality of the process.

Thirdly, we consider the social preferences of the contractor and we further subdivide competitive preference and social welfare preference into several typical types. We investigate how different types of contractor social preference impact the results of negotiation.

3. The Revenue-Sharing Negotiation Model

The parties in the negotiation have independent decision-making ability and the heterogeneity characteristic, meaning that they can choose to change their behavior as they see fit in response to changes in the behavior of their opponent. As a result, the interaction between subjects often shows a nonlinear, dynamic relationship [40, 41]. This paper uses the multiple-agent modeling method to build a construction time optimization negotiation model because of the multiple stages and uncertainty of the negotiation process [42–44]. Various behaviors and phenomena will "emerge" from bottom to top through interaction between the negotiating agents [45]. We extract and analyze the changing parameters which interest us and then determine their impacts on the strategy selection and performance of the main agents by constructing a controllable and reproducible computational model. Lastly, we offer positive management implications drawn from the comparative analysis of the experimental results.

The authors' previous research builds an agent-based model that explains how contractor's different types of inequity aversion preferences impact revenue-sharing negotiations [40]. In this paper, we refer to model of literature [40] and analyze the impacts of competitive preference and social welfare preference on the revenue-sharing coefficient, negotiation success rate, and negotiation time when negotiation reaches agreement and compared the effects of the two preferences.

3.1. Agents' Revenue and the Optimal Time Model. The optimization of construction time can facilitate the project being put into operation as soon as possible and so increase operating income. The logical relationship between

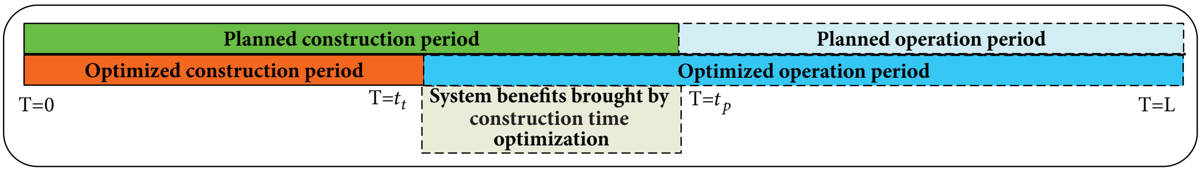


Figure 1: The influence of construction time optimization on system benefits.

the optimization of a project's construction time and the improvement of system benefit is shown in Figure 1.

The increase in system revenue (π_t) is calculated as shown in

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

where p_o represents the per unit of time revenue of the project operation, t_p represents the planned construction period, and t_t represents the optimized operation period, $t_t < t_p$. Based on the revenue-sharing contract, π_t will be allocated to the owner and contractor according to mutual game negotiations. Assuming that the contractor obtains the proportional benefit Φ from π_t, the owner obtains the remaining $(1 - \Phi)$. The owner's and contractor's profits are calculated with formula (2):

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

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

In formula (3), c_o and c_c represent the cost which owner and contractor, respectively, must pay to optimize the timescale of a project.

The negotiations for time optimization between owner and contractor should be considered under certain constraint conditions. First of all, when shortening the construction period, the quality of the project must be ensured. Assuming that the minimum required quality standard for the project is Q_l, the planned quality standard is Q_p, and the project quality after construction period optimization is Q_t, the requirement $Q_t \geq Q_l$ must be met. Time optimization may affect project quality and then affect the maintenance cost during the project operation period. Supposing that the owner's increasing maintenance expense ratio due to the quality factor is γ_t, $\gamma_t = (1 - Q_t)/Q_t$; that is to say, the maintenance expense ratio is closely related to project quality. Assuming that the original planned project operation cycle is L and the maintenance coefficient of the owner's quality cost is μ_o, it can be seen that different time optimization schemes have different influences on the owner's later maintenance cost c_o, as shown in the formula

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

Time optimization may affect project quality, thereby affecting the owner's maintenance costs. It may also affect the contractor's construction cost. It is generally believed that the shortening of construction time will lead to an increase of the cost. According to the literature [46], the functional relation between the timescale of a project and construction cost is $c = m \cdot e^{-\lambda t_t}$. $m, \lambda > 0$ indicates the impact factor of construction time on cost depending on the corresponding characteristics of the project. It can be seen that the cost, c_c, which the contractor must pay for time optimization is shown in the formula

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

According to the literature [47], project quality has a positive correlation with construction time. Generally, we adopt $[0, 1]$ to represent project quality level. Under the same condition, the longer the construction time, the higher the quality of the project, infinitely close to 1. During the time optimization process, construction time cannot be infinitely compressed due to the constraints of project quality, cost, and other factors. The functional relation between project quality (Q_t) and construction time (t_t) is shown in the formula

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

η, δ >0 indicates the impact factor of construction time on quality and can be obtained by bringing the two sets of variables (Q_p, t_p) and (Q_l, t_l) into the solution; t_l represents the shortest construction time corresponding to the minimum quality requirements, Q_l, for the project. Substituting (6) into (4), we can further refine the owner's maintenance cost c_o. The combination of formulae (1), (3), and (5) can be used to obtain contractor's profit (π_c) in the time optimization process, as formula (7) shows:

