Research Article

Study on Design Optimization in Major Railway Projects with Fair Preference Based on Stackelberg Game

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A contractor proposes design changes to achieve design optimization in the design stage of major railway projects, which can effectively solve problems such as project cost overruns. In order to promote cooperation between the construction party and the owner in the design stage, the fairness preference theory was introduced. Based on the relationship characteristics of project participants in a major railway project, a Stackelberg game model between the owner and contractor was established. The influence of fairness preference psychology on both parties’ decision-making behavior and utility changes was discussed. MATLAB software is used to perform numerical simulation analysis on the evolution results of the game model. The research results show the following: The project gain distribution coefficient of the owner and contractor will increase with the increase in their fairness perception strength. The acceptance rate of design changes will decrease with the increase in the contractor’s fairness perception strength, and the owner’s fairness perception intensity has no effect on the acceptance rate of design changes. When only one party has a fairness preference psychology, the project gain distribution coefficient will tilt towards that party. Fairness preference psychology can change the utility of the owner and contractor and narrow the utility gap between two parties.

1. Introduction

At present, the complexity of the internal and external environment of major railway infrastructure projects poses a great challenge to engineering design, leading to a serious disconnection between the two phases of design and construction and frequent problems such as engineering changes and schedule delays during the construction phase, requiring the construction side to advance its participation in the project to the design phase and cooperate with the designer to complete the engineering design. The owner, with the assistance of the government, promotes synergy among the participants of major railway infrastructure projects. This allows the participants to be integrated into the preengineering work earlier and shifts the focus of construction from the construction phase to the design phase [1, 2]. The contractors of major railroad projects participate in engineering design, they use their professional ability and construction experience to make corresponding change requests to the design and construction drawing scheme and participate in project design optimization from the specific construction perspective. Thus, the two phases of project design and construction are realized with high integration, so that the problems existing in the construction phase can be solved in advance in the design phase, which can reduce problems such as engineering changes and cost wastage [3]. But, the lack of clarity in mechanisms such as the distribution of benefits and losses between owners and contractors increases the uncertainty and degree of difficulty in the synergy between the two parties.

Scholars have made some achievements in studying the optimization of design changes in engineering construction projects. In terms of design technology, Su et al. [4] presented an optimization mathematical model of underground pipe corridor structure construction design and developed an optimization design system based on Particle Swarm Optimization algorithm. Tsai et al. [5] proposed an
improved quantum-inspired evolutionary algorithm for solving mixed discrete-continuous nonlinear problems in engineering design. Xie et al. [6] investigated an explicit and comprehensive engineering constraint modeling method to deal with engineering change. Zavala et al. [7] used a multiobjective metaheuristic to analyze the most relevant features of the optimization problem for the design of civil engineering structures. In terms of cooperation management, Liu et al. [8] concluded the design alteration sources systematically and led to excess earnings and excess earnings partition coefficient and extra benefits obtained from default and default cost. It established game models about different design alteration sources and analyzed the cooperative game strategy choice about design-construction union in order to maintain the long cooperative relations. Noghli et al. [9] believed that all major participants in the major infrastructure project jointly formulate project plans and contracts, which is conducive to improving the quality of the project and reducing late construction changes and counterclaim. Czernel [10] believed that the collaborative cooperation of project participants is the key to solving problems such as design changes and construction delays in the construction industry. Zhang et al. [11] argued that the integrated project delivery model has significant advantages in reducing engineering changes and promotes the success of major engineering projects from the perspective of engineering change control. It can be seen that most of the studies are from the perspective of the designer to carry out the design change optimization research and few studies are from the perspective of the cooperation and competition between the owner and the contractor for the design change optimization. This paper intends to use the Stackelberg game method to study the optimization of design changes of major railway project and to clarify the behavioral characteristics and influencing factors of the contractor proposing design changes and the owner accepting design changes.

