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Research Article

A Selection Model on Risk Response Scheme for Complex Equipment Research and Manufacturing

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Risk is an important factor affecting the success of complex equipment research and manufacturing, so how to deal with the risk properly has become the key to risk management of complex equipment cooperative research and manufacturing. In view of this, considering that the choice of risk response schemes for complex equipment research and manufacturing is a consensus issue of group negotiation, this paper exploits group decision-making and utility theory to establish a risk disposal scheme selection model for complex equipment development based on group negotiation consensus, and then a case verifies the validity and rationality of the proposed model. The results show that the consensus scheme selection problem proposed in the paper effectively combines the preference value and utility, considers the supplier's risk preference behavior, and achieves the multisubject consensus scheme.

1. Introduction

The complex equipment is an important factor to measure the science and technology level, industry level, and comprehensive national strength of a country. The complex equipment research and manufacturing has many characteristics such as multisubject, high technology, long period, and high investment [1]. It refers to much more uncertain information and more risks compared with the general project. For example, the development system may face the risks including the technology, production, and finance. To deal with the risk and realize the effective coordination of the complex equipment research and manufacturing, the complex equipment manufacturer adopts the main manufacturer-supplier management mode. In the mode, the interest demand and interest relation of relevant subjects in the project are complementary and consistent, as well as conflicting and competitive. Because of the inconsistency of the interest basic points, the attitudes and disposal methods of various project subjects on project risks also show great differences, which often lead to a complicated equilibrium phenomenon of the relationship between interest and risk among all kinds of project subjects. Therefore, how to effectively deal with the relationship between interest conflict and risk is very important. Similarly, it is significant to choose the risk response scheme for the complex equipment to collaborate research and manufacturing.

The existence of multisubjects in the collaborative development of complex equipment adds difficulty to the selection of risk response scheme, which we can regard as a typical group decision-making problem. For the decision-making bodies in the complex equipment development system, it is their goal to maximize the benefits while completing the equipment development. When faced with risks, they have their own attitudes and preferences. In the main manufacturer-supplier management mode, how the main manufacturer takes action to make consensus decisions among the suppliers in the complex system is the key to the successful development of complex equipment. When the subjects choose the risk response scheme, they usually conduct group game and negotiation based on their initial selection scheme and then draw the selection that the individual thinks is ideal. But that is not the optimal solution for the whole complex equipment system to solve the risk problem. Therefore, it is important to use group negotiation and coordination to analyze the choice of the optimal scheme for risk response.

The existing research about the collaborative development for complex equipment discussed the risk reasons, risk identification, risk assessment and measurement, and risk control. There are many reasons that can explain the risk of collaborative development for complex equipment. The domestic and foreign scholars analyze it from the aspects of market, finance, operation [2], technology [3], coordination, quality, progress [4], and cost [5], and they classify the risk factors. In order to evaluate the risk of equipment development and measure the risk degree, many researches mainly consider the effect of the uncertainty factors, development schedule, and development system cost [6, 7], and then they construct the evaluation index system and evaluation measure program. The main evaluation methods are as follows: review technology [8], grey target [9], fuzzy comprehensive evaluation method [10], NPV risk tool [11] supported by Monte Carlo Simulation, multicriteria analysis (MCA) sustainability evaluation method [12], and maximum entropy [13]. To solve the risk problems, by using game theory principal-agent theory and game model, some scholars analyzed the earnings and relationship between main manufacturer and suppliers under the cooperation or noncooperation [14, 15]. By designing the coordination mechanism and coordination scheme [16, 17], the strategies and methods for risk control were proposed [18–20].

Collaborative development of complex equipment involves many decision-makers such as manufacturers and suppliers. The choice of complex equipment risk response scheme is the game between multiple decision-making bodies, which is a typical group decision-making and group negotiation problem. The existing research about group decision-making and negotiation problem mainly focuses on the fuzzy number [21, 22], fuzzy preference relationship [23], etc. These models and methods mainly solve problems by determining the weights of decision-makers and use fuzzy ideal and linguistics [24–26] to analyze the large-scale group decision-making, but it is difficult to the selection of risk response scheme in complex group. There are other methods that use hierarchical clustering algorithms and integration operators to construct hybrid multicriteria decision-making methods and choose the best solution [27–30]. Although these methods considered the complexity of decision-making by multiple alternatives and used multiple methods to sort the alternatives, they did not consider the satisfaction and preference of the decision-makers, and the decision-making results are one-side. Analyzing preference of group decision-makers can make a satisfaction scheme for the group decision-making [31]. And there are some methods such as grey incidence analysis, grey group negotiation, and grey group decision-making [32]. By analyzing complex group decision-making problem, optimal selection scheme of decision group was proposed. But these researches did not propose a feasible coordination scheme to coordinate the interests of group decision-makers.

According to the above discussion and analysis, there are few researches on how to select the risk management solutions. However, the appropriate solutions accepted by all relevant subjects are crucial to the success of complex equipment research and manufacturing. Therefore, how to choose effective risk management solutions is particularly important. In view of this, aiming at the risk response scheme selection problem of complex equipment research and manufacturing, considering the choice of risk response schemes is usually the process of negotiation and decision-making by groups and multi-decision-makers, such as the main manufacturer and supplier. And the manufacturer is only willing to provide limited coordination costs in the group negotiation. Meanwhile, the suppliers have risk decision preferences. This paper exploits group negotiation, utility function, and minimum cost coordination to establish a risk response scheme selection model for complex equipment cooperative development based on group negotiation consensus. And this paper can provide theory and method for complex equipment manufacturing enterprise management.

