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# Negotiation Model of Design Optimization Profit Distribution with Fairness Concerns in Construction Projects

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## Abstract

Design optimization is an effective strategy to reduce construction project costs. This study focuses on the benefit of design optimization, which should be allocated to the designer. Furthermore, the distribution ratio can be determined through negotiation. In line with this view, this paper initially analyzed the benefits of engineering design optimization and the basic mechanism of its distribution. Second, we established the negotiation model of design optimization profit distribution by considering the fairness concern behavior of subjects. Finally, we set up the following three experimental scenarios: the designer solely has fairness concern behavior, the owner exclusively has fairness concern behavior, and both negotiators have fairness concern behavior. From the engineering projects perspectives, we further analyzed the effects of the fairness concerns of both negotiators in terms of engineering design optimization and negotiation performance using negotiation simulation experiments. Our experimental scenarios results show that the appropriate behavior of fairness concerns by the two negotiators is valuable in improving their own advantages. However, excessive attention to the behaviors of fairness concerns by the two negotiators may lead to an increase in the negotiation cycle, which is not beneficial in attaining optimization. This study aims to provide references for the construction project management.

Keywords: *construction project, design optimization, profit distribution, fairness concerns, negotiation model*

## 1. Introduction

Engineering design is considered the soul of engineering construction projects because it determines the cost, quality, and even the operation benefit of the project (Knotten *et al.*, 2015; Shrestha and Mani, 2014). With the increasing complexity of engineering project, design management is becoming increasingly important (Koskela *et al.*, 2002; Ahadzie *et al.*, 2014). Design optimization is a critical content of design management and an effective approach to as well reduce projects cost (Kuprenas, 2003). Generally, engineering design is divided into preliminary and detailed designs (Ertas and Jones, 1996; Pahl *et al.*, 2007). The task of preliminary design is to determine the main project content and implementation scheme. Furthermore, the detailed design (bidding design, construction drawing design) refines the preliminary design to meet the needs of the engineering construction bid and the construction. In the preliminary design process, engineering design is generally optimized through scheme comparison. However, the complexity of project and the uncertainty of construction conditions limit the optimization depth of the preliminary design. With the deepening of engineering survey work, a large space for optimization still exists in the detailed design process. Furthermore, the professional fees of engineering designs are generally positively related to the project cost (Shrestha and Man, 2015), making it difficult to motivate the designer to optimize the project. Thus, it is one of the urgent challenges for the owner in engineering design management that determining strategies to create an incentive mechanism for engineering design optimization in order to motivate the designer in optimizing project. This topic is generally addressed through principal–agent theory (Smith *et al.*, 2002; Ekanayake, 2004), contract theory (Bolton and Dewatripont, 2005), and game theory (Rasmusen, 2007). On the question of engineering optimization incentive, Tang and Wei (2011) studied the incentive mechanism of engineering design optimization based on principal–agent theory. Similarly, on the value chain perspective, Shen and Wang (2013) used Stakelberg game theory to investigate the incentive problems in optimizing a green building design. Meanwhile, based on game theory, Wang *et al.* (2014) examined the incentive mechanism of design optimization in hydraulic engineering.

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As a matter of fact, engineering design optimization incentive is a problem in optimization profit distribution. Profit distribution is difficult to determine when the design contract is signed, which can only be solved through negotiation during encounters with design optimization events. Negotiation is an important research field in management science (Brett and Thompson, 2016), and it can aid in flexibly and speedily reconciling areas of disagreement (Yousefi *et al.,* 2010; Zhang *et al.,* 2016). Furthermore, engineering management practice is constantly accompanied by many negotiations (Murtoaro and Kujala, 2007), and several studies tackle project negotiation problems. Yuan and Ma (2012) established a bargaining game model of project claim by considering the time value of money. Based on Bayesian theory, Leu *et al.* (2015) studied the problem of game negotiation in engineering procurement. Xue *et al.* (2009) employed the relative entropy method to measure the consensus degree between the negotiators and established an efficient negotiation model of a construction supply chain. Yiu *et al.* (2011) and Yiu and Lee (2011) established a negotiation model of engineering dispute settlement and analyzed the influence of the negotiator's strategy on negotiation outcomes. Based on cusp catastrophe theory, Chow *et al.* (2012) analyzed the influencing factors and formation mechanism of withdrawal in a construction project dispute negotiation.

However, few studies tackle the problem of design optimization profit distribution. In engineering practice, incentivizing the designer with the design optimization profit is also rare for owners. This phenomenon mainly occurs because owners generally have the residual control and claim rights in the construction engineering design contract. Furthermore, they frequently ignore to include an extra payment for the designer, which is also excluded in the design contract, as well as in the design optimization revenue. However, the construction engineering design contract is actually a typical incomplete contract. The engineering design optimization profit should be shared by both parties. If the designer is irrelevant to the extra revenue of engineering optimization (design contract surplus), the designers' additional payment for engineering design optimization will have no compensation. Thus, they will not put in any resourcefulness to optimize the project.

Furthermore, behavioral research shows that people frequently demonstrate significantly strong concerns regarding the fairness of transactions, thereby suggesting that people possess a fairness concern behavior. In the profit distribution process, the participants may refuse to accept the distribution scheme when they sense unfairness (Forsythe, 1994; Scheer, 2003). On the study of fairness concerns, Kahneman *et al.* (1986) introduced fairness concerns into economic management activities, which started the study of the effect of fairness concerns on economic management activities. Ho and Zhang (2008) further confirmed the existence of the behavior of fairness concerns in contract implementation and established the utility function of fairness preference. Loch and Wu (2008) studied the effects of the behavior of the subject's fairness concerns on system efficiency and emphasized that the behavior of the participant's fairness concerns will reduce the entire efficiency of the system. Pavlov and Katok (2011, 2013 and 2014) considered the subject's fairness preference as a private information and further studied the positive effect of the subject's fairness concern behavior on the profit distribution of a supply chain. Thus, fairness concern behavior directly affects the decision-making activities of the stakeholders. In the optimization profit distribution process (the establishment of incentive mechanism), the rational behavior of stakeholders and the irrational behavior of fairness concerns should be considered.

