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Research Article

A Quantitative Model of the Multisubject Quality Responsibility of Construction Projects Based on an IPSO

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In order to solve the problem of the quantitative division of multisubject quality responsibility in construction project quality disputes, this article proposes a quantitative model of multisubject quality responsibility division in construction projects based on an improved particle swarm optimization (IPSO). First, this article proposes a set of classification guidelines for quality risk behaviors based on the theory of organizational behavior. Through these, the interconnections between different types of risk behaviors and quality defects were explored. Following this, this article explored potential laws among 84 practical judicial cases from China using the IPSO. The category coefficients of the three types of quality risk behaviors, namely, technical defects, management violations, and irregularities, were obtained in this analysis. This article also deduced the mathematical expression of the division of engineering quality responsibility using fuzzy mathematical theory and established a multisubject quality responsibility quantitative model. It was then simulated and applied in four practical judicial cases. The simulation results revealed that the multisubject quality responsibility quantitative model based on quality risk behavior has good applicability.

1. Introduction

A construction project quality dispute refers to a dispute put forward by the contracting party when a construction project cannot meet the quality standard agreed upon in the contract due to the failure of other project participants to either fully or partially fulfill their quality responsibilities. The construction quality dispute, itself, is a dispute between those subject to a level of engineering quality responsibility as stipulated in their contract. As such, the subjects of quality responsibility are also the subjects of quality disputes. Using the explanatory structural model (ISM) as their basis, Kumar Viswanathan et al. [1] developed a dispute causation model that depicts six levels of hierarchy among the identified factors. Similarly, Naji et al. [2] proposed an improved hybrid fuzzy structural equation model for quantifying the probability of the occurrence of disputes in construction projects, thus enabling project stakeholders to predict, identify, and correctly manage the occurrence of disputes prior to the start of construction. The prototype proposed by Kassab et al. [3] successfully simulates and predicts the sequence of decisions that occur in case study disputes in the presence of uncertainty. Meanwhile, Wang et al. [4] developed a model for predicting the occurrence of disputes to identify resource allocation strategies for dispute avoidance. This model not only is predictive but can also be used to trace back to the factors that caused the dispute. El-Adaway and Kandil [5] created a multi-intelligent body system for construction dispute resolution (MAS-COR) that can derive important legal arguments to help save time and effort for construction claim and dispute professionals. At the same time, Chen et al. [6] designed a construction quality dispute negotiation model based on the research of existing expert systems. This model follows a two-way, iterative negotiation process in the dispute negotiation, thus ensuring that the whole negotiation process is fairer and more just. In conclusion, this article summarizes the current status of research on dispute resolution models as shown in Table 1.

After the occurrence of engineering quality disputes, the quantitative analysis of engineering quality responsibility is actually a decision-making process. At present, there are many research results in the application of quantitative methods in the field of construction engineering. Kannan and Martin [7] presented a comprehensive literature review of English-language scholarly papers on ELECTRE and ELECTRE-based methods; the 544 papers on the application of ELECTRE are examined and further classified into 13 application areas and a number of subareas, including housing assessments and construction project management. Chen et al. [8] developed a novel ELECTRE III-based MCGDM approach for bid evaluation to solve the indetermination, imprecision, and uncertainty in the bid evaluation process. Chen et al. [9] developed a novel hybrid multicriteria group decision-making model for sustainable building material selection under uncertainty. Khaled and Amr [10] proposed setting quality factors based on the degree of impact of the work on the overall quality of the project and using functions to address the quantification of quality. Zhang [11] proposed "quantitative cause-effect analysis" based on AHP method and cause-effect analysis and used it in construction quality management practice. Douer et al. [12] developed the responsibility quantification (ResQu) model to compute a measure of operator responsibility. The application of the above methods provides research exploration for quantitative analysis in the field of engineering construction, but none of them involves research on the division of quality responsibility. He [13] proposed that fuzzy mathematics and random mathematics are also an indispensable part of the development of mathematics today; therefore, the mathematical expressions of legal acts and legal issues can also be expressed as fuzzy and random expressions. At present, most scholars are focused on how to reduce, entirely avoid, or adopt effective methods for resolving quality disputes after they occur. There are a few studies on how to identify quality responsibility subjects, determine the way to assume quality responsibility, and establish a multisubject responsibility model to quantify and calculate the quality responsibility ratio.

In the construction industry, about 80–90% of accidents are caused by unsafe behaviors [14]. Thus, risky behavior associated with work quality is the main cause of quality problems. It is also the main basis for quantifying the proportion of responsibility placed upon each subject. The study of quality dispute resolution cannot be separated from the study of the quality risk behavior of a subject. The one-time customized production method used by construction projects determines the strength of the quality linkage between upstream and downstream subjects [15], and the riskiness of the quality behavior of one subject is likely to be passed on to the subsequent subjects along the chain channel of engineering construction procedure [16]. In this system, the riskiness of the quality behavior of upstream subjects will have an important impact on the product quality of downstream subjects [17]. Zhang and Li [18] consider engineering quality behavior as an organizational behavior, which can be either positive or negative. Positive quality behavior refers to the actions of those in the construction market subjects that follow the provisions of national laws and regulations and take legal and compliant quality behavior. Contrarily, reverse quality behavior refers to the actions of those construction market subjects that take advantage of the currently prevailing information fragmentation and information asymmetry phenomenon to pursue their own interest maximization and, as a result, engage in behaviors that are detrimental to other subjects or even damage the quality of their projects [19–22]. Therefore, quality risk behavior is a type of reverse organizational behavior. Quality risk behavior, as used in this article, refers to the reverse quality behavior that is detrimental to the engineering quality results made by the construction market subjects in violation of laws and regulations or in breach of their basic duty of care as professional organizations. In a previous study, Ireland [23] studied the reasons behind the failure of engineering projects, and among the 19 reasons he described, 9 are a direct result of the subject's misbehavior. Still, existing scholars mainly focus on the exploration of analysis methods related to behavior selection [24–30], as well as research on the characteristics, problems, and normative countermeasures of the quality behavior of responsible subjects. Indeed, studies are scarce on the intrinsic mechanisms behind quality risk behavior and quality defects, as well as quality dispute resolution based on the quality risk behavior of subjects.