The Stackelberg game approach has been used in various academic fields. Dastidar [12] proved that generally quantity Stackelberg games are less competitive than price Stackelberg games. Li et al. [13] obtained the team-optimal state feedback Stackelberg strategy of an important class of discrete-time two-person nonzero-sum dynamic games. Li et al. [14] established a game model for recycling units in two different situations: with and without remanufacturing capabilities. Long et al. [15] investigated the strategies’ evolutionary paths of production and recycling units by using evolutionary game theory. Shakrina et al. [16] presented a novel method for the operator to predict market prices and electrical load under a real-time pricing demand response program in a microgrid. Várady [17] studied Stackelberg games in which the follower faces a cost for observing the leader’s action. Yang et al. [18] proposed a Stackelberg routing game on a network to analyze the competitive and cooperative relationships between users. Yu et al. [19] discussed how the vendor call takes advantage of this information for increasing his own profit by using a Stackelberg game in a VMI system. Zhang et al. [20] proposed a decision support system for cyber-security by using the Bayesian Stackelberg game approach. In summary, the Stackelberg method provides research ideas for analyzing the game between collaborators, and it expands the idea of studying the optimization of engineering design changes in this paper.

In major railway projects, the contractor participates in the project early and has certain autonomy in the design scheme during the design stage, and it will make the owner and contractor have many uncertainties about contract enforcement for design scheme change [21]. This paper explores game mechanism of the owner’s and contractor’s strategic behavior for design change optimization in the major railway design stage under the consideration of both parties with fair preference psychology and the mechanism of the role of fair preference psychology in the behavioral strategy and utility of both parties, in order to better promote the synergy between the owner and contractor and reduce the rework loss after railway construction. It provides a theoretical basis for early cooperation between the two parties in the design stage.

2. Stackelberg Game Model Based on Fairness Preference

2.1. Problem Description. The constructor and designer of major railway projects cooperate in the design stage for construction drawing design optimization [22], and the design optimization process is shown in Figure 1, where the constructor enters at the project design stage [23], conducts preconstruction surveys, uses construction theoretical knowledge and experience to propose reasonable design changes to the construction drawings, and optimizes and improves the construction drawing design, which helps to improve construction quality and reduce construction cost and risk; the owner will analyze it qualitatively and quantitatively, decide whether to accept the amount of work of design changes, and finally modify, optimize, or even redesign the part of construction drawings that accept design changes [24, 25].

In the design stage of major railway projects, the contractor participates in project design and uses his own professional capabilities to propose corresponding design changes. In this process, the contractor can choose whether to propose a design change, as to grasp the dominant power of gain distribution due to the design change, so the contractor is the first decision-maker. Since the contractor may proceed from the perspective of overall project’s interests and his own interests, the owner needs to consider whether to accept design changes proposed by the contractor, so the owner is the following decision-maker. The cooperative relationship between the two parties is mainly reflected in the effort behavior of the construction party and the owner regarding the proposal and acceptance of design changes and the distribution of benefits, which jointly determine the quality, cost, and schedule of the major railway project, and the fairness of the benefit distribution determines the stability of the cooperation between the two parties.
2.2. Problem Assumptions. Based on the Stackelberg master-slave game relationship between the owner and contractor in the preliminary design change process of the project [26–28], the following assumptions are proposed.

**Hypothesis 1.** The contractor can put forward quantity change in the project design stage by using his own professional knowledge and efforts. The contractor’s effort cost is \( c_1 m^2/2 \), and \( c_1 \) is the contractor’s effort coefficient.

**Hypothesis 2.** After the contractor proposes design change, the owner can make a choice whether to accept it. The owner’s acceptance rate for design changes is \( k \).

**Hypothesis 3.** Due to the design changes in the early stage of the major railway project, the engineering changes at the construction stage of the project are reduced and the additional gain of the project is \( fmk \). \( f \) is the project gain coefficient and \( f \geq 0 \). And, this part of the gain is shared by the owner and contractor. The gain distribution coefficient obtained by the contractor is \( t \), and then, the gain distribution coefficient obtained by the owner is \( 1−t \), where \( 0 \leq t \leq 1 \).

**Hypothesis 4.** The owner needs to redesign for accepting the design changes, so the effort cost is \( c_2 (km)^2/2 \), where \( c_2 \) is the owner’s effort coefficient.

**Hypothesis 5.** For the amount of work that the owner does not accept the design change, the owner’s benefit loss caused by project change in the construction stage is \( l(1−k)m \), where \( l \) is the benefit loss coefficient.