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

In summary, the increasing profit (π) of the system can be expressed as follows:

$\pi = p_o(t_p - t_t) - c_o - c_c$, so that

$$\begin{aligned}\pi &= p_o\left(t_p - t_t\right) \\ &\quad - \left[\mu_o\left(\frac{1 - \eta \cdot \ln\left(\delta \cdot t_t\right)}{\eta \cdot \ln\left(\delta \cdot t_t\right)}\right)\left(L + t_p - t_t\right) - \mu_o \right. \\ &\quad \left. \cdot \left(\frac{1 - Q_p}{Q_p}\right) \cdot L\right] - m \cdot \left(e^{-\lambda t_t} - e^{-\lambda t_p}\right);\end{aligned} \tag{8}$$

TABLE 1: Three typical social preference types.

Type	Name	Ranges of parameters	Descriptions
1	Self-interest preference	$\alpha = \beta = 0$	Only concerned about personal income, unconcerned about the difference in income with other agents
2	Competitive preference	$-1 < \beta \le \alpha < 0$	α means "greed" coefficient; β means "jealousy" coefficient
3	Social welfare preference	$0 \le \beta \le \alpha \le 1$	α means "sympathy" coefficient; β means "generosity" coefficient

the first-order derivative of t_t is

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

the second-order derivative of t_t is

$$\frac{d^2\pi}{dt_t^{\,2}} = -\mu_o \cdot \frac{2(L + t_p - t_t) + (L + t_p)\ln(\delta \cdot t_t)}{t_t^2 \cdot \eta \cdot \ln^3(\delta \cdot t_t)} - \mu_o \cdot \frac{1}{t_t \cdot \eta \cdot \ln^2(\delta \cdot t_t)} - m \cdot \lambda^2 \cdot e^{-\lambda t_t}; \tag{10}$$

because $Q_t = \eta \cdot \ln(\delta \cdot t_t) > 0, \eta > 0, \ln(\delta \cdot t_t) > 0$, $d^2\pi/dt_t^{\,2} < 0$; therefore, the system has the optimal solution of time optimization to make $m \cdot \lambda \cdot e^{-\lambda t_t} - p_o - \mu_o \cdot [(t_t - L - t_p)/(t_t \cdot \eta \cdot \ln^2(\delta \cdot t_t)) - 1/(\eta \cdot \ln(\delta \cdot t_t)) + 1] = 0$. Further analysis of the optimized value of time for the project can be conducted as shown in the formula

$$t_t = \begin{cases} t_l & if\ (t_t^* \le t_l) \\ t_t^* & if\ (t_l < t_t^* < t_p) \\ t_p & if\ (t_t^* \ge t_p) \end{cases} \tag{11}$$

When $t_t^* \le t_l$, due to the minimum quality constraints, the optimized value of time cannot be less than t_l, leading to $t_t = t_l$; while $t_t^* \ge t_p$, without time optimization, the system does not increase revenue; while $t_l < t_t^* < t_p$, there is a time optimization scheme to maximize system profit at point t_t^*. In a centralized decision-making process, the owner and contractor will select the optimal construction time for the project to maximize π, namely, $t_t = t_t^*$.

3.2. Competitive and the Social Welfare Preference Model. Under the influence of competitive and social welfare preferences, agents not only are concerned with their own economic benefits, but also care about differences in income relative to other subjects. In this paper, we will describe two types of preference based on the utility function proposed in the literature [48].

Some studies indicate that decision-makers in a weaker position are more concerned with their own benefits and tend to compare theirs with other decision-makers [14, 49]. In practice, the owner occupies a strong position in China and the contractor is in a weaker position; the contractor does not pay much attention to the difference between his benefits and that of others. Therefore, this paper follows the research hypothesis of relevant literature and only studies the situation in which the contractors have social preferences, namely, the effects on negotiation for time optimization when the contractor has competitive and social welfare preferences. Contractor utility function is shown in the formula

$$U_c(\pi_c) = \begin{cases} \pi_c + \alpha \cdot (\pi_o - \pi_c), & \pi_o < \pi_c \\ \pi_c + \beta \cdot (\pi_o - \pi_c), & \pi_o > \pi_c \end{cases} \tag{12}$$

It can be seen that contractor's utility is the weighted average of his own benefits and the difference in income between the agents; in reality, the owner occupies a strong position and only pays attention to his own income; thus $U_o(\pi_o) = \pi_o$. In accordance with the social preference types which Charness and Rabin proposed [13], this paper focuses on the self-interest of contractors and their competitive and social welfare preferences, three comparatively typical preference types. Parameter ranges and descriptions for the three types are shown in Table 1.