The key issues in the remainder of this paper are organized as follows: Section 2 establishes a decision model of individual ideal scheme selection for complex equipment risk response based on group consensus. In Section 3, we construct a novel consensus selection model of complex equipment risk response scheme based on minimum cost coordination and maximum utility subsidy. A real-world case study is furnished in Section 4 to illustrate how the proposed method can be applied. The paper concludes with some remarks in Section 5.

2. A Decision Model of Individual Ideal Scheme Selection for Complex Equipment Risk Response Based on Group Consensus

The complex equipment research and manufacturing is a complex system engineering which involves a large number of subjects and uncertainties, and the process is accompanied by lots of risks. How to choose an effective risk response scheme is the key to the success of collaborative development of complex equipment. However, the choice of risk response schemes is the process of group negotiation and decision-making between the main manufacturer and suppliers, which can be said to be a typical group consensus problem. In view of this, we consider that the selection of the risk response scheme is the two-stage process, which firstly is negotiated by the manufacturer and supplier group based on maximizing their own goal and secondly is coordinated by the main manufacturer based on the demand of developing systems. In this section, we construct a model for selecting risk response scheme of complex equipment research and manufacturing based on group negotiation consensus by using the group decision, Nash bargaining model, and utility theory.

2.1. Model Assumption. In the process of group grey target decision, an ideal scheme or bulls-eye is usually the result produced by the group negotiation and decision-making system coordination. In general, experts or decision-makers determine their ideal schemes through game negotiation with different bargaining power. However, negotiation schemes are not a consensus scheme accepted by all experts or decision-makers. In this case, founded on the stability of the decision-making system and the effectiveness of decision, decision system (coordinator) takes some actions to induce experts or decision-makers to change their schemes, so that it will produce a consensus ideal scheme or bulls-eye. In view of this, considering the existing problem of the grey target decision, we utilize the asymmetric Nash bargaining model and the thought of the minimization of system coordination deviation to construct a two-step optimization model to determine the stage bulls-eye.

Assumption 1. Assume that there is a complex equipment research and manufacturing system consisting of the main manufacturer and many suppliers, and it is recorded as $S = \{s_0, ..., s_i, ..., s_p\}$. s_0, s_i $(i = 0, 1, ..., p)$ represent the manufacturer and suppliers, respectively. In the system, the main manufacturer is at the core and able to coordinate suppliers to a certain extent, while suppliers are in a subordinate position.

Assumption 2. The subjects may have different losses under different response schemes, so that they will have different preferences for different risk response schemes. Let d_i $(i = 0, 1, 2, ..., p)$ represent the subjects' preference value to any risk response schemes. The greater the preference value is, the higher the degree of recognition of subjects to risk response schemes x_j is and vice versa.

Assumption 3. In the complex equipment research and manufacturing system, in order to deal with risks, the system will have an initial response scheme and a consensus response scheme. The research and manufacturing system will try to formulate an initial response scheme, but the scheme is difficult to effectively solve the risk problem and is not accepted by all the research and manufacturing subjects. In order to form a consensus scheme which is accepted by all subjects and can solve the risk problems, it usually goes through two stages: group negotiation and manufacturer coordination. Each subject thinks that the scheme in the negotiation stage is ideal and it is based on group ability and fairness. The consensus scheme in the coordination stage is that the supplier submits to the scheme of research and manufacturing system to a certain extent after the main manufacturer takes out some funds or profits to coordinate the supplier on the basis of group negotiation. Let x_0, x_0^{**} represent the initial scheme and consensus scheme, respectively. The preference values of the subjects i are d_{i0}, d_{i0}^{**} at the response scheme, respectively. Let x_i^* represent the ideal risk response scheme of the subjects i after the group negotiation and the preference value of the scheme is d_i^* $(i = 0, 1, 2 \cdots p)$.

Assumption 4. In the complex equipment research and manufacturing system, to achieve the risk response scheme consensus, the manufacturer which is at the core no longer only focuses on his own interests. The manufacturer tends to aim at developing the whole system and to take the lead in obedience and will take out some funds to coordinate the suppliers to make up for the loss caused by the ideal scheme that the suppliers have changed. Generally, the manufacturer expects the smaller coordination cost and the suppliers expect to get the most subsidies. Moreover, the decision-making process of suppliers often starts a game with manufacturers to determine the consensus scheme according to the change of subsidy benefits or utility. Let C, c_i represent the total cost coordinated by the manufacturer and the unit preference subsidy cost caused by the manufacturer subsidizing the supplier to change the scheme, respectively.

Assumption 5. In the complex equipment research and manufacturing system, the position of each subject is different. Let ω_0, ω_i represent the importance of the main manufacturer and the suppliers, respectively, which are determined by each research and manufacturing subject's position and ability, and it satisfies $\sum_{i=o}^{p} \omega_i = 1,\ 0 \le \omega_i \le 1$.