**Hypothesis 6.** For the amount of work that the owner does not accept the design change, in the construction stage, the contractor uses part of unaccepted design changes to reprice and the benefit is \( rn(1−k)m \) and the remaining part of unaccepted design change causes the contractor to suffer losses. \( r \) is the gain coefficient of the contractor’s reprice, \( q \) is the contractor’s loss of benefit coefficient, and \( n \) is the engineering volume ratio that can be repriced.

2.3. Establishment of the Effectiveness Function. From the above assumptions, the absolute return function of the owner and contractor can be obtained as

\[
\pi_o = (1−t)fm + l(1−k)m − \frac{c_2 (km)^2}{2},
\]

\[
\pi_c = tfkm + [rn − q(1−n)](1−k)m − \frac{c_2 km^2}{2}.
\]  

The utility function when the owner and contractor have fairness preferences is

\[
U_o = \pi_o − \lambda_o (\pi_o − \pi_o),
\]

\[
U_c = \pi_c − \lambda_c (\pi_o − \pi_c).
\]  

\( \lambda_o \) is the owner’s fairness perception coefficient, \( \lambda_c \) is the contractor’s fairness perception coefficient, and \( \lambda_o \geq 0 \) and \( \lambda_c \geq 0 \).

3. Solution and Analysis of the Stackelberg Game Model

3.1. Stackelberg Game When Neither Side Considers Fairness Preference. When \( \lambda_o = \lambda_c = 0 \), both the owner and the contractor have no fairness preference psychology and both parties seek to maximize their own interests; the utility functions of both parties are \( U_{o1} = \pi_o \) and \( U_{c1} = \pi_c \).

The inverse induction method is applied to find the first derivative of \( k \) for \( \pi_c; \partial \pi_o/\partial k = (1−t)fm + lm − c_2 km^2 \). The
second derivative of $k$ is found: $\frac{\partial^2 \pi_c}{\partial k^2} = -c_2 m^2 < 0$. Therefore, $\pi_c$ is a concave function, and there is an optimal solution to the function $\partial \pi_c / \partial k = 0$; $k_1 = [f + l - n(r + q) + q]/2c_2 m$. Substitute $k_1$ into $\pi_c$, and find the first derivative of $t$ for $\pi_c$: $\frac{\partial \pi_c}{\partial t} = \{f^2 - 2tf + [fl + n(r + q) - q]/c_2\}$. On this basis, the second derivative of $t$ is found: $\frac{\partial^2 \pi_c}{\partial t^2} = -2f^2/c_2 < 0$. Therefore, $\pi_c$ is a concave function, and there is an optimal solution to the function $\partial \pi_c / \partial t = 0$; $t_1 = [f + l - n(r + q) - q]/2f$.

The optimal benefits of the owner and contractor are

$$U_{o1} = \pi_{o}^* = \frac{[f + l - n(r + q) + q]^2}{8c_2 - \text{Im}},$$

$$U_{c1} = \pi_{c}^* = \frac{[f + l - n(r + q) + q]^2}{4c_2} + \frac{[n(r + q) - q]m - c_2 m^2}{2}.$$  

On this basis, the second derivative of $t$ is found: $\frac{\partial^2 U_{c2}}{\partial t^2} = -(2 + 3\lambda) f^2/c_2 < 0$. Therefore, $U_{c2}$ is a concave function, and there is an optimal solution to the function $\partial U_{c2}/\partial t = 0$;

$$t_2 = [(1 + 2\lambda_k)f + (1 + \lambda_c)\{n(r + q) - q\}]/(2 + 3\lambda_c f).$$

Substitute $t_2$ into $k_2:

$$k_2 = (1 + \lambda_k)f + [f + l - n(r + q) + q]/(2 + 3\lambda_c)c_2 m,$$

In this case, owner utility and contractor utility are as follows:

$$U_{o2} = \frac{(1 + \lambda_c)\{f + l - n(r + q) + q\}^2}{2(2 + 3\lambda)^2 c_2} - \text{Im},$$

$$U_{c2} = \frac{(1 + \lambda_c)\{f + l - n(r + q) + q\}^2}{2(2 + 3\lambda)^2 c_2} + \frac{[n(r + q) - q]m - c_2 m^2}{2} + \lambda_c \text{Im}.$$  

**Proposition 1.** When the contractor has fairness preference, the contractor’s project gain distribution coefficient will increase and the owner will reduce the acceptance rate for design changes.