According to the literature [13], it is assumed that weight parameter α, when the contractor's profit is greater than the owner's, and weight parameter β, when the contractor's profit is smaller than the owner's, are within the interval $[-1, 1]$, but different combinations of size, positive, and negative will be able to characterize different social preferences. Based on the combination of positive and negative values of α and β, we can characterize the differences between three typical preferences. When $\alpha > 0$, we call it the "sympathy" coefficient: the more the contractor's revenue exceeds the owner's, the more negative the contractor will be, namely, "the more I get, the more uncomfortable I am." When $\alpha < 0$, we call it the "greed" coefficient: the contractor wants his own profits to be greater than the owner's; the higher the better. When $\beta > 0$, we call it the "generosity" coefficient: the larger the value is, the more the contractor wants the owner's profit to increase. When $\beta < 0$, we call it the "jealousy" coefficient: the greater the absolute value is, the more the contractor envies the owner, because the latter's income is higher, which will have greater negative effects on the contractor.

3.3. Agents' Negotiation Process and Learning Model. Owner and contractor normally follow sequential negotiation rules, one of the most common bargaining behaviors. Certain constraints (e.g., $Q_o \geq Q_l$, $t_t < t_p$, $\pi_o > 0$, and $\pi_c > 0$) locate the revenue-sharing coefficient Φ in a feasible negotiable area interval, $\Phi \in [\Phi_{min}, \Phi_{max}]$.

In the negotiation process for time optimization in construction projects, the owner first proposes a value of Φ, and the contractor decides whether or not to accept it. If he refuses, the contractor will put forward a new value, and then the owner decides whether or not to accept. The owner and the contractor make proposals separately starting from Φ_{min} and Φ_{max}, and each proposal from the owner increases the value of Φ by a magnitude of v, while the contractor's proposals reduce the value of Φ by a magnitude of v each time. When one party accepts the other's proposal, the negotiation is successful. In this paper, it is assumed that the negotiation process is not unlimited; in reality, the negotiation cycle will involve certain negotiation costs, so the model assumes that when one party withdraws or talks continue beyond a certain period, the negotiation fails. In the formula $v = (\Phi_{max} - \Phi_{min})/T$, T is the fixed cycle of negotiations; if the parties fail to agree on the value of Φ in the cycle T, the negotiation fails. The negotiation process is shown in Figure 2. In the negotiation process, owner and contractor both have three kinds of behavior strategy (s).

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

Strategy 2. Reject the Φ put forward by the other agent, and propose a new value. At this time, the expected utility corresponds to the new value of Φ.

Strategy 3. Exit negotiation. The expected utility is zero at this time.

In reality, both negotiation parties will show the characteristics of learning and intelligence. The agents will make the best use of the circumstances and adjust their decisions based on experience and expectations of strategy. In this paper, the Experience Weighted Attraction (EWA) learning algorithm [50], which characterizes agents' learning and intelligence, is used to assign an attraction index to each of the three behavioral strategies and to calculate the probability of each strategy being selected based on certain rules. Therefore, the EWA algorithm can be used to describe the agents' experience accumulation process, as shown in the formulae

$$N(t) = \rho N(t-1) + 1 \tag{13}$$

$$A_i^s(t) = \frac{\{N(t-1)\,\omega A_i^s(t-1) + [\partial + (1-\partial)\,I(s)]\,U_i^s(t)\}}{N(t)} \tag{14}$$

$N(t)$ is the experience weight; ρ is the historical experience discount factor; $A_i^s(t)$ is the attractiveness index of strategy s to agent i; ω is the discount factor of $A_i^s(t)$; $U_i^s(t)$ is the expected utility of strategy s adopted by agent i at time t; ∂ is the weight of the subject's emphasis on the strategy; $I(s)$ shows whether agent i adopts strategy s. $I(s)$=1 shows that strategy s is adopted at time t, while $I(s)$=0 shows that strategy s is not adopted. The corresponding attraction is calculated as shown in

$$A_i^s(t) = \frac{\{N(t-1)\,\omega A_i^s(t-1) + U_i^s(t)\}}{N(t)};\qquad A_i^s(t) = \frac{\{N(t-1)\,\omega A_i^s(t-1) + \partial U_i^s(t)\}}{N(t)} \tag{15}$$

In this paper, the probability of subject selection strategy s is calculated based on Logit reaction function [50], which is determined by $A_i^s(t)$, as shown in the formula

$$Prob_i^s(t+1) = \frac{e^{\psi A_i^s(t)}}{\sum_{s=1}^{3} e^{\psi A_i^s(t)}} \tag{16}$$

ψ is used to characterize the sensitivity of $A_i^s(t)$ in strategy selection, whose reciprocal can be interpreted as noise. The negotiators will randomly select a strategy based on this probability.

4. Experiment Results and Analysis

4.1. Initial Parameter Setting. The multiagent model built in this paper adopts the Repast J developed by the University of Chicago, whose development environment is open source software Eclipse 3.2. Based on contractors' competitive and social welfare preferences, we design a variety of experimental scenarios and analyze the influence of two types of behavioral preference on revenue-sharing negotiation for construction time optimization.

In order to best analyze the effect of different behavioral preferences on the outcome of negotiations and to explore the evolutionary trend of the experimental results with preference degree, we set a different combination of α and β values, based on ranges of parameter values for competitive and social welfare preferences. The contractor's competitive and social welfare preferences are further subdivided into a combination of different preference levels, as shown in Table 2.