2.2. The Model of Individual Ideal Scheme Selection for Risk Response Based on Group Negotiation. In the complex equipment research and manufacturing system, it usually gives an initial scheme to deal with the risk when it has the system risk. Considering the gain and loss of their own interests, the research and manufacturing subjects often take the initial scheme as the reference point and will choose the scheme that minimizes loss. The choice results from the profit maximization of the subjects, game, and negotiation between other parties. So the final result of the game and consultation will form an ideal scheme to solve the problem of risk considering ability and fairness. Before the main manufacturer and suppliers play game and negotiation, the loss caused by the initial scheme is often taken as the reference point. Only when it is not less than the satisfaction at the reference point will the subjects accept the new scheme. The initial risk response scheme can be regarded as the worst risk response scheme, and each subject has a risk response scheme that they consider to be the most acceptable, which is called the individual ideal scheme. In this ideal scheme, a preference value is generated. Let $D^- = (d_{00}, ..., d_{i0}, ..., d_{ip})$, $D^+ = (d_0^+, ..., d_i^+, ..., d_p^+)$ represent the set of preference values of all subjects under the initial response scheme and their own ideal scheme, respectively. Due to resource capacity limitation in collaborative development of complex equipment, all research and manufacturing subjects are limited by the total resources of this system to determine their ideal profit and loss value through negotiation of response scheme. ρ indicates the risk system tolerance coefficient of the research and manufacturing system. The total amount of the main action resources of the development system is generally taken as $\sum_{i=0}^{p} d_i^+$, and $\sum_{i=0}^{p} d_{i0} / \sum_{i=0}^{p} d_i^+ < \rho < 1$. According to the above analysis, $d_i/d_i^+, d_{i0}/d_i^+$ can be regarded as the satisfaction of the subjects i and the starting point of negotiation of the group game, respectively. Through the group negotiation, each subject can achieve a relatively satisfactory result. Considering that the greater the degree of deviation between satisfaction and minimum satisfaction is, the better. An optimization model based on maximization of satisfaction deviation can be constructed, as shown below.

$$\begin{aligned} \max \quad & D = \prod_{i=0}^{p} \left(\frac{d_i}{d_i^+} - \frac{d_{i0}}{d_i^+} \right)^{\omega_i} \\ s.t \quad & d_{i0} \le d_i \le d_i^+ \\ & \sum_{i=0}^{p} d_i^* = \rho \sum_{i=0}^{p} d_i^+ \end{aligned}$$

$$\sum_{i=0}^{p} \omega_i = 1$$
$$\frac{\sum_{i=0}^{p} d_{i0}}{\sum_{i=0}^{p} d_i^+} < \rho < 1$$
$$i = 0, 1, \cdots, p \tag{1}$$

According to the above optimization model, we can obtain the ideal risk response scheme based on fairness and ability of each subject after group negotiation, and the set of preference values of each subject under their ideal scheme is $D_i^* = \{d_0^*, ..., d_i^*, ..., d_p^*\}$.

3. A Consensus Selection Model of Complex Equipment Risk Response Scheme Based on Minimum Cost Coordination and Maximum Utility Subsidy

In the process of choosing a risk response scheme for complex equipment research and manufacturing, through the negotiation and game between the main manufacturer and suppliers, the ideal scheme can only be formed based on their respective positions and abilities. The ideal scheme is only for everyone instead of being the only solution that is agreed upon by the group. In order to form the consensus of risk response scheme, the manufacturer as the leader and manager of the research and manufacturing system tends to give up some of its own interests to pursue the maximization of overall utility. At the time, the main manufacturer will take out a portion of funds to coordinate suppliers for urging them to change the risk response scheme that they consider based on fairness and maximization of their own interests. So the suppliers can accept the optimal negotiation and consensus scheme. In the process of coordinating consensus, the manufacturer expects that the smaller the subsidy is, the better it will be. And the subsidy is not higher than a certain value, and the manufacturer does not receive the subsidy itself. The suppliers expect to receive more subsidies as a result of the loss caused by the change of preference scheme, so as to accept the system setup scheme. When some scheme may cause greater loss, no matter what the subsidy the suppliers can get, suppliers are not willing to change to the scheme set by the system. It can be said that the consensus scheme is determined as a result of a second game between the manufacturer and suppliers (the manufacturer coordinates subsidies).

3.1. The Decision Objectives of the Manufacturer. In the research and manufacturing system, in order to reach a consensus scheme, the manufacturer often takes out a portion of funds to motivate the suppliers to change their preference scheme. In this case, the manufacturer expects that the less the money the better, and it cannot exceed the total amount to be paid. Generally, the manufacturer's subsidies to suppliers are often based on the differences in losses caused by ideal and consensual schemes based on their own equity and ability. On basis of the idea and principle of the minimum cost consensus model proposed by Ben-Arieh [33], we regard the difference of suppliers' preference degree in ideal risk response scheme and consensus scheme as the subsidy amount. According to the hypothesis and analysis of the model, we can know that the total coordination costs paid by the manufacturer are

$$C = \sum_{i=1}^{p} c_i \left| d_{i0}^{**} - d_i^* \right| \tag{2}$$

Due to the actual constraints and requirements of the suppliers, there is a lower limit and upper limit preference for the risk response schemes for the suppliers, which are recorded as d_i^l, d_i^+, respectively, and $d_i \in [d_i^l, d_i^+]$, $d_i^l \le d_{i0} \le d_i^* \le d_i^+$. Accordingly, for the manufacturer, a multiobjective optimization model based on minimum coordination costs can be built as follows:

$$\begin{aligned} \min \quad & C = \sum_{i=1}^{p} c_i \left| d_{i0}^{**} - d_i^* \right| \\ \text{s.t.} \quad & d_{i0}^{**}, d_i^*, d_i \in [d_{i0}, d_i^+] \end{aligned} \tag{3}$$