**Proof.**

$$t_2 - t_1 = \frac{\lambda_c f + [f + l - n(r + q) + q]}{2(2 + 3\lambda_c) f} > 0,$$

$$k_2 - k_1 = \frac{\lambda_c f + [f + l - n(r + q) + q]}{2(2 + 3\lambda_c) c_2 m} < 0.$$  

### 3.2. Stackelberg Game When the Contractor Has Fairness Preference

When $\lambda_o = 0$ and $\lambda_c \neq 0$, the contractor has a fairness preference. The contractor will understand the differences in interests between himself and the owner and take different decisions in accordance with the owner’s interests. When the owner’s interest is greater than the contractor’s, the utility will decrease.

The utility functions of both parties are

$$U_{o2} = \pi_{o}^* = \frac{(1 - t)fnk - l(1-k)m - c_2 (km)^2}{2},$$

$$U_{c2} = (1 + \lambda_c)\{f + l - n(r + q) - q\}(1 - k)m - \frac{c_2 (km)^2}{2}.$$  

The inverse induction method is used to solve for the utility function, $k_2 = [f + l - n(r + q)/2c_2 m$ can also be obtained. Substitute $k_2$ into $U_{c2}$, and find the first derivative of $t$ for $U_{c2}$:

$$\frac{\partial U_{c2}}{\partial t} = (1 + \lambda_c)\{f^2 - 2f^2 t + \text{Im} + f\{n(r + q) - q\}\}c_2 - \lambda_c(4 - f^2 + f^2 t - f^2 t)$$

Owing to $t_2 - t_1 > 0$, it shows that when the contractor has a fairness preference, in order to prevent the owner’s income from being higher than himself, so as to improve his own project gain distribution coefficient, the project gain is inclined to the contractor. The owner finds that the project gain distribution coefficient was reduced and the incentive effect of accepting design changes was reduced, thereby reducing the acceptance rate of design changes. 

**Proposition 2.** When the contractor has a fairness preference, the owner’s utility will be reduced and the contractor’s utility change is related to fairness perception of fairness preference.

**Proof.**

$$U_{o2} - U_{o1} = \frac{\lambda_c(4 + 5\lambda_o)f + [f + l - n(r + q) + q]}{8(2 + 3\lambda_o)^2 c_2} < 0,$$

$$U_{c2} - U_{c1} = \frac{\lambda_c(1 + 2\lambda_c)\{f + l - n(r + q) + q\}^2}{4(2 + 3\lambda_c)^2 c_2} + \frac{\lambda_c[\{n(r + q) - q\}m + \text{Im} - c_2 m^2]}{2}.$$  

Owing to $U_{o2} - U_{o1} < 0$, it shows that when the contractor has fairness preference, the owner’s utility will be lower than when there is no fairness preference. When $\lambda^*_o = 4c_1c_2m^2 - 8c_2 [n(r + q) - q + l]m - [f + l - n(r + q) + q]^2/$
\[2[f + l - n(r + q) + q] + 12c \pi [n(r + q) - q + 1]m - 6c_2 c_4 m^2,\]

the contractor's utility will not change. When \( \lambda_c > \lambda_c^* \) and \( U_{c2} - U_{c1} > 0 \), the contractor’s utility will be reduced. When \( \lambda_c < \lambda_c^* \) and \( U_{c2} - U_{c1} < 0 \), the contractor’s utility will be increased.

**Proposition 3.** When the contractor has fairness preference, the contractor’s project gain distribution coefficient increases as the contractor’s fairness perception intensity increases and the owner’s acceptance rate for design change and utility decreases as the contractor’s fairness perception intensity increases.