In the competitive preference experiment, both α and β take negative values; in the social welfare preference experiment, both take positive values; in the self-interest preference experiment, they both take a value of 0. For each set of data running to 5,000 experiments, we will conduct a statistical analysis of the results obtained to eliminate randomness and to improve the statistical stability and validity of the results. Specific indicators for statistical analysis include the revenue-sharing coefficient when the negotiation reaches an agreement, negotiation time, and the success rate of negotiations. The initial values of the basic parameters in the experimental model are shown in Table 2. The values of parameters such as Q_l,Q_p,t_l,t_p, are chosen according to the literature [46], while the value of η and δ is obtained by substituting two sets of data (Q_p, t_p) and (Q_l, t_l) into formula

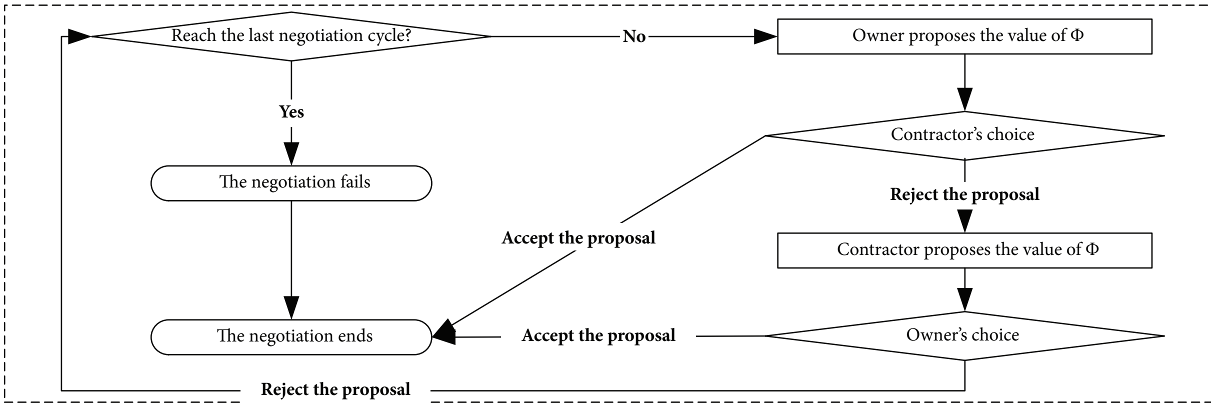


Figure 2: The negotiation process between owner and contractor.

Table 2: The initial values of the model parameters.

Parameter	Meaning	Value	Parameter	Meaning	Value
Q_l	Minimum quality	0.75	t_l	Shortest construction time	27 (months)
Q_p	planned quality	1	t_p	Plan constructing time	36 (months)
η	Quality impact factor	0.6146	δ	Quality impact factor	0.1414
λ	Cost impact factor	0.06	m	Cost impact factor	46000
L_o	Operation period	30 (years)	p_o	Operation unit revenue	5 (millions)
T	Negotiation cycle	10	μ_o	Maintenance cost factor	30
$N(0)$	Experience weight	1	ρ	Empirical discount factor	0.05
ω	Attractive discount factor	0.1	∂	Opportunity discount factor	0.5

(6), $Q_t = \eta \cdot \ln(\delta \cdot t_t)$. The parameters such as $N(0)$=1, ∂=0.5, ω=0.1, ρ=0.05 are chosen within the range of values given in the literature [42].

In Section 3.1, we showed that when construction time is optimal, the increase in system profit π is maximized, while the solution to t_t^* is too complex to give an expression. Therefore, the solution of t_t^* is transformed into the solution of the first-order derivative of $d\pi/dt_t = 0$. Let

$$f(t_t^*) = m \cdot \lambda \cdot e^{-\lambda t_t^*} - p_o - \mu_o \cdot \left[\frac{t_t^* - L - t_p}{t_t^* \cdot \eta \cdot \ln^2(\delta \cdot t_t^*)} - \frac{1}{\eta \cdot \ln(\delta \cdot t_t^*)} + 1 \right] = 0 \quad (17)$$

Under the conditions of the experimental parameters given in Table 2, $f(t_l) < 0$, $f(t_p) > 0$; therefore the approximate optimal solution can be solved by the dichotomy method. In this paper, when the setting precision is 0.0001, the approximate optimal value is $t_t^* = 27.6439$.

