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Research Article

Service Risk Evaluation of the General Contract for Coal Mine Production and Operation: Case Study at Shendong Jinjie Coal Mine in China

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While specialized services continue to be developed in the mining industry, there has been a lack of corresponding risk management research in China. This study develops a risk assessment index framework of general contract for mine production and operational specialized service. From previous research, the risk factors for specialized mine production and operation services are identified and the index framework is set up. An index weight is established using Delphi and set-valued statistics-triangular fuzzy number method, and a fuzzy comprehensive evaluation method is applied to assess the mine production and operation risks. With the Jinjie Coal Mine of the Shendong Coal Group selected as a test case, this shows that safety risk, environmental risk, and economic risk belong to level II. Management risk, resources risk, contract risk, and technological risk belong to level I, and the total risk of Jinjie coal mine belongs to level II. The results of the case study indicated that the proposed prevention and control strategies offered a better guide for the risk management practices for the specialized services at Shendong Coal Group.

1. Introduction

Since its rapid development in the "Golden Decade," China's coal industry has resolved many issues such as overcapacity, inefficient production, insufficient sustainable development, and poor security situations [1]. At the same time, many mining rights owners who are disadvantaged in terms of management, technology, safety, and costs are in urgent need of specialized mining organizations that can provide external production and operation, and technical and management consulting to develop their enterprises during the coal resource integration and industrial restructuring process in China [2].

Mining services are part of the commercial practices of the mining industry. In the 20th century, traditional resource extraction projects were government-dominated or privately-owned mining rights that had to purchase mining equipment and hire labor and professional mining technicians [3]. After World War II, because of the energy demand stimulated by 1960s industrialization, coal production increased substantially. In the 1970s, with significant changes in mining technology, scale, and location, the mining industry expanded rapidly in the United States, Australia, Canada, and other countries [4]. In the 1980s to 1990s, contract mining became the mainstream mode for resource exploitation in the mining industry, with Australia having the most cost-effective model in the world [5], which then expanded to New Zealand, Indonesia and South Africa (Roche, 1996; Buessing and Boden 2016). With the rapid industrialization in developing countries in the 1990s, global mining specialized services entered a period of significant development, which the mining division has been continually refining, while at the same time, mining costs were steadily declining (Washbourne, 2015). Currently, multinational corporations that carry out specialized services around the world include Australia Thiess, South Africa SRK, USA

Morrison Knudsen, and Canada Goldcorp [6, 7]. Thiess, the largest of its kind in coal mining, provides specific service solutions throughout the entire life cycle of the coal mine [8].

Contracting and mining activities were standardized in 1986 [9], after which China started to implement labor contracts for resource extraction projects in the construction and mining sector. In the late 1990s, the "contractual management model" proposed by Zhang accelerated the specialized development of mine construction, production aids, logistics services, and product distribution. In 2013, the government "encouraged specialized safety management teams to manage small coal mines and increase the technology, equipment and management of small coal mines by means of trusteeship and shareholding" [10]. In 2016, "The 13th Five-Year Plan for Coal Industry Development" was focused on coal service industry development and a strengthening of service capacity to encourage old coal enterprises in the process of shutting down and withdrawing from the market to establish specialized production service companies to carry out various technical services, to manage operations such as mine production contracting and individual project contracting, and to promote the transformation of the coal enterprises from offering pure product to providing product services [1]. These two government documents provided policy support for the establishment of specialized coal mine services. The specialized mine services practices at China Shenhua Shendong Coal Group, Beijing Tiandi Huatai Mining Management Company, Inner Mongolia Yitai Group, and others have laid the foundations for related research. Shendong Coal Group is the most advanced coal producers in China and was ranked number one in China's coal science production capacity report for 2017 (Chinese Academy of Engineering, General Administration of Coal Science Hospital, 2017); therefore, it has significant potential to enhance the scientific production capacity of other coal enterprises and raise the level of coal mining science in China.

At present, the most widely used specialized services in China are general mine production and operation contracting (abbreviated as MPO), equipment rental and maintenance, fully mechanized coal mining face installation and withdrawal, and technical consulting. The features of specialized mine services are variety, high investment, and high safety requirements. As more than 90% of mining in China is underground mining [11], there are many risk factors that cause uncertainty for the proprietor and mining service providers.

Specialized mine services have continued to develop in China; however, there has been little associated risk management research. Compared with the risk management of traditional coal enterprises, specialized mine services risks have different types of risks such as contractual risks, with the risk factors having different degrees of importance. There has been a great deal of research into traditional coal enterprise risk management and there has been one preliminary study on contract mining risks; however, it lacked thorough analysis. Overall, however, there has not been any comprehensive research on risk management for specific specialized mine services and, in particular, there has been no research on mine production and operation contracting (MPO) risk management in China.

To fill this gap, this paper defines the general MPO contracting risks, establishes an MPO risk index framework, and then applies this framework to the Jinjie Coal Mine of Shendong Coal Group as a case study, with the aim of assisting mining service providers understand specialized service risks to improve mining services safety and reduce the uncertainty in the specialized mine services sector. The literature method was selected as the risk identification method, the fuzzy comprehensive evaluation method for qualitative and quantitative evaluations was used as the risk research method, and Delphi and set-valued statistics-triangular fuzzy number method was used to determine the weights to overcome the subjectivity of expert opinion and improve the evaluation accuracy.