Proof.

\[
\frac{\partial t_2}{\partial \lambda_c} = \frac{f + l - n(r + q) + q}{(2 + 3\lambda_c)^2 f} > 0,
\]

\[
\frac{\partial k_2}{\partial \lambda_c} = \frac{f + l - n(r + q) + q}{(2 + 3\lambda_c)^2 c_2 m} < 0,
\]

\[
\frac{\partial U_{c2}}{\partial \lambda_c} = \frac{(1 + \lambda_c)[f + l - n(r + q) + q]^2}{(2 + 3\lambda_c)^2 c_2} < 0.
\]

Owing to \( \partial t_2 / \partial \lambda_c > 0 \), \( \partial k_2 / \partial \lambda_c > 0 \), and \( \partial U_{c2} / \partial \lambda_c < 0 \), it shows that when the contractor has fairness preference, the greater the contractor’s perception of fairness, the greater the project gain allocation coefficient tilted toward the contractor and the smaller the tilt toward the owner, resulting in less income for the owner. Therefore, the owner’s acceptance rate for design change is smaller.

3.3. Stackelberg Game When the Owner Has Fairness Preference. When \( \lambda_o \neq 0 \) and \( \lambda_c = 0 \), the owner has a fairness preference. The owner will understand the differences in interests between himself and the contractor and take different decisions in accordance with the contractor’s interests. When the contractor’s interest is greater than the owner’s, the utility will decrease.

The utility functions of both parties are

\[
U_{o3} = \left(1 + \lambda_o\right)(1 - t)k fm - (1 - k)m - \frac{1}{2}c_2 (km)^2
\]

\[\begin{align*}
\end{align*}\]

\[
- \lambda_o f tf m + [n(r + q) - q]m - c_1 m^2 / 2, \tag{10}
\]

\[
U_{c3} = \pi_c = tf m + [n - q(1 - n)](1 - k)m - \frac{1}{2}c_2 m^2.
\]

The inverse induction method is applied to find the first derivative of \( k \) for \( U_{o3} \):

\[
\frac{\partial U_{o3}}{\partial k} = \left(1 + \lambda_o\right)[(1 - t)fm + km - c_2 km^2]
\]

\[\begin{align*}
\end{align*}\]

\[- \lambda_o ftf m - [n(r + q) - q]m.\]  

The second derivative of \( k \) is found:

\[
\frac{\partial^2 U_{o3}}{\partial k^2} = -fm < 0. \text{ Therefore, } U_{o3} \text{ is a concave function, and }\]

\[
\frac{\partial U_{o3}}{\partial t} = 0, \text{ and } k_3 = \left[(1 - t)f + l\right]/c_2 m - \lambda_o [tf - n(r + q) + q]/c_2 m(1 + \lambda_c).
\]

Substitute \( k_3 \) into \( U_{c3} \), and find the first derivative of \( t \) for \( U_{c3} \):

\[
\frac{\partial U_{c3}}{\partial t} = \frac{\{f^2 + f[n(r + q) - q] - 2tf\}}{c_2 - 2\lambda_o f[tf - n(r + q) + q]/c_2 (1 + \lambda_o)}. \tag{12}
\]

The second derivative of \( t \) is found:

\[
\frac{\partial^2 U_{c3}}{\partial t^2} = -2f/c_2 - 2\lambda_c f^2/c_2 (1 + \lambda_o) < 0. \text{ Therefore, } U_{c3} \text{ is a concave function, and there is an optimal solution to the function } \frac{\partial U_{c3}}{\partial t} = 0;
\]

\[
t_3 = \left[(1 + \lambda_o)[f + l + n(r + q) - q] + 2\lambda_o [n(r + q) - q]\right] / 2(1 + 2\lambda_o). \tag{13}
\]

Substitute \( t_3 \) into \( k_3 \), and

\[
k_3 = [f + l - n(r + q) + q]/2c_2 m.
\]

In this case, owner utility and contractor utility are as follows:

\[
U_{o3} = \frac{(1 + \lambda_o)[f + l - n(r + q) + q]^2}{8c_2}
\]

\[\begin{align*}
- (1 + \lambda_o)[ln + \lambda_o \{[n(r + q) - q]m - c_1 m^2 / 2],
\end{align*}\]

\[
U_{c3} = \frac{(1 + \lambda_o)[f + l - n(r + q) + q]^2}{4(1 + 2\lambda_o)c_2}
\]

\[\begin{align*}
+ [n(r + q) - q]m - c_1 m^2 / 2.
\end{align*}\]  

**Proposition 4.** When the owner has fairness preference, the project gain distribution will be tilted towards the owner, which has no effect on the acceptance rate of design changes.