Due to the lack of theory and a comprehensive model for resolving multisubject quality disputes in arbitration and litigation practice, adjudicators can only make decisions based on the circumstances of the disputed cases and their individual experience. The invariable result is different judgments in similar cases, which fails to protect the legitimate rights and interests of the parties and undermines court justice. The quantitative model of multisubject responsibility proposed in this article fills this gap and provides an effective quantitative model to encourage more sensible and scientific adjudication results. This article provides the following four main contributions:

(1) A classification criterion for quality risk behaviors is constructed, and the relationship between different types of quality risk behaviors and engineering quality defects is established
(2) An IPSO is utilized to achieve an optimal solution method for the category coefficients of the three types of quality risks
(3) The initial assignment of the type coefficient $(M_{\text{IPSO}})^T$ is obtained by using case samples from China and an IPSO experiment
(4) Using fuzzy mathematical theory, a mathematical model for quantitative division of the quality responsibility of multiple subjects is established which provides a scientific and reasonable method for the resolution of multiple subjects' engineering quality disputes

Finally, this study is organized into six sections. Following Section 1, Section 2 introduces the classification of quality risk behavior and the establishment of multisubject quality responsibility quantitative model. Section 3 elaborates IPSO theory and optimization method of quality risk

Table 1: Literature review of dispute resolution models.

Representative literature Author	Year	Models	Scope of application and effectiveness	Applicability to calculation of quality responsibility to the subjects of the dispute
Islam	2010	MAS-COR	Ability to make important legal arguments that help save time and effort for construction claims and dispute professionals	No
Chen et al.	2013	A construction quality dispute negotiation model	The process of dispute negotiation creates a two-way, iterative negotiation process, making the entire negotiation process more fairer and more equitable	No
Naji Khalid	2020	An improved hybrid fuzzy structural equation model	Quantify the probability of disputes occurring on construction projects and anticipate, identify, and correctly manage the occurrence of disputes prior to construction	No
Satish	2020	Dispute causation model	Identify the interrelationships among different dispute causes and help reduce construction disputes	No
Peipei Wang	2021	Dispute prediction model	Prediction model not only has a predictive function but can also trace back to the factors that caused the dispute	No
Zhang Haiying	2006	Quantitative cause-effect analysis model	Quantitative causal analysis of engineering quality	No
Zhen-Song Chen et al.	2019	Hybrid multicriteria group decision-making model	Sustainable building material selection	No
Douer Nir et al.	2020	Responsibility quantification (ResQu) model	Compute a measure of operator responsibility	No

behavior type coefficients. Section 4 introduces type coefficient acquisition and simulation results. Section 5 discusses the management implication of the results and concluding remarks are given in Section 6.

2. Multientity Engineering Quality Responsibility Analysis Model

2.1. Quality Risk Behavior Classification. Any quality risk behavior engaged in by an engineering quality responsibility subject is a reverse organizational behavior; that is, through its actions, the quality responsibility subject exists to hinder the realization of the project quality goal. As the most direct and active factor affecting the quality of construction projects, quality risk behaviors engaged in by construction project participating subjects can directly lead to final quality problems for construction projects. For example, an established construction project quality problem can be caused either by one or more quality risk behaviors implemented by one quality responsible subject, or by a series of quality risk behaviors implemented by multiple quality responsible subjects together.

Based on the literature research results [31] and expert interviews, the categories of quality risk behavior of construction project participants were modified and improved, and classification guidelines were established according to the results of the quality risk behavior of construction project participants. The quality risk behavior of the five possible responsible subjects, the developer, survey company, design institute, construction company, and supervision company, is classified as the following three types: technical defects, management violations, and irregularities. Background information on the experts who participated in the interviews is presented in Table 2, and a summary of the content of the expert interviews and expert opinions is presented in Table 3. The classification guidelines for the types of behaviors are detailed in Table 4.

The impact of different manifestations of quality risks on project quality can differ greatly. The construction company and supervision company are mainly responsible for the construction management and supervision of the project. They are often tasked with implementing management-type behavior. In this context, the reverse manifestation of risk behavior is more often manifested as irregularities in the management type or irregularities in the quality of risk behavior. The survey, design, and construction companies exist to provide technical services and perform management responsibilities. Thus, the negative performance of risk behavior in these groups includes both quality risk behavior, such as technical defects and violations in the management and irregularities.

The quality risk behaviors of the technical defects category are directly related to the determination of the project's quality and can be clarified by the appraisal report provided by the third-party appraisal agency. In contrast, the role of the noncompliance management category is to be inherently opposed to behaviors explicitly prohibited by laws and regulations. Although this role indirectly affects the quality of a project, this type of behavior cannot be identified by the appraisal agency. There is a type of quality risk behavior that is considered to be outside the framework of laws and regulations. It is neither a type of technical defect

Table 2: Background information on the experts participating in the interviews.

Expert no.	Location of work	Occupation	Years of experience	Title	Number of cases heard/represented/dealt with on quality of projects
1	Beijing	Arbitrator	21 years	Senior engineer	20 cases
2	Beijing	Lawyer	20 years	Senior lawyer	32 cases
3	Tianjin	University professor	20 years	Professor	10 cases
4	Beijing	Judicial expert	18 years	Professorial senior engineer	60 cases
6	Shanghai	Judge	18 years	Tier 2 judge	30 cases
7	Shanghai	Engineering quality expert	25 years	Professorial senior engineer	20 cases

Table 3: Expert interview content and conclusions.

No.	Content of the interviews	Summary of experts' views
1	What do you think are the main factors to be considered in the division of responsibility for project quality?	The severity of the risk behavior of the participating parties, the causal relationship between the behavior and the results, etc., should be considered
2	What factors do you think should be considered for the classification of engineering quality risk behavior?	Results of quality risk behavior, the nature of the behavior, etc.
3	What do you think are the major difficulties in classifying engineering quality risk behavior?	The need to find suitable classification criteria that includes all forms of risk behavior
4	What do you think should be considered as the basis for the classification of engineering quality risk behavior?	Laws and regulations, regulatory documents, technical appraisal reports, conventions and practices in the industry, etc.
5	What suggestions would you give for the classification of engineering quality risk behavior?	Give full consideration to the main precepts and classification standards of quality risk behavior
6	What do you think is the significance of the classification of engineering quality risk behavior to the resolution of multisubject quality disputes?	Classification can provide a quantitative basis for the severity of different types of quality risk behavior
7	Do judges or arbitrators take the impact of poor-quality behavior on quality liability into account in practical dispute resolution?	Yes, as there is no classification standard and the decision is left to the discretion of the adjudicator on a case-by-case basis

Table 4: Guidelines for categorizing the quality risk behavior of construction project participants.