From the above discussions, this paper argues that the benefit of design optimization should be allocated to the designer and the owner. Furthermore, this study regards distribution ratio as a possibility in the determination of the form of negotiation. In the following sections, we first analyze the benefit of engineering design optimization and the basic mechanism of its distribution. Second, we established a negotiation model of design optimization profit distribution based on the principle of revenue-sharing and in considering fairness concerns of the designer and the owner. Finally, we investigate the effects of fairness concerns on profit of engineering design optimization and negotiation performance, and set up three experimental scenarios which combined with engineering examples to conduct negotiation simulation experiments. We hope that this research can provide references for construction project management.

## 2. Design Optimization Profit Analysis

### 2.1 Benefits of Engineering Design Optimization

Engineering preliminary design budgetary is generally an important basis for project investment control. The definition of optimal benefit of engineering design adopted in this paper is defined as the estimated value difference between the engineering preliminary design and the detailed design after engineering design optimization. Furthermore, the benefit of engineering design optimization $E$ can be expressed as:

$$E = I_0 - I_s \tag{1}$$

where $I_0$ is the budgetary of the engineering preliminary design; $I_s$ is the estimated value of the detailed design after engineering design optimization.

Based on the revenue-sharing principle, the benefit of engineering design optimization is distributed between the project designer and owner. We can assume that the designer obtains $\lambda$ ($\lambda$ is the coefficient of profit distribution, $0 < \lambda < 1$) proportion of the total benefit, and the owner obtains the remaining 1-$\lambda$ part. This paper assumes that $d$ represents the designer, and $a$ denotes the owner; then, $V_d$ and $V_a$ are the net income of the designer and owner, respectively. In this paper, we definition the net income is the benefit of engineering design optimization minus the cost of the engineering design optimization.

$$V_d = \lambda E - C \tag{2}$$

$$V_a = (1 - \lambda)E - C_a \tag{3}$$

where $C_d$ is the cost that the designer pays for the engineering design optimization; $C_a$ is the cost that the owner pays for the engineering design optimization.

At the beginning of a detailed design, the budgetary estimate of the engineering preliminary design $I_0$ is a determined value. Furthermore, the estimated value of detailed design $I_s$ is related to the preliminary design budgetary estimate $I_0$ and the degree of the project design optimization. The degree of project design optimization is assumed as $\eta$, and $0 \le \eta < 1$. Normally, the estimated value after project optimization is negatively related to the degree of project optimization. Thus, we obtained the following:

$$I_s = I_0(1-\eta) \tag{4}$$

$$E = \eta I_0 \tag{5}$$

However, there is a certain range of the degree of engineering optimization. When the degree of project optimization is overrun, it will inevitably affect the quality or schedule of construction project. Therefore, in order to ensure the engineering construction's project quality and successful implementation, the degree of engineering design optimization should have an upper limit. The maximum degree of the engineering design optimization is assumed as $\Phi$, and $0 \le \Phi < 1$; where, $\Phi$ is related to the complexity of the project that can be optimized using optimization techniques. Thus, the maximum benefit $E_{\max}$ that can be achieved through engineering design optimization is as follows:

$$E_{\max} = \Phi I_0 \tag{6}$$

where $E_{\max}$ is the possible maximum benefit gained from project design optimization. However, the actual optimal benefit of engineering design is associated with the realized degree of design optimization. $\varphi\,(0 \le \varphi \le 1)$ is assumed to represent the degree of the realized design optimization. Furthermore, the actual optimal benefit of design optimization is $E$, $E = \varphi E_{\max}$. $\varphi$ (the degree of the realized design optimization) is related to the degree of the designer's effort and its utility. $\chi$ is assumed as the degree of the designer's effort, and $\chi \in [0,1]$; $\alpha$ is the designer's utility coefficient of design optimization, and $\alpha \in [0,1]$.

$$\varphi = f(\alpha, \chi) \tag{7}$$

Obviously, the degree of design optimization is positively correlated with the degree of the designer's effort and its utility coefficient. Therefore, $f(\alpha, \chi)$ should strictly have a monotonically increasing function for $\chi$, and $\partial f/\partial\chi > 0$. Then we suppose

$$\varphi = \alpha\chi \tag{8}$$

the actual optimal benefit of the design optimization can be represented as follows:

$$E = \alpha\chi\Phi I_0 \tag{9}$$

Design optimization requires human and material resources, which need cost input. The net income of project design optimization is assumed as $V$, $V = E - C$; where $C$ is the total cost of engineering design optimization (the cost of the designer and the possible payment of the owner). Thus,

$$V = \alpha\chi\Phi I_0 - C_d - C_a \tag{10}$$

### 2.2 Engineering Design Optimization Cost

#### 2.2.1 The Designer's Optimization Costs

The designer plays an important role in design optimization. The costs of the designer can be divided into two parts: tangible and knowledge costs. The former includes equipment and material purchase expenses, whereas the latter refers to the knowledge cost in the design optimization process. The design optimization costs of designer $C_d$ can be expressed as:

$$C_d = C_0^d + C_K^d \tag{11}$$

where $C_0^d$ is the tangible cost of the designer; $C_K^d$ is the knowledge cost. Tangible cost is easy to measure. However, the knowledge cost input is difficult to directly measure. Knowledge cost is constantly measured by the cost coefficient of the knowledge input and the degree of efforts (Zhang *et al.*, 2011). Thus, $C_K^d$ can be expressed as follows:

$$C_K^d = g(\beta, \chi) \tag{12}$$

where $\beta$ is the cost coefficient of the knowledge input, and $\beta \in [0,1]$. $\beta$ can be obtained through evaluation or experience. Furthermore, knowledge cost is generally proportional to the degree of efforts. Therefore, $g(\beta, \chi)$ is the increasing function of the degree of efforts $\chi$, and $g' > 0$. The marginal cost of knowledge simultaneously increases, that is, $g'' > 0$. Furthermore, knowledge cost and the maximum benefit that engineering design optimization can achieve has a certain relationship. Thus, we can assume that:

$$C_K^d = E_{\max}\beta\chi^2 \tag{13}$$

Combine Eq. (13) with Eq. (11):

$$C_d = C_0^d + \Phi I_0 \beta\chi^2 \tag{14}$$

$$V_d = \lambda\alpha\chi\Phi I_0 - C_0^d - \Phi I_0 \beta\chi^2 \tag{15}$$

Profit distribution should meet each party with a net income, that is, $V_d > 0$. Thus, we can obtain:

$$\lambda^d > \frac{C_0^d + \Phi I_0 \beta\chi^2}{\alpha\chi\Phi I_0} \tag{16}$$

Let $\frac{\partial V_d}{\partial\chi} = 0$, we can obtain the best effort degree of the designer by only considering their own benefit to maximize $\chi^*$ as follows:

$$\chi^* = \frac{\lambda\alpha}{2\beta} \tag{17}$$

From Eq. (17), it can be found that the best effort degree of the designer is positively proportional to the coefficient of profit distribution. Furthermore, integrating Eq. (17) into Eq. (15), we can get the following:

$$V_d = \frac{\lambda^2\alpha^2\Phi I_0}{4\beta} - C_0^d \tag{18}$$

#### 2.2.2 The Owner's Optimization Costs

A complete engineering design optimization scheme may sometimes leads to the risk of quality or safety during the implementation of the scheme or after project completion. This would be the possible cost of engineering design optimization to the owner, when those risks happen. The level of the risk loss can be measured by the amount of risk loss and the probability of risk occurrence. The amount of risk loss $R$ due to engineering optimization can be calculated by multiplying the design estimated price $I_s$ of the proposed project and the loss coefficient $\gamma$ as follows:

$$R = I_s \gamma \tag{19}$$

where $\gamma$ is the loss coefficient of the owner to recover or repair the project when accidents occur according to the design optimization scheme, $0 \le \gamma < 1$.

The probability of risk occurrence is assumed as $p$. The probability of the occurrence of risk $p$ is associated with the degree of engineering design optimization $\varphi$. Thus, we can assume:

$$p = \omega\varphi \tag{20}$$

where $\omega$ is the correlation coefficient, indicating the level of correlation between the occurrence probability of risk $p$ and the degree of engineering design optimization $\varphi$, $0 \le \omega \le 1$. Thus, the owner's cost of engineering design optimization can be expressed as follows:

$$C_a = I_s \gamma p \tag{21}$$

Placing the relevant parameters in Eq. (21), we can obtain:

$$C_a = I_s \gamma\varphi\omega = (1-\varphi\Phi) I_0 \gamma\varphi\omega \tag{22}$$

$$V_a = (1-\lambda)\alpha\chi\Phi I_0 - (1-\alpha\chi\Phi) I_0 \omega\chi\gamma \tag{23}$$

Placing Eq. (17) in Eqs. (23) and (10):

$$V_a = \frac{2\lambda(1-\lambda)\alpha^2\Phi I_0\beta - \lambda(2\beta-\lambda\alpha^2\Phi)I_0\omega\alpha^2\gamma}{4\beta^2} \tag{24}$$

$$V = \frac{2\lambda\alpha^2\Phi I_0\beta - \lambda^2\alpha^2\Phi I_0\beta - \lambda(2\beta-\lambda\alpha^2\Phi)I_0\omega\alpha^2\gamma}{4\beta^2} - C_0^d \tag{25}$$

Furthermore, the profit distribution must meet $V_a > 0$; thus:

$$\lambda^a < 1 - \frac{(1-\alpha\chi\Phi)\omega\gamma}{\Phi} \tag{26}$$

### 2.3 Utility Function of Fairness Concerns

The behavior of fairness concerns is a type of psychological behavior that draws the attention of the owner or the designer, particularly on the fairness of their own profit in the profit distribution process. Furthermore, this behavior can be expressed by introducing profit difference into utility function (Ho and Zhang, 2005). With reference to the utility function established by Ho and Zhang (2005), the utility function of fairness concerns of the owner and the designer can be expressed as follows:

$$U_d(V_d) = V_d - \mu_d(V_d - V_d) \tag{27}$$

$$U_a(V_a) = V_a - \mu_a(V_a - V_a) \tag{28}$$

where $\mu_d$ is the coefficient of fairness concerns of the designer, and $\mu_d \ge 0$; $\mu_a$ is the coefficient of fairness concerns of the owner, and $\mu_a \ge 0$. As the coefficient of fairness concerns increases, the degree of the fairness concerns of both sides rises. Furthermore, they pay extra attention to the fairness of profit distribution. In the profit distribution process, the designer and owner may not only focus on how much profit they can gain but also consider the fairness of profit distribution. When the fairness concern psychology of both sides is satisfied, the profit distribution possibly can reach an agreement, that is, $U_d(V_d) > 0$ and $U_a(V_a) > 0$. Thus:

$$\lambda^d > \frac{\mu_d[\Phi-\omega\gamma((1-\alpha\chi\Phi))]}{(1+2\mu_d)\Phi} + \frac{(\mu_d+1)(C_0^d+\Phi I_0\beta\chi^2)}{(1+2\mu_d)\alpha\chi\Phi I_0} \tag{29}$$

$$\lambda^a < \frac{(\mu_a+1)[\Phi-(1-\alpha\chi\Phi)\omega\gamma]}{(1+2\mu_a)\Phi} + \frac{\mu_a(C_0^d+\Phi I_0\beta\chi^2)}{(1+2\mu_a)\alpha\chi\Phi I_0} \tag{30}$$