Proof.

\[
t_3 - t_1 = \frac{\lambda_o [f + l - n(r + q) + q]^2}{2(1 + 2\lambda_o)f} < 0,
\]

\[
k_3 - k_1 = 0.
\]

Owing to \( t_3 - t_1 < 0 \), it shows that when the owner has fairness preference, in order to prevent the contractor’s income from being higher than his own, so as to improve his own project gain distribution coefficient, the contractor does not have fairness preference and will not feel unfairness to it, so the owner does not need to adjust his strategy.
Proposition 5. When the owner has fairness preference, the contractor's utility will be reduced and the owner's utility change has nothing to do with the fairness perception of fairness preference.

Proof

\[
U_{o3} - U_{o1} = \lambda_o \left\{ \frac{(f + l - n(r + q) + q)^2}{8c_2} + \left\{ \frac{[n(r + q) - q - l]m - 1/2 \cdot c_1 m^2}{2(1 + 2\lambda_o)^2f} \right\} \right\}
\]

Owing to \( U_{o3} - U_{o1} < 0 \), it shows that when the owner has fairness preference, the contractor's utility will be lower than when the owner does not have fairness preference. The owner's fairness perception strength \( \lambda_o \geq 0 \), so there is no relationship to the sign of \( U_{o3} - U_{o1} \); that is, the owner's utility change has nothing to do with the fairness perception of fairness preference. □

Proposition 6. When the owner has fairness preference, the owner's project gain distribution coefficient increases as the owner's fairness perception intensity increases, which has no effect on the acceptance rate of the owner's design changes.

Proof

\[
\frac{\partial t_3}{\partial \lambda_o} = -\frac{f + l - n(r + q) + q}{2(1 + 2\lambda_o)^2f} < 0,
\]

\[
\frac{\partial k_3}{\partial \lambda_o} = 0,
\]

\[
\frac{\partial U_{c3}}{\partial \lambda_o} = -\frac{(f + l - n(r + q) + q)^2}{4(1 + 2\lambda_o)^3 c_2} < 0.
\]

Owing to \( \frac{\partial t_3}{\partial \lambda_o} < 0, \frac{\partial k_3}{\partial \lambda_o} < 0, \) and \( \frac{\partial U_{c3}}{\partial \lambda_o} < 0 \), it shows that when the owner has fairness preference, the greater the owner's perception of fairness, the greater the project gain distribution coefficient tilted toward the owner, and the smaller the tilt toward the contractor, resulting in less revenue for the contractor. The owner's acceptance rate for design plan will not change. □

3.4. Stackelberg Game When Both Parties Have Fairness Preferences. When \( \lambda_o \neq 0 \) and \( \lambda_c \neq 0 \), both the owner and contractor have psychology of fairness preference. The owner and contractor will understand the difference between each other's interests and will take different decisions based on the other's interests. When the other party's interests are greater than their own, the utility will be reduced.

\[
U_{o4} = (1 + \lambda_o) \left\{ (1 - t)fkm - l(1 - k)m - c_2 (km)^2/2 \right\}
\]

\[
- \lambda_o \left\{ tfkm + [n(r + q) - q]m - c_1 m^2/2 \right\},
\]

\[
U_{c4} = (1 + \lambda_o) tfkm + ([n(r + q) - q] (1 - k)m - 1/2c_1 m^2)
\]

\[
- \lambda_c \left\{ t - (1 - t)fkm - l(1 - k)m - c_2 (km)^2/2 \right\}.
\]