3.2. The Decision-Making Objectives of the Suppliers. In the research and manufacturing system, according to the model assumptions and analysis above, the decision-making behavior of suppliers can also be divided into two stages: group negotiation and consensus coordination. The behavior of suppliers in group negotiation stage is mainly related to other players' game and their own preference (it is not discussed here). Meanwhile, the behavior of suppliers in group coordination consensus stage is closely related to their own preference or risk attitudes and subsidies. When taking into account the losses as a result of a consensual solution to system requirements, suppliers expect to receive more compensation from the manufacturer. However, the amount of compensation is related to the differences of preference and loss between the ideal scheme and consensus scheme based on their own equity and ability. The greater the deviation, the more the compensation. But the compensation amount is not only the reference for the supplier to make the decision, and it also needs to pay attention to the decision risk attitude of the suppliers. Therefore, the decision-making behavior of the suppliers can be described by the utility of the preference degree of the compensated scheme. In view of this, in order to realize the stability of the consensus scheme of the research and manufacturing system, we exploit the utility function of [2, 34–38] for reference to measure the decision utility of the suppliers and then construct the model to maximize the suppliers' utility.

Let u represent the utility of the supplier group (this utility value must not be less than the minimum utility value of all suppliers), which is a function of the risk response scheme preference value d_i of the supplier i, and $0 \le u \le 1$, $d_i \in [d_{i0}, d_i^+]$. The supplier's risk attitude and preference are generally nonlinear; according to the characteristic of supplier's utility preference and referring to the nonlinear utility function [2, 34–38], three kinds of parabola utility functions can be constructed: left skew type,

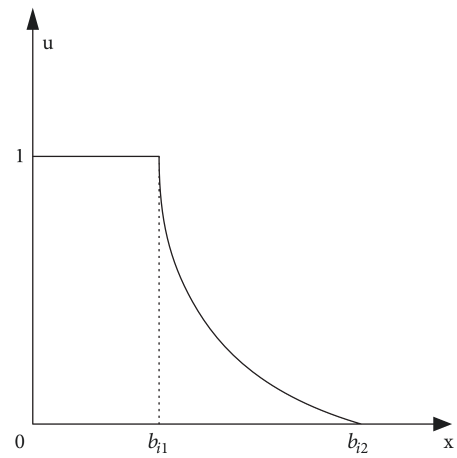

FIGURE 1: The utility function of left skewed parabola.

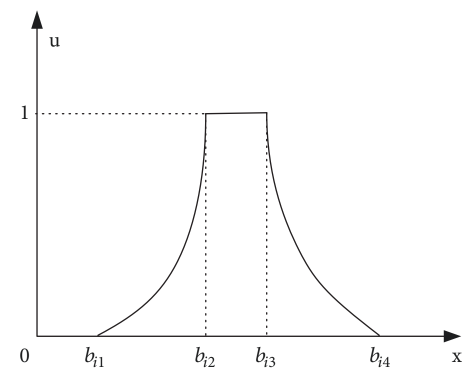

FIGURE 2: The utility function of interval parabola.

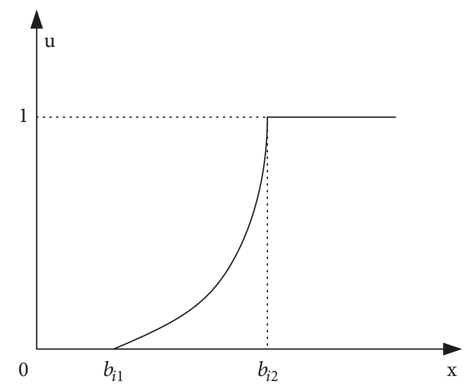

FIGURE 3: The utility function of right skewed parabola.

interval type, and right skew type. As shown in Figures 1–3, the corresponding formulas (4)-(6) are shown, respectively:

$$u = \begin{cases} 1 & if\ d_i^{**} < b_{i1} \\ \left(\dfrac{b_{i2} - d_i^{**}}{b_{i2} - b_{i1}}\right)^2, & if\ b_{i1} \le d_i^{**} < b_{i2} \\ 0, & if\ d_i^{**} \ge b_{i2} \end{cases} \tag{4}$$

$$u = \begin{cases} 0, & if\ d_i^{**} < b_{i1} \\ \left(\dfrac{d_i^{**} - b_{i1}}{b_{i2} - b_{i1}}\right)^2, & if\ b_{i1} \le d_i^{**} < b_{i2} \\ 1, & if\ b_{i2} \le d_i^{**} < b_{i3} \\ \left(\dfrac{b_{i4} - d_i^{**}}{b_{i4} - b_{i3}}\right)^2, & if\ b_{i3} \le d_i^{**} < b_{i4} \\ 0, & if\ o_i \ge b_{i4} \end{cases} \tag{5}$$

$$u = \begin{cases} 0, & if\ d_{i0}^{**} < b_{i1} \\ \left(\dfrac{d_{i0}^{**} - b_{i1}}{b_{i2} - b_{i1}}\right)^2, & if\ b_{i1} \le d_{i0}^{**} \le b_{i2} \\ 1, & if\ d_{i0}^{**} > b_{i2} \end{cases} \tag{6}$$

The preference threshold of the supplier i to risk response schemes are indicated by $b_{i1}, b_{i2}, b_{i3}, b_{i4}$, respectively. d_{i0}^{**} represents the supplier's preference value for consensus scheme after coordination.