Features	Basis for judgment	Classification category
Whether it can be identified by a third-party identification agency	Project quality appraisal report	Technical defects
Whether it violates the relevant provisions of laws and regulations	Construction related laws and regulations	Management violations
Whether it is against the normative documents or agreed industry practices	Engineering practical experience or principles of good faith or a duty of reasonable care based on professional bodies	Irregularities

identified by the third-party identification agencies as the quality risk behavior nor the quality risk behavior of management violations expressly prohibited by laws and regulations. This is a type of quality risk behavior that is either contrary to the provisions of the relevant normative documents, it does not align with the common practice of industry conventions, it violates the principle of honesty and crediting the subject, or it can be avoided based on the premise of the reasonable duty of care expected of professional institutions. Given these qualifications, such quality risk behaviors are uniformly classified as irregular quality risk behaviors. The purpose of a quality risk behavior classification study is to categorize and sort out different manifestations of quality risk behaviors according to their characteristics and manifestations in order to identify the complex and variable quality risk behaviors of construction project participants and establish the corresponding classification guidelines. Based on the above typological identification results, the severity of different types of quality risk behaviors can be determined quantitatively by using appropriate decision-making methods, thus providing a scientific and reasonable basis for the allocation of engineering quality responsibilities. The table of project quality responsibility allocation based on the classification criteria of quality risk behaviors is shown in Table 5.

Table 5 shows g denotes the number of units, Z_g denotes the share of responsibility of the gth unit, β_S, β_B, and β_P are the coefficients of technical defects, management violations,

Table 5: Project quality responsibility allocation table.

Responsibility subject	Technical defects Category coefficient β_S	Management violations Category coefficient β_B	Irregularity Category coefficient β_P	Responsibility sharing ratio
Unit 1	$S_1^1, S_1^2, \ldots, S_1^K$	$B_1^1, B_1^2, \ldots, B_1^K$	$P_1^1, P_1^2, \ldots, P_1^K$	Z_1
Unit 2	$S_2^1, S_2^2, \ldots, S_2^K$	$B_2^1, B_2^2, \ldots, B_2^K$	$P_2^1, P_2^2, \ldots, P_2^K$	Z_2
Unit 3	$S_3^1, S_3^2, \ldots, S_3^K$	$B_3^1, B_3^2, \ldots, B_3^K$	$P_3^1, P_3^2, \ldots, P_3^K$	Z_3
...	...	...	...	...
Unit g	$S_g^1, S_g^2, \ldots, S_g^K$	$B_g^1, B_g^2, \ldots, B_g^K$	$P_g^1, P_g^2, \ldots, P_g^K$	Z_g

and irregularities, and S_g^K, B_g^K, and P_g^K represent the specific quality risk behaviors implemented, while K denotes the number of behaviors.

2.2. Calculation Model of Multisubject Engineering Quality Responsibility Division. Based on the fault imputation principle of engineering quality responsibility, the degree of fault of the quality responsibility subject and the size of the cause force of the act and result can be taken as the main factors in the division of quality responsibility of multiple subjects. As professional subjects of engineering construction, the five categories of quality responsibility subjects have the obligation of working together to pay attention in order to produce an engineering quality higher than expected of most people in the society. In other words, they are inevitably responsible for any fault presumption results caused by any risky behaviors they themselves engage in. Based on this, the degree of fault can be presumed according to the severity of the quality risk behaviors the responsible subjects are engaging in. Therefore, according to the jurisprudential characteristics of engineering quality responsibility and the principle of the fault imputation of engineering quality responsibility, there are two basic factors that must be considered in the comprehensive evaluation of engineering quality responsibility: (1) the degree to which the responsible subject is at fault, which can be determined by the severity of their quality risk behavior; (2) the size of the cause force that is generated by the quality risk behavior and damage results. The correlation between the above two factors is also taken into account. According to the principle of fuzzy mathematics, the comprehensive decision-making problem of the division of engineering quality responsibility can be simplified to a single-factor judging problem as follows:

$$(\text{Degree of fault domain})\mathbf{R}(\text{Causal force domain}) = (\text{Proportional responsibility domain}), \tag{1}$$

where $\mathbf{R}$ is the operator.

Different types of risky behaviors have different magnitudes of causality for causing the abnormal state of engineering quality, which can be used as the evaluation index of the causality theory domain. The severity of quality risk behavior can be used as the presumption basis for the degree of fault of the actor subject. Therefore, a set of multiobject quality responsibility allocation methods based on engineering quality risk behavior can be established. This method is on the basis of the type of risk behavior corresponding to the engineering quality risk behavior implemented by the responsible subject, the degree of harm of the risk behavior, and the correlation between them. Based on equation (1), the quantitative analysis equation of quality responsibility can be written as

$$(\text{quality risk behavior damage domain})\mathbf{R}(\text{quality risk behavior category domain}) = (\text{proportional responsibility domain}). \tag{2}$$

In equation (2), the engineering quality risk behavior harm degree domain refers to the existing degree of harm resulting from the risk behavior engaged in by a subject. It is the degree of fault of the corresponding implementation subject, which is composed of (X_1, X_2, ..., X_m). The quality risk behavior type domain refers to the type of quality risk behavior. This is determined by categorizing it according to the characteristics of the different types of behavior and the degree of damage caused to the quality of the project. This measurement corresponds to the risk behavior and size of the damage caused by the force, which is composed of (Y_1, Y_2, ..., Y_n). The responsibility proportional theory domain says that those subjects who engaged in the quality risk behavior should bear a proportion of quality responsibility, which is expressed by Z:

$$(X_1, X_2, \ldots X_m)\mathbf{R}(Y_1, Y_2, \ldots, Y_n) = k, \tag{3}$$

where k is the calculated value of the corresponding responsible subject's quality responsibility and $\mathbf{R}$ is the operator.