According to Eqs. (16) and (29), we can obtain the coefficient of profit distribution that the designer can reject (profit distribution coefficient threshold) as $[\lambda_{\min}^d, 1]$. Similarly, according to Eqs. (26) and (30), we can derive the coefficient of profit distribution that the owner can reject as $[0, \lambda_{\max}^a]$.

$$\lambda_{\min}^d = \max\left\{\frac{C_0^d+\Phi I_0\beta\chi^2}{\alpha\chi\Phi I_0}, \frac{\mu_d[\Phi-\omega\gamma((1-\alpha\chi\Phi))]}{(1+2\mu_d)\Phi} + \frac{(\mu_d+1)(C_0^d+\Phi I_0\beta\chi^2)}{(1+2\mu_d)\alpha\chi\Phi I_0}\right\} \tag{31}$$

$$\lambda_{\max}^a = \min\left\{1-\frac{(1-\alpha\chi\Phi)\omega\gamma}{\Phi}, \frac{(\mu_a+1)[\Phi-(1-\alpha\chi\Phi)\omega\gamma]}{(1+2\mu_a)\Phi} + \frac{\mu_a(C_0^d+\Phi I_0\beta\chi^2)}{(1+2\mu_a)\alpha\chi\Phi I_0}\right\} \tag{32}$$

Only when the two sides accept the coefficient can the profit distribution possibly reach an agreement. Thus, we can obtain the threshold of the profit distribution coefficient that the distribution can be achieved (below calls negotiation feasible region) as $[\lambda_{\min}^d, \lambda_{\max}^a]$; where $\lambda_{\max}^a$ must be greater than $\lambda_{\min}^d$.

## 3. Negotiation Model Design

### 3.1 Study Assumptions

(1) Engineering design optimization is profitable; it has a certain net income. Furthermore, the optimal benefit is completely distributed between the designer and the owner.

(2) The designer and owner are willing to solve the problem of design optimization's profit distribution through negotiation.

(3) The designer and owner are rational men. When the negotiation breaks down, the designer and the owner fail to obtain optimal benefit. Therefore, both sides are assumed to refuse withdrawing from the negotiations.

(4) In the negotiation process, the owner occupies the leading position. Thus, the owner initially provides the profit distribution scheme in the negotiation process.

### 3.2 Negotiation Principles

The design optimization's profit distribution is essentially the determination of distribution proportion. The negotiation process can be regarded as a bargaining game, and the owner and designer follow the sequential negotiation rules. Initially, the owner proposes a profit distribution scheme and presents the profit distribution coefficient. The designer decides whether to accept or not. If the designer does not accept the scheme, similarly, the designer should propose a new scheme with the owner deciding whether to accept it or not. Negotiation succeeds when one party accepts the scheme proposed by the other (Fatima *et al*., 2009; Liu, 2013). However, negotiations require significant amounts of energy and time, whereas project implementation has a time limitation. Thus, negotiation cannot continue indefinitely. The maximum negotiation cycle is assumed as *T*. When the negotiation cycle exceeds the maximum negotiation cycle, the negotiation ends and fails.

The owner and designer will typically incur certain consumptions as negotiation progresses. The time and opportunity costs, as well as other negotiation-related factors should be considered. During each negotiation cycle, the negotiating loss coefficient of the designer is assumed as $\sigma_d$, and the owner as $\sigma_a$, $\sigma_x \in [0,1]$, ($x = a$ or $d$) (Li *et al.*, 2013). In this study, the loss coefficient is the fictitious loss set for the negotiation, considering the time cost of negotiation and opportunity cost, which are excluded in the final actual optimization profit and distribution result.

## 3.3 Negotiation Process

Based on the above principles and the research results of Li *et al.* (2013), the negotiation processes of the two negotiators are designed as follows:

First round (negotiation cycle $t = 1$): The owner provides the distribution scheme and coefficient of profit distribution ( $\lambda_{a\to d}(t)$ ). The designer will choose whether to accept or not. If the designer accepts the negotiation succeeds and ends. If the designer does not accept, the designer should propose a new profit distribution coefficient ( $\lambda_{d\to a}(t+1)$ ). However, if the designer refuses the distribution scheme, the negotiation enters the next round. Furthermore, the expected benefits will be a certain loss. At this time, the designer can get the expected benefit when they accept or refuse the distribution scheme proposed by the owner is as follows:

$$V_d\,(\text{accept}) = V_d(\lambda_{a\to d}(t)) \tag{33}$$

$$V_d\,(\text{reject}) = (1-\sigma_d)V_d(\lambda_{d\to a}(t+1)) \tag{34}$$

Expected benefit is an important basis for the designer when he making decisions. If $V_d$ (accept) > $V_d$ (reject), the designer accepts the owner's distribution scheme, and the negotiation ends. However, if $V_d$ (reject) > $V_d$ (accept), the designer rejects the owner's distribution scheme and proposes a new scheme of benefit distribution. The negotiation will then enter into the second round.