For formula (4), in the utility function of left skewed parabola, the lower the supplier's preference for the coordinated risk response scheme is, the higher the supplier's utility is. Because the slope of the supplier's utility curve is negative and gradually increasing, it shows that the marginal utility of the supplier's preference to risk response scheme increases with the increase of risk response scheme preference. It can be said that the utility function of left skewed parabola belongs to risk preference type. For formula (5), when $b_{i1} \le d_i^{**} < b_{i2}$, the utility and marginal utility of the supplier increase with the increase of preference, which indicates that the supplier has a risk preference attitude in this range. When $b_{i2} \le d_i^{**} < b_{i3}$, the utility value of the supplier reaches 1. When $b_{i3} \le d_i^{**} < b_{i4}$, although the utility level of the supplier decreases with the increase of opinions, the marginal utility of the supplier is still increasing. Therefore, the supplier is still risk preference type in the subinterval. For formula (6), when $b_{i1} \le d_{i0}^{**} \le b_{i2}$, the utility value and marginal utility of the suppliers increase with the increasing of preference, which indicates that the utility function of right skewed parabola is risk preference type.

3.3. The Consensus Selection Models for Complex Equipment Risk Response Scheme. In the research and manufacturing system, in order to deal with the system risk, the main manufacturer and suppliers need to coordinate through game and consultation for the consensus scheme. The generation of the consensus scheme needs to ensure the minimum coordination cost of the manufacturer and the maximum utility of suppliers. Moreover, the coordination cost paid by the main manufacturer must not be higher than the amount it can afford, and the deviation of the suppliers' consensus scheme and the ideal scheme based on fairness and capability must not be greater than the tolerance. Let B, ε_i represent the manufacturer's coordination cost tolerance and supplier's tolerance, respectively. According to the model hypothesis and analysis, considering that the supplier has three different types of utility function, assume that the supplier simultaneously serves a certain type and the other mixed models are based on the evolution and combination of the three types in this paper. Correspondingly, three risk response consensus models based on minimum coordination cost and the utility function of left skewed, interval, and right skewed parabola can be given, respectively, as follows:

$$\begin{aligned}
\min \quad & C = \sum_{i=1}^{p} c_i \left| d_{i0}^{**} - d_i^{*} \right| \\
\max \quad & u \\
s.t. \quad & \sum_{i=1}^{p} c_i \left| d_{i0}^{**} - d_i^{*} \right| \leq B \\
& \left| d_{i0}^{**} - d_i^{*} \right| \leq \varepsilon_i \\
& u \leq \left(\frac{b_{i2} - d_{i0}^{**}}{b_{i2} - b_{i1}} \right)^2 \\
& d_{i0}^{**} \in \left[d_{i0}, d_i^{+} \right], \; u \in [0,1]
\end{aligned} \tag{7}$$

$$\begin{aligned}
\min \quad & C = \sum_{i=1}^{p} c_i \left| d_{i0}^{**} - d_i^{*} \right| \\
\max \quad & u \\
s.t. \quad & \sum_{i=1}^{p} c_i \left| d_{i0}^{**} - d_i^{*} \right| \leq B \\
& \left| d_{i0}^{**} - d_i^{*} \right| \leq \varepsilon_i \\
& u \leq \left(\frac{d_{i0}^{**} - b_{i1}}{b_{i2} - b_{i1}} \right)^2 \\
& u \leq \left(\frac{b_{i4} - d_{i0}^{**}}{b_{i4} - b_{i3}} \right)^2 \\
& d_{i0}^{**} \in \left[d_{i0}, d_i^{+} \right], \; u \in [0,1]
\end{aligned} \tag{8}$$

$$\begin{aligned}
\min \quad & C = \sum_{i=1}^{p} c_i \left| d_{i0}^{**} - d_i^{*} \right| \\
\max \quad & u \\
s.t. \quad & \sum_{i=1}^{p} c_i \left| d_{i0}^{**} - d_i^{*} \right| \leq B \\
& \left| d_{i0}^{**} - d_i^{*} \right| \leq \varepsilon_i \\
& u \leq \left(\frac{d_{i0}^{**} - b_{i1}}{b_{i2} - b_{i1}} \right)^2 \\
& d_{i0}^{**} \in \left[d_{i0}, d_i^{+} \right], \; u \in [0,1]
\end{aligned} \tag{9}$$

3.4. The Steps of Constructing a Consensus Selection Model of Risk Response Scheme for Complex Equipment Research and Manufacturing. The consensus selection model proposed in this paper has a clear decision-making process, as shown in what follows (Figure 4).

Step 1. Collect the initial risk response scheme d_i ($i = 0, 1, 2, \ldots, p$) for subjects in complex equipment research and manufacturing systems.

Step 2. According to the initial scheme of subjects and their risk preference, construct the model based on the maximization of satisfaction bias. Solve the ideal risk response scheme based on fairness and ability of each development subject after group negotiation and the set of preference values of various subjects under their ideal scheme.

Step 3. Analyze the decision-making objectives of the main manufacturer and suppliers based on the minimum cost consensus model and the nonlinear utility function of reference, respectively.

Step 4. Based on the model constructed in Step 3, construct the consensus selection model of complex equipment risk response scheme, in which the main manufacturer takes out part funds to coordinate with suppliers with minimal coordination costs and maximum subsidy utility.

Step 5. Based on the selection model of group negotiation and coordination, give the consensus risk response scheme.

4. Illustrative Example

Large equipment manufacturing ETO, also known as project manufacturing company, such as Jiangsu Jucheng Software Technology Co., Ltd., is a complex and unique type of production in the manufacturing industry. Typical companies are ships, aircraft, and large special equipment. It has the characteristics of complex product structure, high customer requirements, long production cycle, and small order form. Therefore, the management of such enterprises has high requirements for resource allocation, capacity balance, quality management, cost, and delivery time control.