Given that the subject g has jointly implemented a series of quality risk behaviors leading to the abnormal state of project quality, when **R** adopts matrix multiplication operation, the corresponding proportion of quality responsibility to be borne by subject g can be expressed as follows:

$$\left(\left\{S_g^1, S_g^2, \cdots, S_g^K\right\}, \left\{B_g^1, B_g^2, \cdots, B_g^K\right\}, \left\{P_g^1, P_g^2, \cdots, P_g^K\right\}\right)\begin{pmatrix} \beta_S \\ \beta_B \\ \beta_P \end{pmatrix} = k_{g.} \tag{4}$$

In equation (4), the set of engineering quality risk behaviors and the set of quality risk behavior type correlations need to satisfy the following two conditions:

(1) The quality risk behavior set should satisfy $S_g^K \in [0,1]$, $B_g^K \in [0,1]$, and $P_g^K \in [0,1]$, as well as $\sum_{g=1,K=1}^{g=N,K=M} S_g^K + B_g^K + P_g^K = 1$, where N denotes the maximum number of subjects and M denotes the maximum number of behaviors as categorized as different types

(2) The quality risk type sets $\beta_S \in [0,1]$, $\beta_B \in [0,1]$, $\beta_P \in [0,1]$, $\beta_S + \beta_B + \beta_P = 1$, and $\beta_S > \beta_B > \beta_P$

Furthermore, according to the above formula, it can be calculated that Z_g responsible subjects should bear the respective quality proportion as follows:

$$Z_g = \frac{k_g}{\sum_{g=1}^{N} k_g}. \tag{5}$$

3. Optimization Method of Quality Risk Behavior Category Coefficients

3.1. IPSO Theory. Each quality risk behavior has a different degree of causality for the negative impact on engineering quality resulting from different types of behavior. This is recorded as the quality risk behavior category coefficient. The solution of the category coefficients can be determined through the large sample data approach. The intelligent optimization algorithm can be used to explore the potential connection between the data. This can, in turn, make the values of different categories of coefficients more scientific. For this reason, the specific values of each category of coefficients are selected in this paper using an IPSO.

The particle swarm optimization has good global optimization capability, as it starts from a random solution and ultimately locates the optimal solution through iteration. The particles in the swarm move once, their positions change accordingly, and then the new individual extremum $\mathbf{p}_{\text{best}}$ and population extremum g_{best} are obtained after each iteration. For this operation, we assume a D-dimensional target search space has W particles forming a group, where the qth particle can be represented as a D-dimensional degree vector shown in equation (6):

$$\mathbf{Q}_q = \left(Q_{q1}, Q_{q2}, \cdots, Q_{qD}\right) q = 1, 2, \cdots, W. \tag{6}$$

Then, the velocity V_q of the qth particle can be expressed as in equation (7):

$$\mathbf{V}_q = \left(V_{q1}, V_{q2}, \cdots, V_{qD}\right) q = 1, 2, \cdots, W. \tag{7}$$

The optimal individual extremum p_{best} searched by the qth particle is given by equation (8):

$$\mathbf{p}_{\text{best}} = \left(p_{q1}, p_{q2}, \cdots, p_{qD}\right) q = 1, 2, \cdots, W. \tag{8}$$

The optimal population extremum p_{best} searched by the entire particle population is equation (9):

$$\mathbf{g}_{\text{best}} = \left(p_{g1}, p_{g2}, \cdots, p_{gD}\right) q = 1, 2, \cdots, W. \tag{9}$$

After finding p_{best} and g_{best}, the velocity v_{id} and position Q_{id} of the particles can be updated using equation (10):

$$\begin{cases} v_{qd}^{t+1} = w \times v_{qd}^t + c_1 \times r_1 \times \left(p_{qd}^t - Q_{qd}^t\right) + c_2 \times r_2 \times \left(p_{gd}^t - Q_{qd}^t\right), \\ Q_{qd}^{t+1} = Q_{qd}^t + v_{qd}^{t+1}, \end{cases} \tag{10}$$

where t denotes the number of iterations, c_1 and c_2 are the influence factors, and w denotes the inertia weights. In this article, w is taken as 1, and c_1 and c_2 are updated according to equations (11) and (12), which is the reason for calling it an IPSO. $T_{\max}$ denotes the maximum number of iterations:

$$c_1 = \frac{2.5 - 1.5t}{T_{\max}}, \tag{11}$$

$$c_2 = \frac{1 + 1.5t}{T_{\max}}. \tag{12}$$

3.2. Optimal Acquisition Method of Category Coefficients. In order to apply the IPSO to the category coefficient acquisition, the objective function of the IPSO needs to be set as in equation (13), while the optimization search direction of this objective function corresponds with the direction of the minimum value of equation (13):

$$F = \sum_{j=1}^{J} \sum_{u=1}^{U} \left| W_{j_u}^{L} - W_{j_u}^{l} \right|. \quad (13)$$

In equation (13), b denotes the number of the subject involved in the case, B denotes the maximum value of the subject involved in the case, $W_{j_u}^{l}$ is the true responsibility proportion of the uth unit of the jth sample, and $W_{j_u}^{l}$ is the estimated responsibility proportion of the uth unit of the jth sample.

Using equations (6)–(13), the specific steps of the category coefficient optimization acquisition method can be obtained as detailed below, and the whole flowchart of this IPSO can be shown in Figure 1:

Step 1: we set the percentage of three types as the variables to be optimized, where population size is W, the maximum number of iterations t is $T_{\max}$, the range of individual is '$(Q_{\min}, Q_{\max})$, the range of particle update velocity is $(V_{\min}, V_{\max})$, and the objective function is equation (13).

Step 2: we randomly initialize the position and velocity of the particles and set the number of iterations t to 1. We calculate the objective function value F_1 of each particle based on the position and velocity of the particle. Then, we obtain the initial minimum values of the objective function F^{ε}, the initial individual extreme value $\mathbf{p}_{\text{best}}^{\varepsilon}$, and the initial population extreme value $\mathbf{g}_{\text{best}}^{\varepsilon}$.

Step 3: we update the position and velocity of each particle according to equation (10), set the number of iterations t to $t+1$, then calculate the objective function value F_t, obtain the minimum value of the function value F_t, the individual extreme value $\mathbf{p}_{\text{best}}^{t}$, and the population extreme value $\mathbf{g}_{\text{best}}^{t}$, and determine whether the updated value F_t is less than F^{ε}. If yes, then let $F^{\varepsilon} = F_t$, $\mathbf{p}_{\text{best}}^{\varepsilon} = \mathbf{p}_{\text{best}}^{t}$, and $\mathbf{g}_{\text{best}}^{\varepsilon} = \mathbf{g}_{\text{best}}^{t}$; if not, then we allow the values of F^{ε}, $\mathbf{p}_{\text{best}}^{\varepsilon}$, and $\mathbf{g}_{\text{best}}^{\varepsilon}$ to remain unchanged.