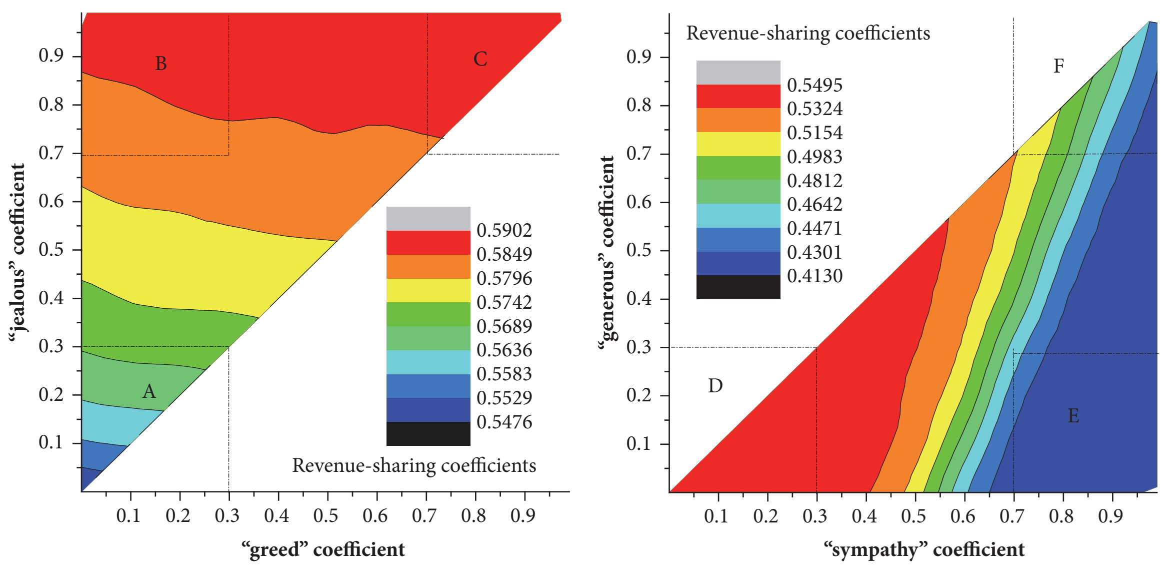
4.2. The Impact of Preferences on the Revenue-Sharing Coefficient. The results of negotiations for the revenue-sharing coefficients of the contractor with competitive preferences (Figure 3(a)) and social welfare preferences (Figure 3(b)) are shown in Figure 3. We take the "greed" coefficient and "jealousy" coefficients in competitive preference as absolute values. Comparing the results of these two preference scenarios, the revenue-sharing coefficient in the competitive preference experiment is generally higher, indicating that competitive preferences will make the agent pay more attention to his own gains in the negotiation process and thus achieve much more revenue.

Based on the different values of α and β in the contractor's competitive and social welfare preferences, we can subdivide these two types of preference into three relatively typical types, as shown in Table 3. As an example, competitive preference has three types, namely, type I, characterized by "light greed, light jealousy"; type II, "light greed and heavy jealousy"; and type III, "heavy greed and heavy jealousy." When the negotiation reaches an agreement, the revenue-sharing coefficient under these three types of preference corresponds to areas A, B, and C in Figure 3(a), respectively. Similarly, based on the different values of α and β, social welfare preferences can be divided into types IV, V, and VI; the revenue-sharing coefficients obtained by negotiation under these types correspond to areas D, E, and F in Figure 3(b), respectively.

It can be seen in Figure 3(a) that when the contractor has a competitive preference, α and β values continue to increase, and the negotiated revenue-sharing coefficient also increases. This indicates that the contractor who has a competitive preference will want his income to be higher than the owner's, and the more the better. Thus, with increasing weight given to this objective, the outcome of the negotiation will be more beneficial to the contractor. When the contractor belongs to type II, the revenue-sharing coefficient obtained by him is

Table 3: Description of three typical types in competitive preference and social welfare preference and revenue-sharing coefficient area.

competitive preference	Type	I	II	III
	Description	Light greed, light jealousy	Light greed, heavy jealousy	Heavy greed, heavy jealousy
	The region of the experiment result	area A	area B	area C
	Absolute value interval of α,β	$\alpha \in (0, 0.3)$, $\beta \in (0, 0.3)$	$\alpha \in (0, 0.3)$, $\beta \in (0.7, 1)$	$\alpha \in (0.7, 1)$, $\beta \in (0.7, 1)$
social welfare preference	Type	IV	V	VI
	Description	Light generosity, light sympathy	Light generosity, heavy sympathy	Heavy generosity, heavy sympathy
	The region of the experiment result	area D	area E	area F
	Absolute value interval of α,β	$\alpha \in (0, 0.3)$, $\beta \in (0, 0.3)$	$\alpha \in (0.7, 1)$, $\beta \in (0, 0.3)$	$\alpha \in (0.7, 1)$, $\beta \in (0.7, 1)$



(a) Competitive preference

(b) Social welfare preference

Figure 3: Revenue-sharing coefficients under different preferences.

substantively the same as that of the contractor belonging to type III, and both are higher than that obtained by the contractor belonging to type I. The experimental results show that the jealousy component in competitive preference has an important influence on improving the subject's personal income, while the greed component is not a significant means for the contractor to enhance his revenue-sharing coefficient.

Figure 4(a) shows the evolutionary trend of the revenue-sharing coefficient in the competitive preference experiment when $\alpha = \beta$ and the value of both increases continuously. As analyzed in conjunction with Figures 3(a) and 4(a), as the value of α and β increases to a certain extent, the growth rate of the revenue-sharing coefficient slows down, which indicates that when the value of α and β reaches a certain point, its impact on the negotiation results decreases.