The research and manufacturing of large-scale ship are a very difficult task; its development project integrated many high and new technologies including application of computer technology, virtual reality technology, sensor technology, and new energy, new materials, etc. It not only involves the hull construction technology, but also involves the mechanical, electrical, metallurgical, and other fields. It has features such as the highly intensive knowledge, highly difficult technology, and high quality products. Ships are made up of thousands of parts and almost have relations of every industrial sector. The equipment of communication, navigation, and control needed is provided by dozens to hundreds of suppliers. Relationships with suppliers will affect the efficiency of the coordinated development of complex equipment. Because of the large number of suppliers, the supply of ship parts will be uncertain, which may bring risks to the main manufacturer. In order to solve the problem of selecting a solution for complex equipment risk response under the negotiation of multiple decision subjects such as the main manufacturer

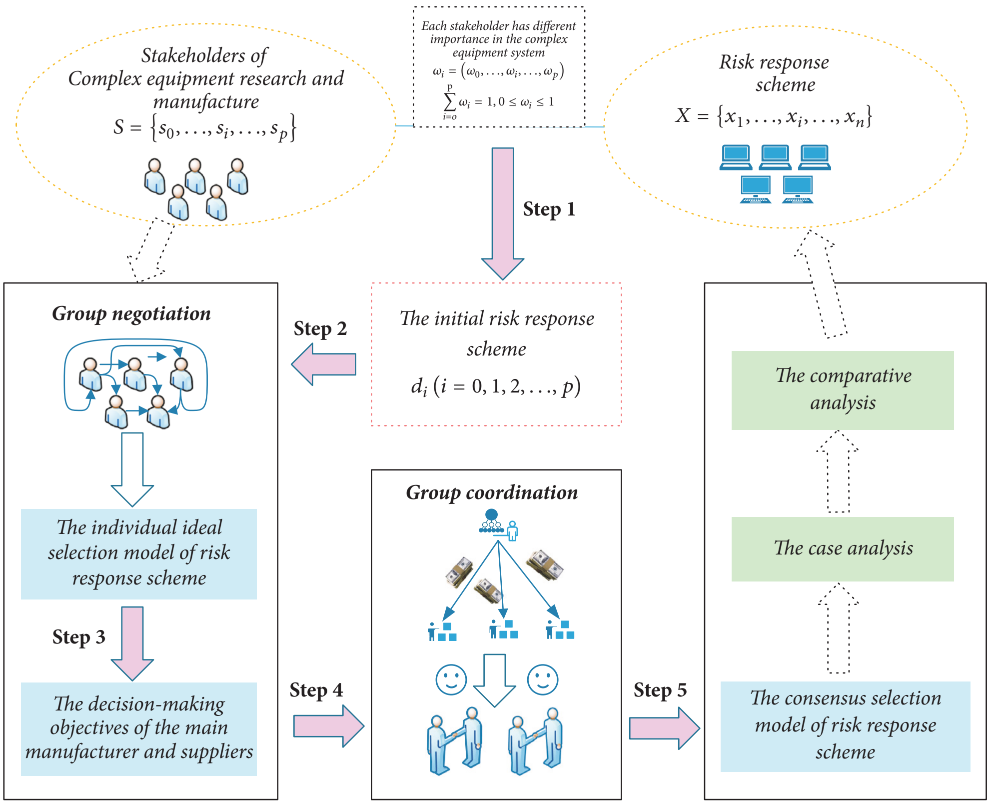

FIGURE 4: The decision-making process of consensus selection model of risk response scheme in this paper.

and suppliers, we use the constructed model to analyze it.

In order to develop a new type of ship, a large-scale shipbuilding company, which we call A, invited strong suppliers in four fields to carry out joint research and manufacturing. Let $S = \{s_0, s_1, s_2, s_3, s_4\}$ indicate the main manufacturer and suppliers, respectively. Shipbuilding involves the process of introducing new technologies, making up for design defects, improving technology, strengthening key technologies, etc., while key technologies include precision control technology, regional coating technology, modular shipbuilding technology, and green shipbuilding technology. Along with the high risk of technology in these processes, any part of the risk not properly dealt with will affect the success of the final shipbuilding and efficiency. Therefore, in the face of uncertainties in shipbuilding, it is necessary for all suppliers to cooperate and respond quickly to sudden technical risks. As the leader of collaborative development of large-scale ship, the main manufacturer needs to coordinate suppliers to reach a consensus risk response scheme to promote the research and manufacturing of the ship. In the collaborative development of large-scale ships, the main manufacturer and suppliers differ in their importance and ability due to their status, and the weight can be determined by authoritative experts in the field, that is, $\omega = \{0.35, 0.1, 0.22, 0.15, 0.18\}$. The support vector machine (SVM) method is used to identify the risk of ship's collaborative development, and the expert decision-making group is invited to develop five sets of risk response schemes: $X = \{x_1, x_2, x_3, x_4, x_5\}$. Based on their own assessment of capabilities and identification of risks, the main manufacturer and suppliers first select the initial risk response scheme; at this time, the preference value of each subject is $d_{i0} = \{114, 86, 72, 94, 105\}$. However, this solution is difficult to effectively solve the risk problem and not fully accepted by the development subjects. In order to form a consensus that is fully acceptable to all subjects and that can effectively address risk problem, there are two stages of group negotiation and system coordination.