In the same way,

\[
t_4 = \frac{(1 + \lambda_c + \lambda_o) \left\{ f + l - n(r + q) + q \right\}}{(1 + 2\lambda_o) \left\{ 2\lambda_o + 3\lambda_c + 2\lambda_o \lambda_c + 2 \right\}} - \frac{[\lambda_o (3\lambda_o + 4\lambda_c + 2\lambda_o \lambda_c + 3) \left\{ n(r + q) - q \right\}}{(2\lambda_o + 3\lambda_c + 2\lambda_o \lambda_c + 2)f}
\]

\[
k_4 = \frac{(1 + \lambda_c + \lambda_o) \left\{ f + l - n(r + q) + q \right\}}{(2\lambda_o + 3\lambda_c + 2\lambda_o \lambda_c + 2)c_2 m},
\]

\[
U_{o4} = \frac{(1 + \lambda_o)(1 + \lambda_c + \lambda_o)^2 \left\{ f + l - n(r + q) + q \right\}^2}{2 \left\{ 2\lambda_o + 3\lambda_c + 2\lambda_o \lambda_c + 2 \right\}^2 c_2} - (1 + \lambda_o)lm - \lambda_o \left\{ (n(r + q) - q)m - 1/2c_1 m^2 \right\},
\]

\[
U_{c4} = \frac{(1 + \lambda_o)(1 + \lambda_c + \lambda_o)^2 \left\{ f + l - n(r + q) + q \right\}^2}{2 \left\{ 2\lambda_o + 3\lambda_c + 2\lambda_o \lambda_c + 2 \right\} c_2} + (1 + \lambda_c) \left\{ (n(r + q) - q)m - 1/2c_1 m^2 \right\} + \lambda_l lm.
\]
Proposition 7. When the owner and contractor have fairness preferences, the owner's project gain distribution coefficient increases with the increase in owner's fairness perception intensity and decreases with the increase in contractor's fairness perception intensity. The acceptance rate of design change decreases with the increase in fairness perception intensity of the owner and contractor.

Proof. 

\[
\begin{align*}
\frac{\partial t_i}{\partial \lambda_o} &= \frac{(1 + \lambda_o)^2 [f + l - n(r + q) + q]}{(2\lambda_o + 3\lambda_i + 2\lambda_o + 3\lambda_o + 2)^2} > 0, \\
\frac{\partial t_i}{\partial \lambda_c} &= -\frac{2(1 + \lambda_o)(1 + 2\lambda_i)(1 + \lambda_o + \lambda_i) [f + l - n(r + q) + q]}{(1 + 2\lambda_o)^2 (2\lambda_o + 3\lambda_i + 2\lambda_o + 3\lambda_o + 2)^2} < 0, \\
\frac{\partial k_i}{\partial \lambda_o} &= \frac{(1 + 2\lambda_o)(1 + \lambda_o) [f + l - n(r + q) + q]}{(2\lambda_o + 3\lambda_i + 2\lambda_o + 3\lambda_o + 2)^2} c_i m < 0, \\
\frac{\partial k_i}{\partial \lambda_c} &= \frac{\lambda_o (1 + 2\lambda_i) [f + l - n(r + q) + q]}{(2\lambda_o + 3\lambda_i + 2\lambda_o + 3\lambda_o + 2)^2} c_i m < 0.
\end{align*}
\] 

(20)

Owing to $\frac{\partial t_i}{\partial \lambda_o} > 0$, $\frac{\partial t_i}{\partial \lambda_o} < 0$, $\frac{\partial k_i}{\partial \lambda_o} < 0$, and $\frac{\partial k_i}{\partial \lambda_c} < 0$, it shows that when both the owner and contractor have fairness preference, the acceptance rate of design changes (owner's strategy) decreases with the increase in the fairness perception strength of both parties. The project gain distribution coefficient (contractor's strategy) is inclined toward the side with greater fairness perception strength.

4. Numerical Simulation Analysis

According to the model assumptions, the relevant parameters are assumed to be $m = 10$ million dollars, $f = 0.8$, $l = 0.1$, $n = 0.5$, $r = 0.15$, $q = 0.05$, $c_1 = 3 \times 10^{-4}$, and $c_2 = 6 \times 10^{-4}$.
MATLAB software is used for numerical simulation analysis of the above three situations, and the impact of fairness preference on the strategies and utilities of the owner and contractor is discussed [29, 30]:

1. When the contractor has fairness preference, as shown in Figure 2, as the intensity of the contractor’s fairness preference increases, the contractor’s project gain distribution coefficient gradually increases and the rate of increase gradually slows down; the acceptance rate of the owner’s design change gradually decreases, and the rate of decrease gradually slows down. The contractor’s utility is gradually increasing, the owner’s utility is gradually decreasing, and the rate of increase of contractor’s utility is much higher than the rate of decrease of owner’s utility.