The experimental results show that as the contractor's competitive preference (actually the jealousy preference) continues to increase, he continually pursues an increase in the value of Φ in the negotiation process to enhance his own profit. When the contractor's competitive preference is not strong, the negotiated revenue-sharing coefficient improves significantly, while when the value of α and β increases, the contractor pays more attention to comparing his revenue with the owner's, but the growth rate of the revenue-sharing coefficient slows down.

It can be seen that the contractor's competitive preference is one of the most important factors affecting the distribution of profits. In the process of profit distribution, the higher the degree of the contractor's competitive preference is, the more the contractor can increase his profits. However, when the contractor acts to squeeze the owner's profits, the latter shows features of "tolerance first, then suppression" behavior. Under the constraints of economic income targets, when the behavior of contractors squeezed profits, owners showed a certain degree of tolerance in the early stages and then suppressed the contractors to improve the revenue-sharing coefficient, in order to maintain their own revenue.

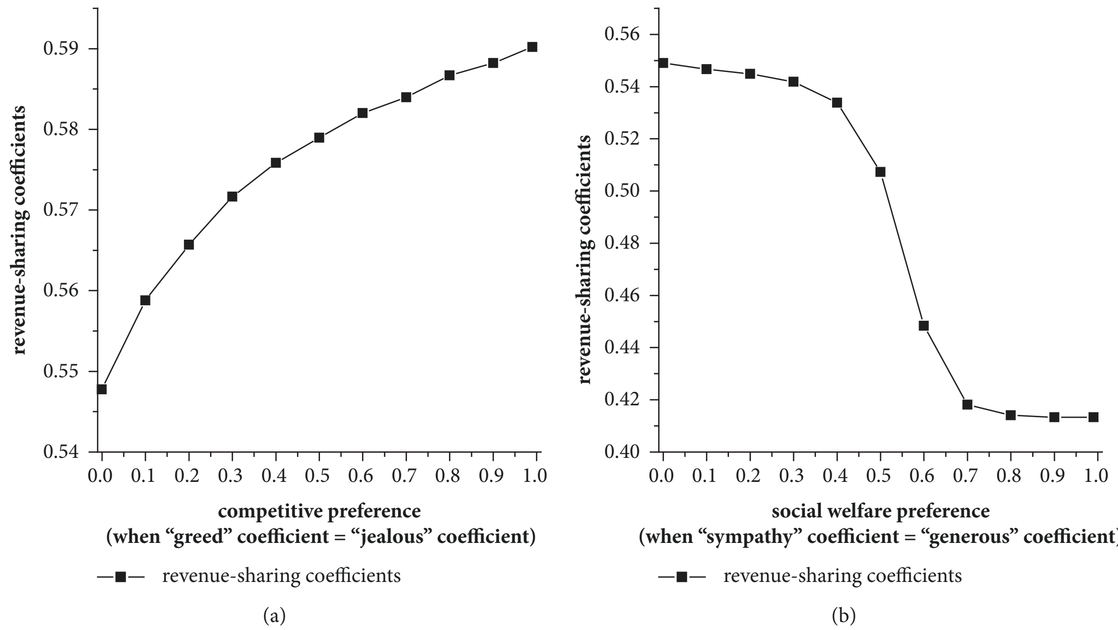


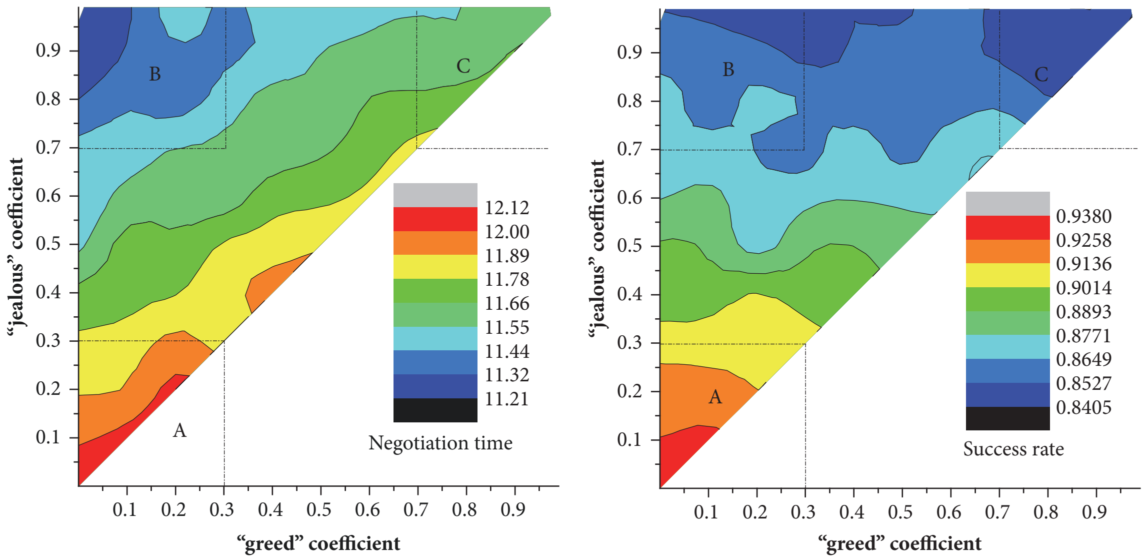
Figure 4: Evolution of revenue-sharing coefficients as preference changes.