4.1. Group Negotiation Stage. The main manufacturer and suppliers have minimum and maximum preference for the initial risk response scheme, recorded as D^-, D^+, respectively. The minimum preference value is the preference value chosen by each subject in response to the initial risk response scheme, that is, $D^- = \{114, 86, 72, 94, 105\}$, and the maximum preference value is $D^+ = \{134, 106, 112, 124, 125\}$. The group negotiation model is constructed according to (1) in Section 2.2 mentioned above; taking the system resource constraint coefficient ρ as 0.9, we exploit Matlab 2016a to solve the optimal preference values of the main manufacturer and suppliers in the group negotiation stage, which are shown as follows:

$$\begin{aligned} D_i^* &= \{133.99, 93.68, 88.88, 105.52, 118.82\} \\ &\approx \{134, 94, 89, 106, 119\}, \end{aligned} \tag{10}$$

$$\max D = 0.1228.$$

Table 1: Relevant parameter table.

Supplier	c_i	b_{i1}	b_{i2}	b_{i3}	b_{i4}
1	2.89	86.59	88.62	90.17	93.68
2	3.54	72.97	75.67	83.14	88.88
3	4.61	94.78	96.56	101.78	105.52
4	6.52	105.63	109.55	113.39	118.82

4.2. System Coordination Stage. After the group negotiation between the main manufacturer and suppliers, the ideal risk response scheme for each research subject based on fairness and ability is adopted. But it is not only the solution that is accepted by the group. In order to form a consensus scheme on risk response, the main manufacturer as the leader of collaborative development will be considered in the overall interests of the system and allocate some funds for coordination. Assume that the total coordination cost budget B of the main manufacturer does not exceed RMB 950,000 (for the convenience of calculation, the actual amount is reduced by 10,000 times, recorded as 95) and the tolerance of the suppliers is $\varepsilon_i = 8, 13, 16, 9$, respectively. The supplier utility function is an interval parabola utility function. Based on the model constructed in this paper, the relevant parameters are shown in Table 1.

Based on this, according to formula (8), we can obtain the following:

$$
\begin{aligned}
\min\quad & C \\
& = 2.89 * \left|d_{10}^{**} - 93.68\right| + 3.54 * \left|d_{20}^{**} - 88.88\right| \\
& \quad + 4.61 * \left|d_{30}^{**} - 105.52\right| + 6.52 \\
& \quad * \left|d_{40}^{**} - 118.82\right| \\
\max\quad & u \\
s.t.\quad & 2.89 * \left|d_{10}^{**} - 93.68\right| + 3.54 * \left|d_{20}^{**} - 88.88\right| \\
& \quad + 4.61 * \left|d_{30}^{**} - 105.52\right| + 6.52 \\
& \quad * \left|d_{40}^{**} - 118.82\right| \le 95 \\
& \left|d_{10}^{**} - 93.68\right| \le 8 \\
& \left|d_{20}^{**} - 88.88\right| \le 13 \\
& \left|d_{30}^{**} - 105.52\right| \le 16 \\
& \left|d_{40}^{**} - 118.82\right| \le 9 \\
& u \le \left(\frac{d_{10}^{**} - 86.59}{88.62 - 86.59}\right)^2 \\
& u \le \left(\frac{d_{20}^{**} - 72.97}{75.67 - 72.97}\right)^2 \\
& u \le \left(\frac{d_{30}^{**} - 94.78}{96.56 - 94.78}\right)^2 \\
& u \le \left(\frac{d_{40}^{**} - 105.63}{109.55 - 105.63}\right)^2 \\
& u \le \left(\frac{93.68 - d_{10}^{**}}{93.68 - 90.17}\right)^2 \\
& u \le \left(\frac{88.88 - d_{20}^{**}}{88.88 - 83.14}\right)^2 \\
& u \le \left(\frac{105.52 - d_{30}^{**}}{105.52 - 101.78}\right)^2 \\
& u \le \left(\frac{118.82 - d_{40}^{**}}{118.82 - 113.39}\right)^2 \\
& 86 \le d_{10}^{**} \le 106 \\
& 72 \le d_{20}^{**} \le 112 \\
& 94 \le d_{30}^{**} \le 124 \\
& 105 \le d_{40}^{**} \le 125 \\
& u \in [0, 1]
\end{aligned}
\tag{11}
$$

Using Matlab 2016a programming to solve formula (11), we can obtain the optimal preference values of the main manufacturer and suppliers risk response consensus scheme, $d_{i0}^{**} = \{91.49, 83.93, 104.15, 115.07\}$; actual coordinated total cost is $\min C = 54.68$ (the actual is RMB546,800), and system utility optimal value is $\max u = 1$. From the above analysis results, it can be seen that, after the main manufacturer coordinates, suppliers can reach a consensus risk response scheme, and implementing the solution can well solve the complex equipment development risk and make the system utility optimization.

4.3. Sensitivity Analysis of Coordination Cost Budget B. In order to better explore the practical application value of the model, it is assumed that the coordination cost of the main manufacturer can be adjusted at any time. In order to determine a reasonable coordinated total budget, the impact of the coordination cost on the decision-making behavior of suppliers and the choice of consensus risk response options is analyzed. Providing countermeasures for the collaborative development of the complex equipment of the main manufacturer-supplier, now making analysis as follows: when $B = 40, 60, 80, 100, 120, 140, 160$, the calculation results are as shown in Table 2.

Table 2: Coordination cost budget B sensitivity analysis table.

B	d_{10}^{**}	d_{20}^{**}	d_{30}^{**}	d_{40}^{**}	C	$\max u$
40	93.66	83.83	104.28	118.80	23.71	0.486
60	91.59	84.30	104.54	114.74	53.44	0.648
80	91.49	83.98	104.19	115.05	54.40	0.859
100	91.49	83.92	104.14	115.08	54.65	1
120	91.49	83.88	104.10	115.10	54.83	1
140	91.49	83.85	104.07	115.12	54.98	1
160	91.49	83.78	104.01	115.14	55.33	1

And then we can make a curve as shown in Figure 4.