This remainder of this paper is organized as follows. Section 2 identifies the MPO risks and sets up the index system of MPO risks, Section 3 establishes the assessment model of MPO risks, Section 4 applies the model developed in Section 3 to the Jinjie Coal Mine, Section 5 gives suggestions to control the risks, and the final section concludes the paper with management suggestions.

2. Risk Identification

2.1. MPO Risk Definitions. General mine production and operation contracting is in the production phase of specialized mine services. The service providers are able to offer a range of services depending on their particular specializations such as technology, resources, operations and management, and mining life cycle services (exploration, design, infrastructure, production, and mine closures). The service provider is entrusted by the proprietor to conduct follow-up operations after mine construction such as mine production, auxiliary production, operations, safety management, equipment maintenance, materials procurement, processing, and washing, and is normally responsible for safety, output, cost, quality, and environmental protection, while the proprietor is responsible for daily supervision, inspections, control, examination, and assessment of the service provider's performance.

MPO contracting risk, therefore, refers to the possibility and consequence of the threats that coal enterprises face when providing MPO services for technology, resources, operations, or management.

2.2. Risk Identification. Risk involves the probability of loss or loss risk, threats, missed opportunities, or uncertainty [13], and organizational threat is a multilevel concept (Smith & Mckeen, 2009) that focuses on the two main dimensions of severity and frequency [14], with severity being the intensity or magnitude of damage or loss and frequency being the probability of loss, damage, or missed opportunities (Hampton, 2009). The ISO31000 Risk Management-Principles and Implementation Guide (2009), the IEC62198 "Managing Risk in Projects - Application Guidelines" (2013), and the COSO ERM-Integration Framework (2016) all provide risk management frameworks for industries, companies, and projects.

Table 1: Research on common coal enterprise risks.

Risk Factors	Source
Market, Resources, Technology, Engineering, Finance, Policy, External Cooperation Conditions, Social and Other	"Guidelines for the Feasibility Study of Investment Projects" [12]
Resources, Marketing, Security, Technology, Management, and Staff	Wan Shanfu et al. (2008)
Policy, Market, Society, Management, Technology, Funding	Cheng lin (2008)
Economy, Policy, Society, Politics, Technology, Management, Resources	Wang Tao (2009)
Policy, Resources, Market, Nature, Economy, Organization and Management, Decision-making, Technology	Zhang Ning (2010)
Policy, Market, Technology, Resources, Organization and Management, Social Environment	Lu Chunlei (2010)
Policy, Market, Technology, Resources, Financing, Strategy, Management	Zhao Wentao (2010)
Decision-Making, Management, Contract, Safety, Environmental Protection	Xie Liang (2011)
Political Environment (including policy and law), social environment, natural environment, economic environment (including market), organization and management, technology, decision-making and resources	Huang Guoying (2011)
Market, Technology, Enterprise Capability, Management Team, Finance	Zeng Hongliang (2013)
Policy, Economy, Market, Management, Safety, Enterprise Operation, Cost Control	Yang Bin et al. (2015)
Political Science, Economy, Science and Technology, Natural Environment, Industrial Competition, Enterprise Resources, Business Capability, Organizational Structure	Wei Lijun (2015)
Policy, Nature, Economy, Society, Technology, Market, Management, Security, Finance	Wang Liukai et al. (2015)
Political, Economic, Social Environment, Natural Environment, Technology, Management	Wu Fengping (2015)

As risk needs to be identified, quantified, and transferred, there have been many risk identification and quantitative descriptive techniques developed such as the Delphi method, risk matrices, the ordinal method, fault trees, failure modes and effect analysis, risk indices, Markov analysis, Monte Carlo simulation, and the Bayesian method [15]. However, the use of these quantitative risk management methods has meant that many sources of risk that are neither quantifiable nor quantifiable have been ignored [16, 17] and the use of risk assessment math and informatics in large enterprises has been extremely limited [18]. In this study, the literature investigation method was selected as the risk identification method.

The State Development Planning Commission issued the "Guide for the Feasibility Study of Investment Projects" in 2002, in which relevant provisions were outlined for the identification of risk factors under nine categories and twenty-four subcategories (National Development Planning Commission, 2002). Studies focused on Chinese coal industry risk management in recent years are shown in Table 1.

Specialized service mine risk is not the same as traditional risks in coal mines, which are generally focused on eco-environmental risks [19], safety and technical risks [20, 21], employee occupational health risks [22–24], and enterprise risk [18].