When the contractor has a social welfare preference, as the contractor's α and β values continue to increase, the revenue-sharing coefficient will continue to decrease. When the contractor belongs to type IV, the revenue-sharing coefficient in area D is higher than those of area E and area F. As can be seen in Figure 3(b), when α belongs to (0,0.3) or $[0.7, 1]$, the revenue-sharing coefficients are in area D and area E, respectively. As the value of β increases, the trend of the revenue-sharing coefficient is not obvious; this indicates that the strength of the generosity preference makes no difference to the outcome of the negotiations. Figure 4(b) shows the evolutionary trend of the revenue-sharing coefficient when $\alpha = \beta$ and the value of both increases continuously. It is further verified that the change in the revenue-sharing coefficient is not significant when α belongs to (0,0.3) or to $[0.7, 1]$, but when $\alpha = \beta \in (0.3, 0.7)$, the revenue-sharing coefficient is sensitive to changes in α and β values and decreases dramatically with increases in these parameters.

Social welfare preferences tend to be altruistic to some extent. Social welfare-minded contractors want owners to make a profit and that also benefits them. When contractors' social welfare preference is low, their altruistic behavior is not obvious and contractors are more concerned about their own revenue, so the decline in the rate of revenue-sharing coefficient is slow. As contractors' social welfare preference increases, they increasingly expect to enhance owners' revenue, and therefore the decline in the rate of the revenue-sharing coefficient is fast. However, when the revenue-sharing coefficient decreases to a certain level, the owners receive more benefits. In this case, the negotiating parties are basically able to reach an agreement. The revenue-sharing coefficient is therefore maintained at a certain level rather than decreasing further. The results show that when the contractor's social welfare preference is high, the owner will allow the negotiation to reach an agreement with relative satisfaction instead of continuing to squeeze the contractor's profits.

In construction practice, in order to maintain good relations with owners, or when forced by owners by executive order to reduce costs, or based on a certain interest demands, contractors may present social welfare preferences; that is, they will not be concerned about their own income, only expect the income of the owners to increase. This situation calls for owners to be vigilant; the stronger the contractor's social welfare preference is, the more the owner needs to identify the real motivation and objectives of the contractor. The owner should not use the contractor's social welfare preferences to make the contractor benefit less, as this may affect the quality of the project.

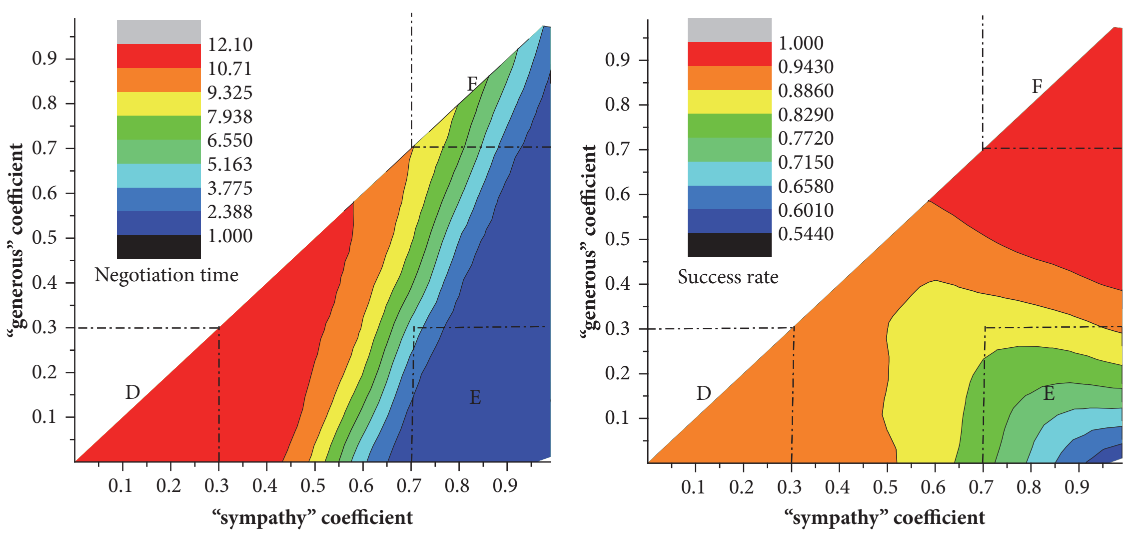
4.3. The Impact of Preferences on Negotiation Time and Success Rate. Figures 5 and 6 show the negotiation time and success rate under different parameters of competitive and social welfare preferences. When competitive and social welfare preferences are low, the negotiation time and success rate differ very little. However, as the two preference types become stronger, negotiation time and success rate show different evolutionary trends. The specific types of competitive and social welfare preferences correspond to the areas of the experimental results. In Figures 5(a) and 6(a), it can be seen that the time needed to reach agreement and the negotiation success rate both show certain nonlinear characteristics corresponding to different values of greed and jealousy components. However, in the social welfare preference experiment, under different generosity and sympathy parameters, the time needed to reach agreement and negotiation success rate both show a certain regularity.