The graph in Figure 5(a) shows the change curve of suppliers' preference value with the coordinate total cost budget B of the main manufacturer under the consensus risk response scheme. As the coordinate total cost budget B increases, the preference value of supplier 1 gradually decreases to a stable trend. Suppliers 2 and 3 first increase, and then appears reduction trend; supplier 4's preference value drops first and then appears increases trend. The graph in Figure 5(b) shows the actual coordination cost as a function of the coordination cost budget. It can be seen from the figure that when the cost budget is less than RMB600,000, the actual coordination cost increases significantly with the increase of the budget. When the cost budget is greater than RMB600,000, the actual coordination cost increases small and tends to be stable. From the results of the coordination stage and Table 2, it can be seen that when the coordination cost budget B is greater than RMB950,000, the system utility reaches 1 and the utility is optimal. It can be seen that the main manufacturer should comprehensively consider various factors in the collaborative development of complex equipment and set a reasonable coordination cost budget when the utility is optimal.

The consensus selection model of risk response scheme has high applicability. In the collaborative development of actual complex equipment, the main manufacture-supplier mode is adopted, such as large ships, aircraft, military facilities, rail transit, satellite, and marine engineering equipment. The risk response scheme decision problem of the complex equipment system needs to be coordinated by the main manufacturer on the basis of negotiation. The main manufacturer expects that coordination costs are minimized and suppliers expect maximum utility. This paper constructs a two-stage risk response scheme by constructing a model. In the negotiation stage, the behavioral factors of the decision makers can be fully taken into account, and the ideal scheme of the system can be obtained. Due to the influence of various factors in reality, the ideal scheme cannot be achieved. The main manufacturer can effectively mobilize the enthusiasm of the suppliers by coordinating in the form of cost subsidies. The model constructed in this paper, through the group negotiation and the coordination of the main manufacturers, enables the various subjects to realize the choice of the consensus risk response scheme under multiple consultations and coordination and achieve the optimal system utility. And it can solve the problem of actual complex equipment risk response scheme selection.

5. Conclusions

In this paper, the researchers study the group consensus decision-making problem of complex equipment collaborative development risk response scheme, considering the risk preference behavior of suppliers, and exploit the idea of group negotiation to propose a risk decision-making model based on group negotiation and a consensus scheme selection model based on utility maximization and minimization coordination cost of the main manufacturer, respectively, and then use them to solve the ideal risk response scheme under the self-cognition of collaborative development subject and the group consensus risk response scheme under the system utility. Through the model and case analysis, the decision model constructed has the following conclusions and advantages.

(1) The model proposed in this paper can effectively describe the multiobject joint decision-making problem in the selection of risk response scheme for complex equipment research and manufacturing and achieve the satisfaction of each decision-making subject, so that the system utility is optimal.

(2) The consensus scheme selection problem proposed in the paper effectively combines the preference value and utility, considers the supplier's risk preference behavior, and achieves the multisubject consensus scheme.

The model constructed focuses on the selection of consensus schemes under multisubject joint decision-making in complex equipment research and manufacturing, and the paper analyzed the decision-making methods of each decision-making subject based on group negotiation and how to ensure that the consensus scheme can be realized while optimizing the system utility. However, there are some problems in the model. For example, the model only discusses the decision-making problem between noncooperation and cooperation between the main manufacturer and the first-tier suppliers, without considering the classification of suppliers. The schemes selection problem can be further explored among the main manufacturer, general suppliers, partner suppliers, and strategic suppliers in the future.

Data Availability

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

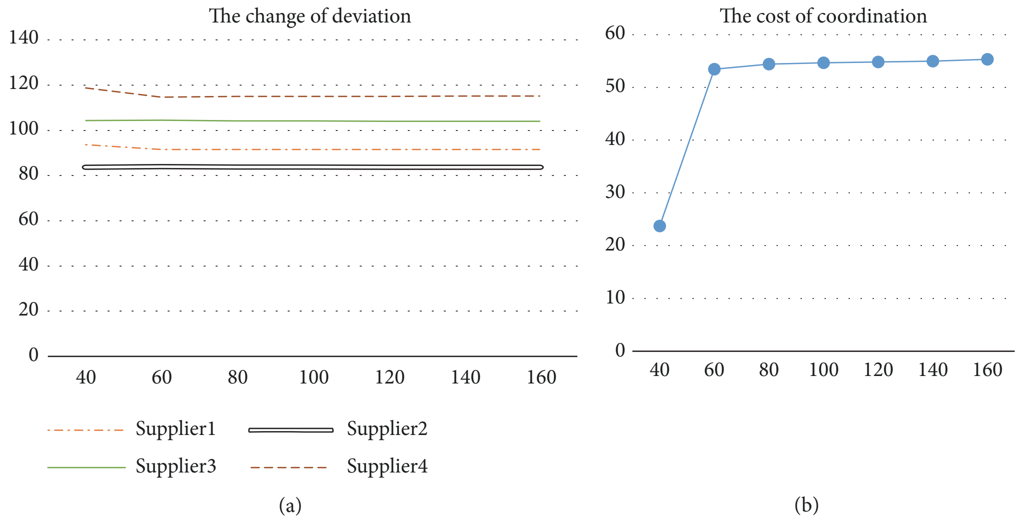

Figure 5: Coordination cost budget change impact curve.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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