Step 4: we determine whether t is greater than $T_{\max}$. If yes, then the optimization search ends, and we output Q_{qd}^{t}, F^{ε}, $\mathbf{p}_{\text{best}}^{\varepsilon}$, and $\mathbf{g}_{\text{best}}^{\varepsilon}$. If not, then we return to Step 3.

4. Simulation Verification

4.1. Type Coefficient Acquisition. In order to determine the category coefficients of quality risk behavior, this article selects 84 typical multiobject engineering quality dispute cases from China Judgment Document Network as the case traceability source for particle swarm optimization solution. The subjects involved can be divided into the following types: two-party subject, three-party subject, four-party subject, and five-party subject type. The subjects meanwhile can be taken as the following: the developer as A, survey company as B, construction company as C, supervision company as D, and design institute as E. The combination pattern and number distribution of responsible subjects are detailed in Figure 2.

Although the selection of cases inevitably bears some traces of selectivity, the selection of the exemplary cases used here has some compilation factors and the public attitudes of courts in different places towards these cases vary greatly. Thus, these selections represent precisely the mainstream judges' understanding of the cases and therefore have research value. At the same time, cases from multiple locations were carefully selected to reduce the imbalance of the influence of geography on the resultant verdicts and to ensure the universality of the obtained research results. The distribution of regions and the number of subjects involved in the cases are detailed in Table 6.

The parameters of the IPSO itself have a certain influence on its optimization results. Therefore, based on the above samples, the IPSO method and the category coefficient constraints, the maximum and minimum values of the particles can only be 1 and 0, respectively, in order to obtain more scientific category coefficients. This article mainly focuses on the population size, iteration number, and particle update speed involved in the IPSO as Experiment 1, Experiment 2, and Experiment 3 are conducted.

4.1.1. Experiment 1. We set the maximum number of iterations as 200 and the maximum and minimum values of particle update speed as 1 and −1, respectively, and then change the particle population size to 10, 100, 500, 1000, 1500, and 2000 in turn. Following this, the iteration diagram of the IPSO can be obtained as shown in Figure 1.

Figure 3 shows the minimum value of the objective function decreases as the population size increases. However, it is also clear that when the population size is 1000, 1500, and 2000, the minimum values of their three objective functions are basically the same. This indicates that when the population size reaches a certain level, the minimum value of the objective function also tends to be stable. Based on experiment 1, therefore, the population size used in this article is set as 1500.

After the population size was determined, Experiment 2 was conducted in this paper.

4.1.2. Experiment 2. We set the population size as 1500; the maximum and minimum values of particle update rate as 1 and −1, respectively. We change the number of iterations to 10, 100, 200, 400, 600, and 800 in turn, after which the iteration diagram of the IPSO can be obtained as shown in Figure 4.

Based on Figure 4, as the maximum number of iterations increases, the minimum value of the objective function decreases before it increases. This means that the maximum number of iterations is not as large as it has the potential to be. For this reason, based on Experiment 2, the maximum number of iterations was set to 200 in this article.

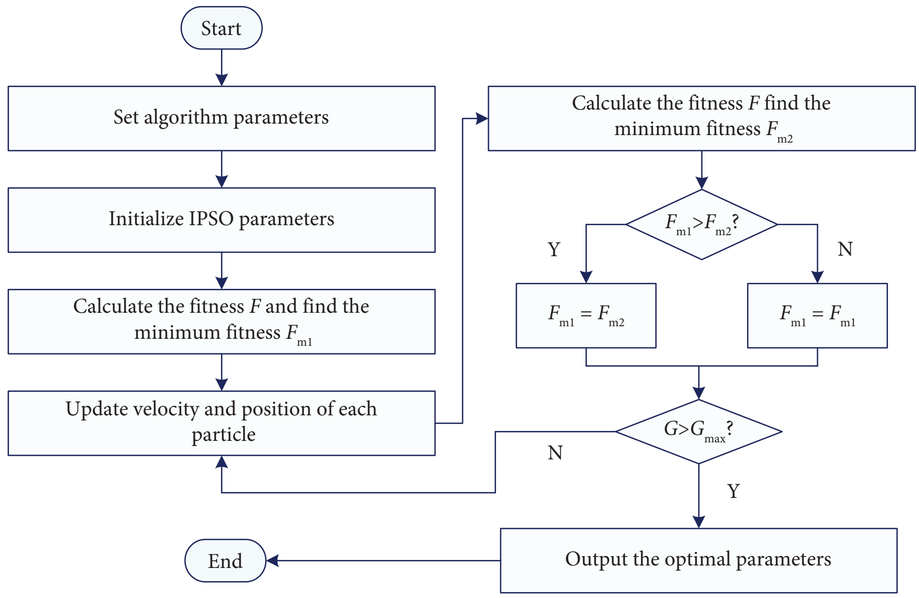

FIGURE 1: The flowchart of IPSO.