2. When the owner has fairness preference, as shown in Figure 3, as the intensity of owner’s fairness preference increases, the contractor’s project gain distribution coefficient gradually decreases and the owner’s project gain distribution coefficient gradually increases; the acceptance rate of owner’s design plan change remains unchanged. The contractor’s utility gradually decreases, the owner’s utility gradually increases, and the rate of increase of owner’s utility is much higher than the rate of decrease of contractor’s utility.

3. When both the owner and contractor have fairness preferences, as shown in Figure 4, the owner’s project gain distribution coefficient increases with the increase in owner’s fairness perception strength and decreases with the increase in contractor’s fairness perception strength. And, the impact of owner’s fairness perception strength on the project gain distribution coefficient is greater than the impact of contractor’s fairness perception strength on the project gain distribution coefficient. The acceptance rate of design change decreases with the increase in fairness perception intensity of the owner and contractor. The impact of contractor’s fairness perception strength on the strategies and utilities of the owner and contractor is discussed [29, 30]:

![Figure 2: The impact of contractor’s fairness preference on the strategies and utility of both parties.](image)
perception strength on the acceptance rate of design change is greater than the impact of owner’s fairness perception strength on the acceptance rate of design change.

As shown in Figure 5, the intensity of contractor’s fairness preference has an improved effect on the contractor’s utility and a reduced effect on the owner’s utility. The intensity of owner’s fairness preference has an improved...
effect on the owner’s utility and a reduced effect on the contractor’s utility. The impact of the owner’s fairness preference intensity on the contractor’s utility is far less than the impact of contractor’s fairness preference intensity on its own utility. The impact of contractor’s fairness preference intensity on the owner’s utility is far less than the impact of owner’s fairness preference intensity on its own utility.

5. Conclusion and Recommendation

5.1. Conclusion. This paper studies the impact of fairness preferences on the decision-making behavior and utility of the owner and contractor for design changes in major railway projects. The research shows the following: (1) When the contractor has fairness preference, the contractor’s project gain distribution coefficient will increase, and it will increase with the increase in fairness perception strength. The contractor’s utility change is related to the fairness perception strength of fairness preference. The owner’s acceptance rate and utility of design changes will decrease. (2) When the owner has fairness preference, the owner’s project gain distribution coefficient will increase, and it will increase with the increase in fairness perception strength, which has no effect on the acceptance rate of design changes. The owner’s utility change has nothing to do with the fairness perception strength of his fairness preference, and the contractor’s utility will decrease. (3) When both parties have fairness preference, one side’s project gain distribution coefficient increases with the increase in fairness perception strength and decreases with the increase in the other party’s fairness perception strength. The impact of one party’s fairness preference intensity on other party’s utility is far less than the other party’s own influence on the utility. The acceptance rate of design changes decreases with the increase in the fairness perception strength of both parties.

5.2. Recommendation. Based on the above conclusions, the following management and policy insights can be obtained: (1) When formulating incentive contracts, owners should not only consider the cost of the contractor’s design change optimization efforts but also consider the influence of factors such as the degree of the contractor’s fair preference and the degree of benefit reduction of engineering changes. (2) In order to improve the enthusiasm of contractors to participate in the design phase of major railway projects, in addition to increasing the share of gain in design change optimization, the owner should select the contractor with a higher degree of fair preference for design change optimization as far as possible. (3) In order to improve the acceptance rate of the owner for design change optimization, the contractor with a lower degree of fair preference should be selected for design change.

This paper studies the game and cooperation between the owner and the contractor on design change optimization of major railway projects, focusing on the influence of fair preference on the decision of both parties. In the practice of major railway infrastructure projects, design changes have been prevalent during the construction period, other subjects involved in the project, such as designers, supervisors, consultants, should be considered, and the synergistic cooperation between multiple subjects for the optimization of engineering design changes is worthy of in-depth exploration and research.

Data Availability

No data were used to support this study. This study uses formula derivation for the proof.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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