Second round (negotiation cycle $t = 2$): The designer will provide the coefficient of profit distribution ( $\lambda_{a\to d}(t)$ ). The owner then chooses whether to accept or not. If the owner accepts it, the negotiation reaches an agreement, thereby ending the negotiation. If the owner does not accept the proposed distribution scheme, the owner presents a new coefficient of profit distribution ( $\lambda_{a\to d}(t+1)$ ); then, the negotiation enters the next round. Simultaneously, this process will again bring about loss of expected profit. At this point, the owners' expected benefit when they accept or refuse the profit distribution scheme is as follows:

$$V_a\,(\text{accept}) = (1-\sigma_a)V_a(\lambda_{d\to a}(t)) \tag{35}$$

$$V_a\,(\text{reject}) = (1-\sigma_a)^2 V_a(\lambda_{a\to d}(t+1)) \tag{36}$$

Simultaneously, if $V_a$ (accept) > $V_a$ (reject), the owner accepts the distribution scheme proposed by the designer, thereby ending the negotiation; If $V_a$ (reject) > $V_a$ (accept), the owner rejects the distribution scheme and a new profit distribution will be proposed. Negotiation then enters the third round.

Third round (negotiation cycle $t = 3$): The owner will provide the coefficient of profit distribution ( $\lambda_{a\to d}(t)$ ) again. The designer then chooses whether to accept or not. If the designer accepts the proposal, the negotiation reaches an agreement and ends. If the designer does not accept the distribution scheme, the designer must propose a new coefficient of profit distribution ( $\lambda_{d\to a}(t+1)$ ) again; then, the negotiation enters into the next round. Furthermore, it will once again bring about loss of expected profit. At this point, the designers' expected benefit when they accept or refuse the distribution scheme is as follows:

$$V_d\,(\text{accept}) = (1-\sigma_d)^2 V_d(\lambda_{a\to d}(t)) \tag{37}$$

$$V_d\,(\text{reject0} = (1-\sigma_d)^3 V_d(\lambda_{d\to a}(t+1)) \tag{38}$$

Similarly, if $V_d$ (accept) > $V_d$ (reject), then, the designer accepts the distribution scheme proposed by the owner; then, the negotiation ends; If $V_d$ (reject) > $V_d$ (accept), the designer refuses the distribution scheme and proposes a new scheme of profit distribution. Negotiation then enters the fourth round.

The negotiation process will continue until one of the parties accepts the distribution scheme of the other; otherwise, when the negotiation cycle exceeds the maximum negotiation cycle ( $t > T$ ), the negotiation ends. Negotiators will bargain for the coefficient of profit distribution $\lambda$. For each profit distribution coefficient $\lambda$, the designer will decide the corresponding degree of design optimization effort, which will lead to a corresponding total net income of the optimization and net income ( $V_a$ and $V_d$ ) that the two sides can obtain.

## 3.4 Bargain Strategy

In the negotiation process, both negotiators have their respective thresholds of the coefficient of profit distribution (the designer's is $[\lambda^d_{\min}, 1]$, and the owner's is $[0, \lambda^a_{\max}]$ ). In the sequential negotiation mode, both the owner and designer will start from their most favorable distribution scheme. They will provide their respective allocation schemes (corresponding to the profit distribution coefficient $\lambda$) based on a certain strategy. When creating a

Table 1. Model Parameters

| Parameters | Value | Parameters | Value |
|---|---|---|---|
| $I_0$ (Preliminary estimated value of the project) | 12.78 billion | $\omega$ (Correlation coefficient) | 0.15 |
| $\Phi$ (The maximum degree of optimization can achieved) | 0.05 | $k^x$ (Initial utility coefficient) | 0.00 |
| $\alpha$ (Utility coefficient of the input of knowledge by designer) | 0.80 | $\psi^x$ (The control coefficient) | 2.00 |
| $\beta$ (The cost coefficient of knowledge by designer) | 0.40 | $\sigma_d$ (The negotiating loss coefficient of designer) | 0.15 |
| $C_0^d$ (Direct cost of the designer) | 153.68 million | $\sigma_a$ (The negotiating loss coefficient of owner) | 0.05 |
| $\gamma$ (Loss coefficient) | 0.05 | $T$ (Maximum negotiation cycle) | 20 |

Note: Each negotiation process is relatively simple. To study the influence of fairness concerns on negotiation effect, the maximum negotiation cycle is set to 20.

bargain strategy, each side may base on a certain criteria, such as time and resources; the most common of which is time series (Ren and Zhang, 2014). Under such conditions, time is a key factor in determining the bargain parameters. At moment $t$, the bargaining parameter $\lambda_{x \to x'}(t)$ that negotiator $x$ provides opponent $x'$ can be expressed as (Faratin *et al.*, 1998; Yu *et al.*, 2013):

$$\lambda_{x \to x'}(t) = \begin{cases} \lambda_{\min}^x + \phi^x(t)(\lambda_{\max}^x - \lambda_{\min}^x) & x = a \\ \lambda_{\max}^x - \phi^x(t)(\lambda_{\max}^x - \lambda_{\min}^x) & x = d \end{cases} \tag{39}$$

where function $\phi^x(t)$ is called the Negotiation Decision Function (NDF), which is defined as follows:

$$\phi^x(t) = k^x + (1 - k^x)(\frac{t}{T})^{1/\psi^x} \tag{40}$$

where $k^x$ is the initial utility coefficient, $k^x \in [0,1]$ ; $\psi^x$ is the control coefficient, $\psi^x > 0$ . $k^x$ and $\psi^x$ determine the bargaining parameters of both negotiators each time. Their specific values are related to the negotiator's negotiation strategy.