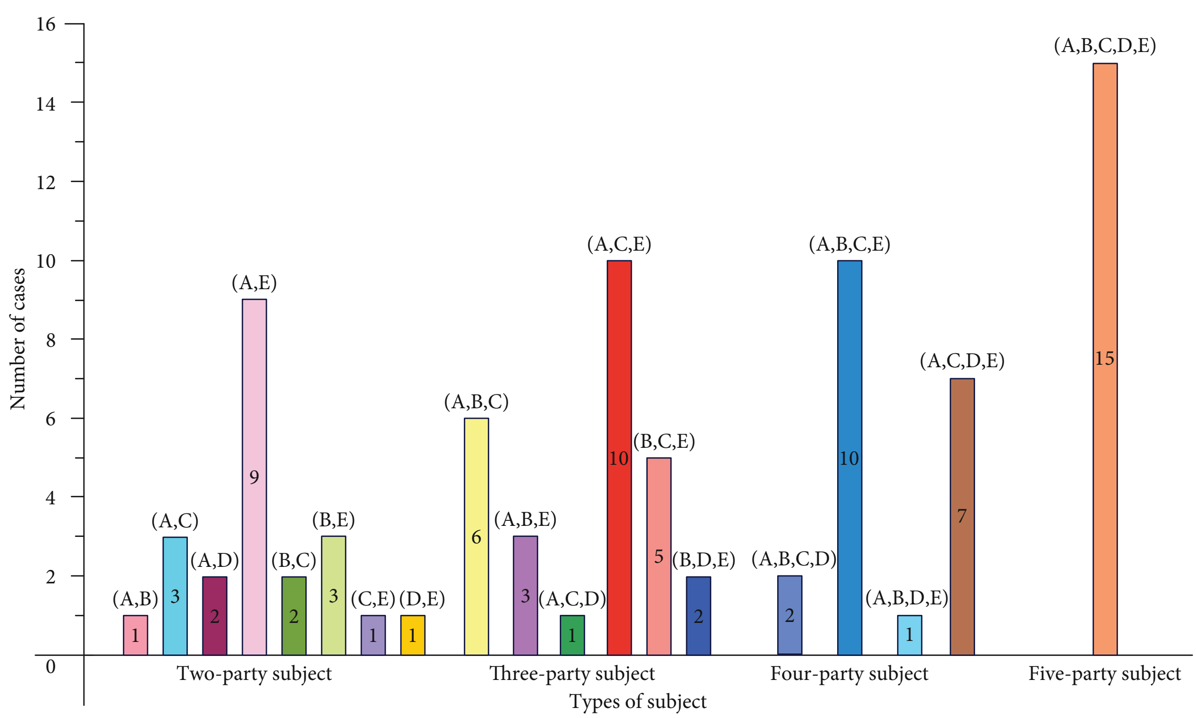

FIGURE 2: Combination pattern and number distribution of responsible subjects.

4.1.3. Experiment 3. We set the population size as 1500, the maximum number of iterations as 200, and the maximum and minimum values of particle update speed as [−0.01, 0.01], [−0.05, 0.05], [−0.1, 0.1], [−0.2, 0.2], [−0.6, 0.6], and [−1, 1], respectively. Following this, the IPSO shown in Figure 5 can be obtained.

Figure 5 shows that, as the particle update speed increases, the minimum value of the objective function will first increase and then decrease. However, it does not reach the initial minimum value. Therefore, based on Figure 4, the minimum and maximum values of the particle update speed were selected as −0.01 and 0.01 in this article.

Based on the above case samples and experiments using the IPSO, it is found that the IPSO is able to follow the specified search direction. When it reaches the minimum fitness value, its output optimal variables are shown in equation (14), which represents the coefficient of quality risk behavior type of technical defects, the coefficient of quality risk behavior type of management violations, and the coefficient of quality risk behavior type of irregularities:

Table 6: Regional distributions of cases and the number of subjects involved.

Regions	East China	North China	Northeast China	Central China	South China	Southwest China	Northwest China
Number of subjects	24	9	8	11	8	8	16
Percentage (%)	29	11	10	13	10	10	19

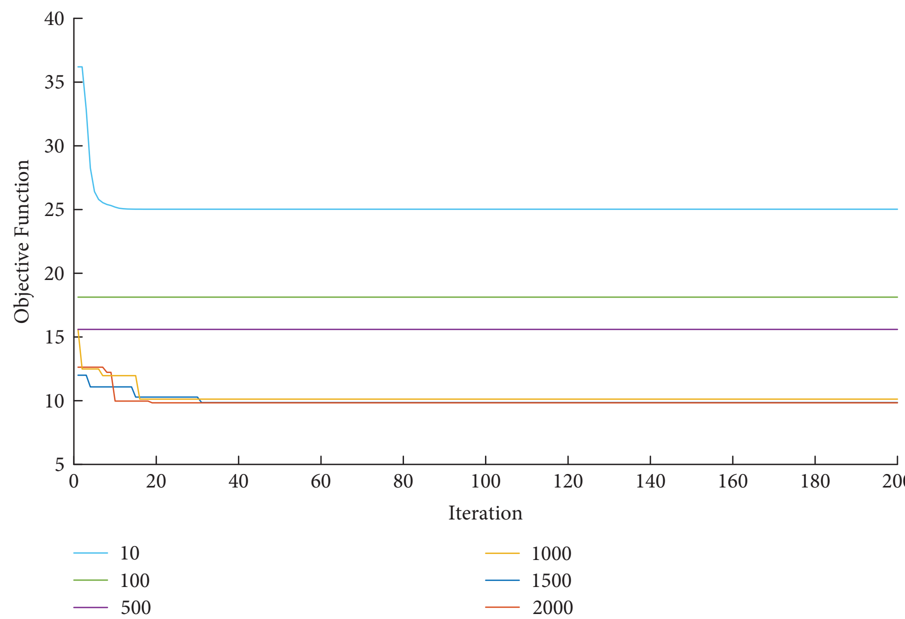

Figure 3: Iteration diagram of IPSO with different number of populations.

$$(\mathbf{M}_{\text{IPSO}})^T = (0.5994, 0.3131, 0.0875). \quad (14)$$

Moreover, as shown in the theory of traditional PSO, the update rule of PSO depends on c_1 and c_2. In the traditional PSO, c_1 and c_2 are set manually, which may not have the best result. However, in this article, through IPSO, c_1 and c_2 can automatically change with iteration number and then the best result can be obtained. This point can be supported by Figure 6.

As shown in Figure 6, with different c_1 and c_2, different iteration curves can be obtained. However, IPSO has the minimum fitness value. Hence, IPSO is better than traditional PSO because IPSO can automatically set c_1 and c_2. This is the advantage of IPSO and the reason why this article utilizes IPSO.

4.2. Modeling and Calculation. In this article, a total of four practical engineering quality dispute cases involving two, three, four, and five responsible subjects were selected as the validation cases of the model. These are indicated by the codes Subject II, Subject III, Subject IV, and Subject V, respectively. The $(M_{\text{IPSO}})^T$ value obtained from equation (13) represents the type coefficient for three types of quality risk behaviors, namely, technical defect class, irregular management class, and nonstandard class. When the subjects involved in the practice cases do not display a certain type of risk behavior or only two types of the specified quality risk behaviors occur, it is necessary to perform normalization for the two types of risk behaviors that are occurring. The processing results are detailed in Table 7.

Taking the case code Subject IV as an example, all parties, including the developer, supervision company, design institute, and construction company, engaged in one or more quality risk behaviors and were at fault for the resulting building collapse that was caused in the case. The quality risk behaviors and risk behavior categories of the above four responsible parties are summarized in Table 8.

Chen et al.'s [32] method was used to determine the severity for different quality risk behaviors, and the determination values for the SUBJECT IV case are detailed in Table 9.

Based on the simulation determination results seen in Table 9, the judgment matrices of quality risk behavior sets of technical defects and management violations were constructed and the judgment coefficients were calculated, respectively. The results are detailed in Tables 10 and 11.