(a) Negotiation time

(b) Negotiation success rate

FIGURE 5: The negotiation results under different combinations of greed and jealousy.



(a) Negotiation time

(b) Negotiation success rate

FIGURE 6: The negotiation results under different combinations of sympathy and generosity.

In the competitive preference experiments, the time needed to reach agreement in area A is longer than in area C and longer in area C than B, but the difference is not significant; meanwhile, the negotiation success rate in area A is higher than in areas B and C. The results show that when the contractor belongs to type I, although the time needed to reach a consensus is longer, the negotiation success rate is high. The negotiation time of the contractor belonging to type III will be longer than his type II counterpart, indicating that an increase in greed preference will lead to an extension of negotiation time and, to a certain extent, it will lead also to a reduction of the negotiation success rate. Therefore, if the contractor wants to reduce the cost of increasing negotiation time or improve the negotiation success rate, then the degree of his greed preference should be controlled and maintained within a moderate range.

As the contractor’s competitive preference increases, the time needed for the negotiation to reach agreement shows a downward trend and the rate of decline is relatively slow, while the negotiation success rate shows a more obvious downward trend. The results show that an increase in the contractor’s competitive preference does not have a significant impact on the time needed for the negotiation to reach agreement but has a negative impact on the negotiation success rate. As the contractor’s competitive preference continues to increase, he expects to squeeze more profits from the owner in the negotiation process, while the owner with a self-interest preference will not blindly tolerate the behavior of a contractor trying to squeeze his profits, which may lead to negotiation failure.

In the social welfare preference experiment, as the generosity and sympathy components increase, the time needed for negotiations to reach agreement is shortened. When α belongs to $(0, 0.3)$ or $[0.7, 1)$, the negotiation time is in areas D and E, respectively, while as β increases the trend of change in negotiation time is not obvious. It can be seen that sympathy preference does not have an influence on the negotiation time no matter the degree of generous preference.

For the negotiation success rate, when the contractor belongs to type VI, the negotiation success rate in area F is higher than that in D when the contractor belongs to type IV, and both are higher than that in area E area when the contractor belongs to type V. When the contractor's social welfare preference is low, that is, when both α and β are in the interval $[0, 0.3]$, negotiation time and success rate are in a relatively stable range. When social welfare preference is low, the contractor is still more concerned about his own income, and the result of the negotiation is more stable. As the degree of the contractor's social welfare preference intensifies (X, Y are in $[0.3, 0.7]$), he will show much stronger "altruistic" behavior; that is, an increase in owner's revenue will bring a positive effect for the contractor. In this case, the two sides will soon reach a consensus. The negotiation time will therefore be significantly reduced and the negotiation success rate will increase significantly. When the social welfare preference reaches a certain extent (α and β belong to $[0.7, 1]$), the time needed for the negotiations to reach agreement and the success rate enter a steady state due to the owner's satisfaction with his own revenue.

5. Conclusion

In practice, whether decisions regarding the optimization of construction time are scientific and reasonable or not depends on the revenue-sharing negotiation between owner and contractor. The contractor's typical social preferences, such as competitive and social welfare preferences, have significant effects on the negotiation process and project results. So, in order to clarify the mechanism, this paper builds an agent-based model of revenue-sharing negotiation and focuses on the process and results of the time optimization negotiation, introducing the contractor's competitive and social welfare preferences into the negotiation game model. We have analyzed the impacts of different contractor preferences on the revenue-sharing coefficient, negotiation success rate, and negotiation time when negotiation reaches agreement. Finally, we compared the influences of contractor competitive, social welfare, and self-interest preferences.

The experimental results show that (1) compared to social welfare preferences, competitive preferences will make the agent pay more attention to his own gains in the negotiation process and thus his revenue; the stronger the contractor's competitive preference is, the more he can improve his profit; (2) the jealousy component in competitive preference has an important influence on improving the subject's own income, while the greed component is not a significant motivator for the contractor to enhance the revenue-sharing coefficient; (3) the sympathy component in social welfare preference does not have an influence on the revenue-sharing coefficient, no matter the degree of the generosity component.

When the degree of competitive and social welfare preferences is low, the negotiation time and success rate under the influence of both are similar. However, when both types of preference become stronger, the negotiation time and success rate show different evolutionary trends. A stronger greed component in competitive preference will lead to the extension of the negotiation time and, to a certain extent, a reduction of the success rate. The sympathy component in social welfare preference does not have an influence on the negotiation time, no matter how strong the generosity component is.

In the negotiation process, except the social preferences, the bounded rationality also affects agents' decision-making and negotiation strategies, such as loss aversion, heuristics, and biases. So we can combine more bounded rationality with social preferences to construct the utility system of the subject in future research.

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 are no conflicts of interest regarding the publication of this paper.

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