## 4. Experiments and Analyses of the Simulated Negotiation

### 4.1 Model Parameters

To verify the validity of the negotiation model and to further study the influence of the fairness concerns behaviors of the two negotiators on the benefit of project design optimization and negotiation effect, this study sets three experimental scenarios: the designer solely has the behavior of fairness concerns (Scenario one), the owner solely has the behavior of fairness concerns (Scenario two), and both negotiators have the behavior of fairness concerns (Scenario three). Furthermore, the actual engineering case was carried out negotiation simulation experiments.

First, determine the preliminary estimated value $I_0$ and the maximum degree of optimization can achieved $\Phi$. The preliminary estimated value $I_0$ is determined at the beginning of the detailed design of a project. The maximum degree of optimization $\Phi$ is related to the complexity of the project that can be optimized using optimization techniques. According to the circumstances of the project, $\Phi$ can be estimated. With the value of $I_0$ and $\Phi$ the benefit of design optimization can be calculated.

Next, in order to calculate the net income that the designer and owner can obtain by design optimization, the utility coefficient of the input of knowledge by designer $\alpha$, cost coefficient of knowledge by designer $\beta$, direct cost of the designer $C_0^d$ , loss coefficient $\gamma$ and correlation coefficient $\omega$ should be determined. Among them, the utility coefficient of the input of knowledge by designer $\alpha$, cost coefficient of knowledge by designer $\beta$ can be estimated according to the designer's situation, such as the designer's ability, experience and so on. The direct cost of the designer $C_0^d$ is easily to be calculated according to the direct input of the designer. The loss coefficient $\gamma$ is related to the scope of design optimization which can be estimated according to the optimization program. At the same time, the correlation coefficient $\omega$ is related to the reliability of the optimization technology. Then, the net income of the designer and owner can be calculated with these values.

At last, the initial utility coefficient $k^x$, control coefficient $\psi^x$, negotiating loss coefficient of the designer $\sigma_d$ and the owner $\sigma_a$ also should be determined. The values of these parameters depend on the bargain strategy of the designer and owner. With these values the bargain values of each cycle can be determined by utilizing Eqs. (39) and (40).

In this paper, the basic parameters of the experiments are shown in Table 1.

### 4.2 Analysis of the Experiment Results

Based on the negotiation model of profit distribution and the parameters of project example, the cases were simulated using "The R Programming Language" to obtain the influence of the fairness concerns of the two sides on the optimal performance of engineering design and the negotiation result of profit distribution. From the simulation experiments, the following results can be obtained:

#### 4.2.1 Impact of the Behavior of Fairness Concerns on the Negotiation Threshold and Negotiable Feasible Region of Both Negotiators

(1) Impact of the behavior of fairness concerns on the negotiation threshold of both sides

From Eq. (17), we can see that the degree of efforts of designer is related to its profit distribution coefficient. Furthermore, the profit distribution coefficient is related to the degree of fairness concerns of both sides. According to Eqs. (16), (17), (26), (29), (30), (31), and (32), simulation analysis allows us to obtain the profit distribution coefficient threshold of both designer and owner as shown in Fig. 1. The vertical line in Fig. 1 represents

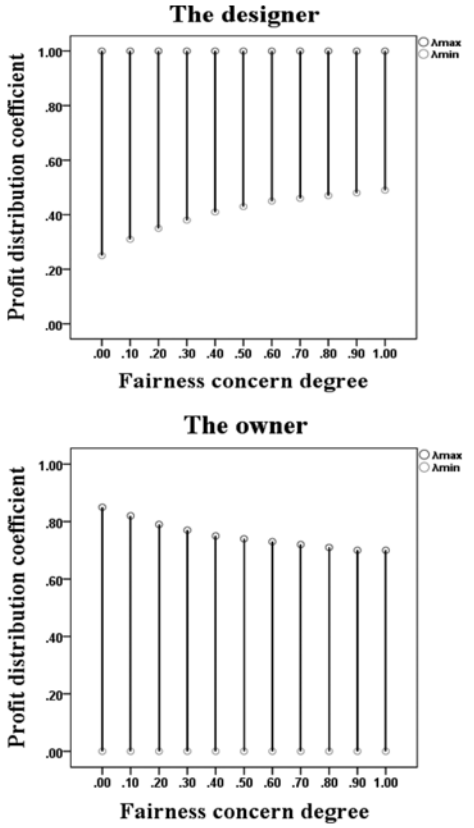


Fig. 1. Corresponding Threshold of the Profit Distribution Coefficient with the Different Degrees of Fairness Concern of Both Sides

the threshold of the respective coefficient of profit distribution under the given degree of fairness concerns.

From Fig. 1, we can see whether the designer or the owner has a gradual narrowing degree of fairness concerns that enhances the threshold of the profit distribution coefficient. Furthermore, the profit distribution coefficient thresholds of both sides determine the size of the negotiation feasible region of the profit distribution.

(2) Impact of the behavior of fairness concerns on the negotiation feasible region

Similarly, according to Eqs. (16), (17), (26), (29), (30), (31), and (32), simulation analysis allows us to obtain the negotiation feasible regions [ $\lambda_{\min}, \lambda_{\max}$ ] under different degrees of fairness concerns in the three scenarios as shown in Fig. 2. The vertical line in Fig. 2 represents the negotiation feasible region of the profit distribution coefficient under the given fairness concern degrees in different scenarios.

From Fig. 2, we can see that the negotiation feasible regions [ $\lambda_{\min}, \lambda_{\max}$ ] of the profit distribution coefficient $\lambda$ are gradually reduced in the three scenarios along with the fairness concerns degree enhancements of both sides. Particularly, the scenarios of both sides include the fairness concern behavior (Scenario three). As the degree of fairness concerns is enhanced, the negotiation feasible region of profit distribution coefficient is significantly reduced. The negotiation feasible region of profit distribution coefficient determines the scope reached in the negotiation. Therefore, the behavior of fairness concerns of both negotiators may directly impact profit distribution negotiation.