According to equation (4), the corresponding parameters were assigned to the calculation, and the simulation calculation results were obtained as detailed in Table 12.

4.3. Comparison of Model Calculation Results and Litigation Practice Results. The simulation results of Subject II, Subject III, and Subject V were obtained by referring to the modeling and calculation process of Subject IV. The simulation results

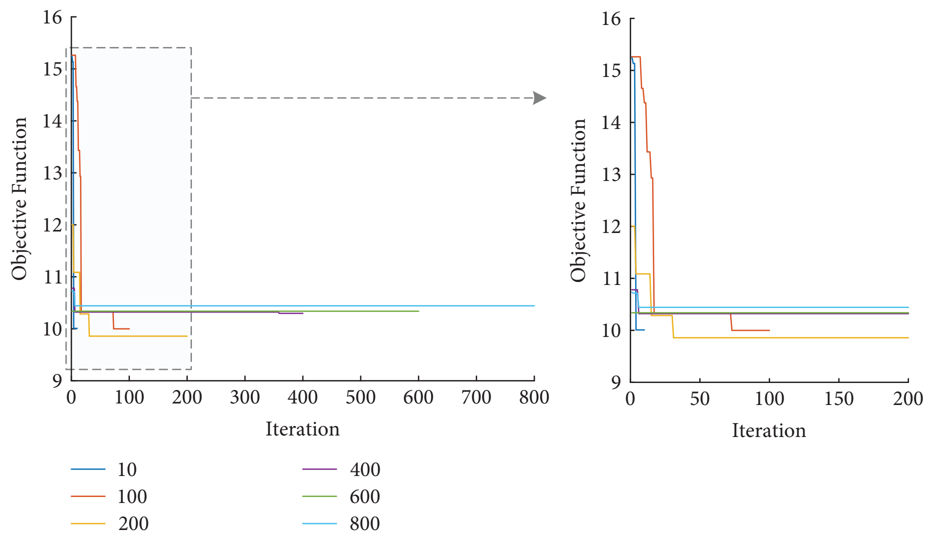

FIGURE 4: Iteration diagram of IPSO with different maximum number of iterations.

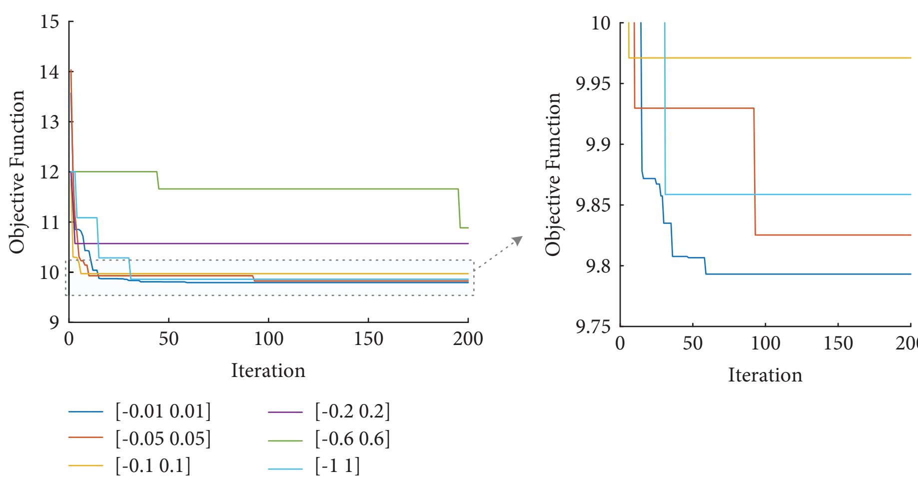

FIGURE 5: Iteration diagram of IPSO with different update speeds.

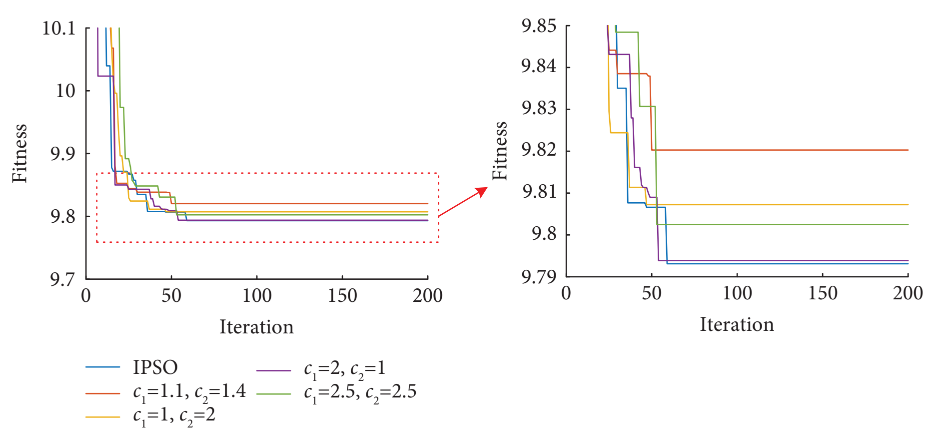

FIGURE 6: Iteration curves with different c_1 and c_2.

of Subject II, Subject III, Subject IV and Subject V are comparable to the practice judgment values as shown in Figure 7.

From Figure 7, we can see that the simulation results of the construction company and supervision company are in good agreement with the judgment values in practice.

Table 7: Type coefficient values of different groups.

Normalized group I		Normalized group II		Normalized group III	
Technical defects	Management violations	Technical defects	Irregularities	Management violations	Irregularities
0.6569	0.3431	0.8726	0.1274	0.7816	0.2184

Table 8: Quality risk behavior of the responsible parties summary table in Subject IV.

Category	The occurrence of specific quality risk behavior	Responsible subject
Technical defects	Not designed in accordance with the mandatory standards for engineering construction	Design institute
	Construction not conducted in accordance with the design drawings	Construction company
	Construction conducted against the technical standards of construction	Construction company
Management violations	Failure to perform supervision duties in accordance with laws and regulations and relevant technical standards, design documents and construction contracts	Supervision company
	Failure to carry out project quality supervision procedures	Developer
	Construction design plan not been reviewed or failed to review; unauthorized arrangements for construction	Developer

Table 9: Simulation determination results.

Categories	Responsible subject	Simulation verification results
Technical	Design institute Construction company	For technical risk behaviors, the quality risk behaviors of the construction company are much more serious than those of the design institute
Management violations	Construction company Supervision company	For the risk behavior of management violations, the quality risk behavior of the construction company is much more serious than that of the supervision company

Table 10: Technical evaluation criteria.

Technical	Design institute	Construction company
Design institute	1	1/7
Construction company	7	1
Determination coefficient	0.125	0.875

The reason is that the risk behavior of the construction company and supervision company are relatively simple, and the identification of practices is straightforward. The simulation results of the construction company, design company, and survey company are different from judgment values in practice. The main reason is that the construction company, design company, and survey company have more forms of risk behavior in practice and are harder to categories, so the identification of risk behavior in practice is prone to bias due to the discretion of the judges. In addition, the deviation of the simulation results of Subject IV and Subject V from the actual judgment values is significantly smaller than that of Subject II and Subject III. The main reason is that when the number of subjects and the types and numbers of risk behaviors implemented increase, the initial assignment of the type coefficient $(M_{\mathrm{IPSO}})^T$ can be better corrected to reduce dispersion. Overall, the simulation results obtained by the multisubject liability model established in this article are in high agreement with the actual determination values.

5. Discussion and Managerial Implication

The classification criteria of quality risk behavior proposed in this article can be used to classify quality risk behavior, and the severity of risk behavior can be qualitatively determined by combining type coefficient $(M_{\mathrm{IPSO}})^T$. The administrative supervision department can formulate standardization guidelines for engineering quality behaviors according to the classification identification mechanism of quality risk behaviors and formulate different penalty standards for different quality risk behaviors according to the type coefficient $(M_{\mathrm{IPSO}})^T$. At the same time, in the process of quality accident handling, the administrative supervision department can quickly lock the responsible subject through the type identification mechanism of quality risk behaviors combined with the type coefficient $(M_{\mathrm{IPSO}})^T$, so as to improve the efficiency of administrative supervision.

The multisubject quality responsibility quantitative model established in this article can quickly calculate the proportion of responsibility of each responsible party and provide quantitative basis for multisubject quality

Table 11: Management violations' evaluation criteria.

Management violations	Developer	Supervision company
Developer	1	9
Supervision company	1/9	1
Determination coefficient	0.900	0.100

Table 12: Case simulation calculated values in Subject IV.

Responsible subject	Technical 0.6569	Management violations 0.3431	Simulation calculation results (%)
Developer	0	0.900	30.88
Supervision company	0	0.100	3.43
Design company	0.125	0	8.21
Construction company	0.875	0	57.48

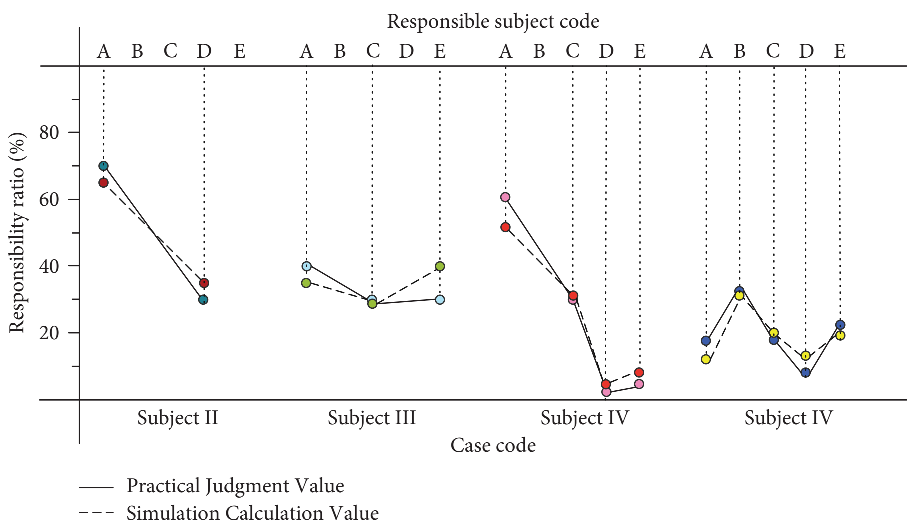

Figure 7: Comparison of simulation and actual determination values.

responsibility disputes. Based on the quantitative model proposed in this article, the court or arbitration commission can develop a quality responsibility quantitative software program with territorial application value to assist judges in case hearing, so as to improve the efficiency of case hearing and make more scientific and reasonable judgment conclusions.

6. Conclusion

In this article, a detailed study was conducted on classification criteria, category coefficients acquisition, and responsibility quantification calculation for the multisubject quality responsibility model of construction projects. Based on this, the following conclusions were reached:

(1) The concept of quality risk behavior classification criterion and type coefficient was proposed based on the theory of organizational behavior. The initial assignment of $(M_{\mathrm{IPSO}})^T$ was carried out for three types of quality risk behavior category coefficients using the IPSO. This process verified by simulation that $(M_{\mathrm{IPSO}})^T$ has good applicability.

(2) When determining the division of quality responsibility between two or three responsible parties, the determination of responsibility depends entirely on the initial assignment of the type coefficient $(M_{\mathrm{IPSO}})^T$, especially when the types of quality risk behaviors implemented by each responsible party are different. This cannot be combined with the actual situation of quality disputes, and it is more discrete. On the contrary, when the number of responsible subjects and the type and number of risk behaviors performed by each subject is larger, the severity determination coefficient of the same type of quality risk behaviors needs to be introduced in conjunction with the actual situation of the disputed case. This corrects the dispersion problem caused by the initial assignment of the type coefficient $(M_{\mathrm{IPSO}})^T$. In this way, the simulation effect is better.

(3) The method provided in this article can quantitatively calculate the division ratio of multisubject quality responsibility. However, the number of cases is not very large. To further improve the accuracy of the method, the more cases should be collected.

(4) The quality responsibility division model for multiple quality subjects established in this article is effective when applied in the context of a multi-subject quality dispute resolution.

However, the model developed in this article did not take into account the influence of external factors such as natural environmental changes or natural disasters on the allocation of quality responsibility, and the reasons for the high correlation between the type of quality risk behavior and quality results need to be further explored. Furthermore, the samples in this article were drawn from only one country, which has some limitations in terms of representativeness. In future studies, external factors such as natural environmental changes or natural disasters should be considered in the model, while increasing the number and diversity of samples, so as to build a multisubject quality responsibility quantitative division model with wider applicability and practicality.

Data Availability

The data used to support the findings of this study can be obtained from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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