### 4.2.2 Impact of Fairness Concerns on Negotiation Performance

Under different degrees of fairness concerns, the thresholds of the coefficient of profit distribution differ between the designer and owner, and the negotiation feasible regions similarly vary. Therefore, the behavior of fairness concern of both negotiators impacts the outcome of the negotiations (negotiation cycle, coefficient of profit distribution, and net income). According to the mentioned negotiation model of design optimization's profit distribution and the basic parameters of the negotiation, the negotiation outcomes under the different degrees of fairness concern analyzed through simulation experiments of the three scenarios. Through simulation analysis, the negotiation cycle $t$ is obtained when the negotiation is successful, the coefficient of profit distribution $\lambda$, and the net income of the design optimization system $V$ in the three types of scenarios under different degrees of fairness concerns as shown in Fig. 3.

From Fig. 3, we can see that the negotiation cycle increases as the degree of fairness concerns of both sides rise. At the same level of fairness concern, the achieved negotiation cycle of both sides having behavior of fairness concerns (Scenario three) is larger than the condition that "only one participant has the

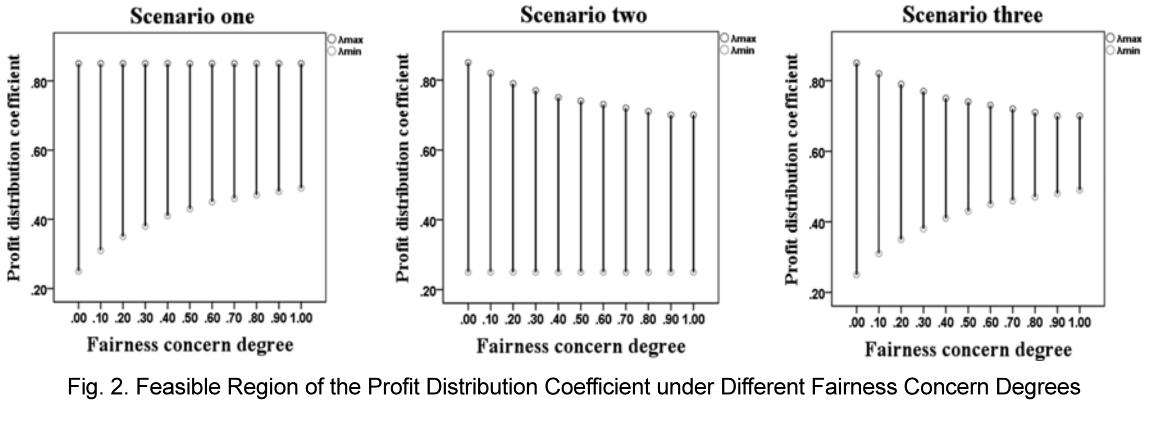
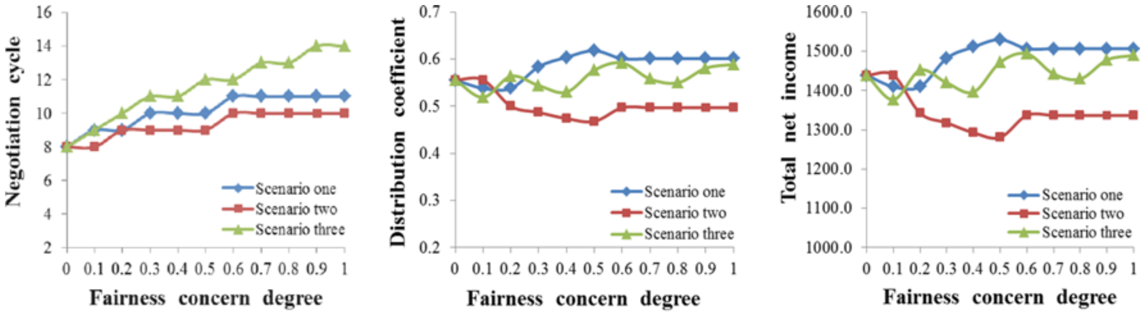


Fig. 2. Feasible Region of the Profit Distribution Coefficient under Different Fairness Concern Degrees



(a) (b) (c)

Fig. 3. Impact of Fairness Concerns on Negotiation Performance: (a) Negotiation Cycle, (b) Distribution Coefficient, (c) Total Net Income

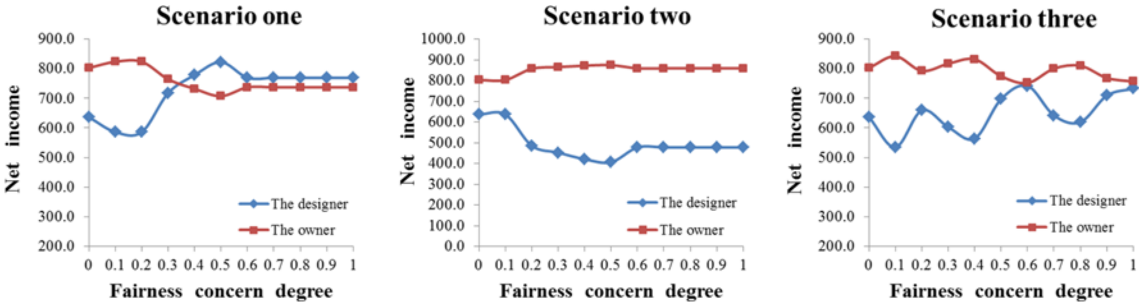


Fig. 4. Impact of Fairness Concerns on the Net Income of Both Sides

behavior of fairness concerns (Scenarios one and two).”

In the case that the designer exclusively has the behavior of fairness concerns (Scenario one), the coefficient of profit distribution $\lambda$ increases with the rise in the degree of fairness concerns when the negotiation is reached. Meanwhile, in the case wherein the owner solely concerning fairness (Scenario two), the coefficient of the profit distribution $\lambda$ will decrease as the degree of fairness concerns rising when the negotiation is reached. In the case that both sides concerning fairness (Scenario three), with the degree of fairness concerns increasing, the coefficient of the profit distribution $\lambda$ obviously fluctuates and increases slightly during the fluctuation when the negotiation is reached.

When the designer solely has the behavior of fairness concerns (Scenario one), with the increasing in the degree of fairness concerns, the net income $V$ of the system optimization will increase when the negotiation is reached. In the case that owner exclusively concerning fairness (Scenario two), with the increasing in the degree of fairness concerns, the net income $V$ of the system optimization will decrease when the negotiation is reached. In the case wherein both sides concerning fairness (Scenario three), with the increasing in the degree of fairness concerns, the net income $V$ of the system optimization evidently fluctuates and slightly increases during the fluctuation when the negotiation is reached.

### 4.2.3 Impact of Fairness Concerns on the Net Income of Both Sides

From Eqs. (18) and (24), we can see that the optimal net income obtained by the designer and owner is related to the profit distribution coefficient. The profit distribution coefficient is placed in the different degrees of fairness concern under the different scenarios when negotiation is reached in Eqs. (18) and (24). We can obtain the changes regarding the optimal net income obtained by both sides with the degrees of fairness concerns when negotiation is reached in the three cases as shown in Fig. 4:

From Fig. 4, in the case that the designer exclusively concerning fairness (Scenario one), the net income of the designer will increase and the net income of owner will decline as the degree of fairness concerns rising when the negotiation is reached. Simultaneously, in the case wherein the owner solely has the behavior of fairness concerns (Scenario two), with the increasing in the degree of fairness concerns, the net income of the owner generally increases when the negotiation is reached; furthermore, the net income of the designer generally declines. In the case that both sides have the behavior of fairness concerns (Scenario three), the net income of both sides obviously fluctuates with the increase in the degree of fairness concerns when the negotiation is reached. However, the net income of the owner displayed a slight downward trend, whereas the net income of designer displayed a slight upward trend.

In summary, in the case whereby one negotiator has the behavior of fairness concerns (Scenarios one and two), with the increase in the degree of fairness concerns, the net income of the party with the behavior of fairness concerns increases, at the same time the net income of the party without fairness concern behavior decreases. In the case wherein both sides have the behavior of fairness concerns (Scenario three), the net incomes that both parties can obtain fluctuates as the degrees of fairness concerns of both sides increase. In the case that “only one participant has the behavior of fairness concerns (Scenarios one and two)," the net income of the party with the behavior of fairness concerns increases with a higher degree of fairness concerns. However, with the increase in the degree of fairness concerns, the negotiation cycle simultaneously increases when the negotiation is reached. Therefore, from the point of project optimization, the behavior of fairness concerns of the two sides should maintain an appropriate principle.

## 5. Conclusions

Design optimization is an effective strategy to reduce the cost of engineering construction projects. Under the condition of design commission, determining the strategies that will motivate the designer to optimize the project.

This paper focuses on the benefit of design optimization that should be allocated to the designer. Considering the behavior of fairness concerns of the designer and owner, this research established the negotiation model of design optimization profit distribution. We used the negotiation mechanism using a new approach to solve the problem of the designer's lack of motivation in the engineering design optimization process. Moreover, this study established three types of experimental scenarios. Through simulated negotiation experiments, we further analyzed the effects of the fairness concerns of the designer and the owner on the profit of engineering design optimization and the negotiation performance. Experiment results show the following result. First, the owner should not ignore negotiation with the designer. Second, in the profit distribution process of design optimization, the negotiation feasible region is reduced as the degrees of fairness concerns of the owner and designer increase, and the negotiation cycle enlarges when negotiation is successful under any scenario. When negotiations are successful, in the case wherein only one negotiator has behavior of fairness concerns (Scenarios one and two), with the increase in the degree of fairness concerns, the net income of the negotiator with the behavior of fairness concerns increases; whereas the net income of the other negotiator without the behavior of fairness concerns decreases. In case whereby both negotiators have the behavior of fairness concerns (Scenario three), the net incomes that both parties can obtain fluctuates as the degree of fairness concerns increases. Furthermore, from the perspective of total net profit that design optimization can obtain, in the case wherein only one participant has the behavior of fairness concerns (Scenarios one and two), the net income of the design optimization system increasing as the degree of fairness concerns of the designer increases. But the owner`s increasing degree of fairness concerns would make the net income of the design optimization system decrease. In the overall, in a situation wherein one negotiator exclusively has the behavior of fairness concerns, the negotiator with the behavior of fairness concerns benefits itself when the degree of fairness concerns is higher. However, from the perspective of the project, an excessive behavior of fairness concerns extends the negotiation cycle. Thus, to ensure the efficiency of negotiations, the degree of fairness concerns of both negotiators should maintain an appropriate principle during negotiation processes.

The purpose of design optimization is not just to decrease the estimated project budget. There are many other design optimization purposes, such as improving the design of the constructability, improve project performance. But to decrease the estimated project budget is the most important purpose of design optimization, often seen in engineering practice. In this paper, we mainly studied the situation of decreasing the estimated project budget. However, this study has some guiding significance for the other purposes. For other purposes, in order to encourage the designer to optimize the design, the owner can give the designer a certain subsidy. The amount of the subsidy may be determined by negotiation between the two parties.

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