Coal price fluctuations have increased because of climate change worries and the dramatic changes in the energy market [25]. Coal as a share of the growing energy market has fallen in favor of less polluting sources such as natural gas, shale gas, and renewable energy. Chinese coal companies have also been the target of government policies such as those seeking to reduce excessive production capacity and change fuel from coal to natural gas. The emergence of specialized mine services has been accompanied by a growth in contractual risk and service provider market competition risk. Contract mining brings risks to both the proprietor and service provider; therefore, monitoring contract execution has been the main method for outsourcing the risk management of mine production services [26]. Kirk [27]considered eight risk categories for contract mining from an investment decision perspective. Dunlop [28] studied five dimensions of risk: equipment performance, production schedule adherence, latent conditions, force majeure, and general litigation risk. Anon [29] and Suglo [30] classified contract mining risks into four broad categories: technical, managerial, commercial, and economic, which covered risks associated with equipment, consumables, human resources, and costs. Rupprech [31] studied nine types of risks: tender invitation, site survey, job definition, contract duration, contract review, payment and fines, contract escalation, contract management, and contractual dispute resolution, from a contract life cycle perspective.

This study examines eight MPO risk dimensions: the policy, the economy, technology, management, resources, safety, environmental protection, and contracts, extracted from the previous studies in Table 1, as well as traditional coal mine risks and other contract mining risk research in Section 1.

2.2.1. Policy Risk. Policy risk has great influence on MPO service, especially to private enterprise. China has experienced policy of changing fuel from coal to natural gas, affair of urgent for electricity-coal; Shi [32] studies the consequences of China's coal capacity cut policy. China fully implements the policy of replacing business tax with Value Added Tax (VAT) in 2016 and imposed a comprehensive environmental tax in 2018, and carbon tax enacted in other countries may appear in China in the future. At the same time, the change of policy also accompany with the reform of tax which has a direct influence to coal enterprise, for example, the coal capacity cut policy along with the VAT deduction policy. By analyzing previous research results, we selected industry risk and tax risk as the indices for policy risk.

2.2.2. Economic Risk. Jonek-Kowalska [33] found that the coal share in the domestic energy balance and the domestic coal consumption are the key risk factors of coal enterprise book value. Reference [34] studies the impact path of economic fluctuation on coal industrial symbiosis networks performance. Yang et al. [25], Liu et al. [35] examines China's coal price fluctuations. MPO also face the risk of market competition, due to the market size and number of MPO enterprise. Market structure is a crucial factor to market performance and market size and production scale have sustained negative effects on market concentration ratio [36]. On this basis, we considered four aspects: macroeconomic condition, coal prices, market demand, and market competition.

2.2.3. Contract Risk. Kirk [27], Dunlop [28], Anon [29] and Suglo [30] studied contract mining risk. Monitoring contract execution is a main method [26]. Rupprech [31] analysed nine types of risks from a contract life cycle perspective. Di Maria [37] found a greater emphasis on efficiency at coal mines contracting with restructured plants which has a 17% improvement in productivity at these mines, relative to those contracting with regulated plants. This study analyzes context and its performance.

2.2.4. The Other Risk. Management risk, technologic risk, resource risk, safety risk, and environment risk of MPO are the same with traditional coal mine risks. A lot of scholars have studied coal enterprise risk [18, 33, 38], safety and technical risks [20, 21], eco-environmental risks [19], and Chinese scholars' shown in Table 1. Therefore, we selected these risk factors from previous research.

2.3. Index System Framework and Description. The service risk index system framework was established based on an in-depth analysis of the professional services risks at coal service enterprises and research on traditional mine operations risks and contract mining risks, as shown in Figure 1.

Specific introduction of the index is in Table 2.

3. General MPO Contracting Risk Assessment Model

3.1. Model

3.1.1. Evaluation Standard. The probability (P) criteria for risk occurrences is first determined, classified into five grades, as shown in Table 3.

Then, the risk severity of the consequences (C) is classified into five grades: level 1, minor, level 2, medium, level 3, significant, level 4, major, and level 5, severe**.**

Based on the established probability classification consequence degree criteria, five evaluation sets are established; $V = \{p_1 ... p_5, c_1 ... c_5\}$, where $p_1 ... p_5$ represent the five grades of risk occurrence possibilities.

The risk evaluation results, $r = P * C$, are then divided into **I-IV** grades $\{(\mathbf{1 \le r \le 4}), (\mathbf{5 \le r \le 10}), (\mathbf{10 < r \le 15}), (\mathbf{16 < r \le 25})\}$ based on the risk matrix study of Nijs Jan Duijm [39] and Jianping Li et al. [40], as shown in Figure 2.

3.1.2. Weight Set. The weight set is then established; the first level of weight is $W = (w_1, w_2, \dots, w_n)$, $i = 1, 2, \dots, n$; the second level of weight is $W_i = (w_{i1}, w_{i2}, \dots, w_{ij})$, $i = 1, 2, ..., n$, $j = 1, 2, \dots, m$.

The Delphi and set-valued statistics-triangular fuzzy number method is used to determine the results for the weight evaluation data from an expert survey and the importance value for each level of the index derived to calculate the weight of the first-level factors, and the second-level factors.

3.1.3. Evaluation

(1) Secondary Factors Risk. With each expert's assessment result, $r = P * C$; for risk levels I to IV, the specific risk evaluated by all the experts can be expressed as vector set $r_{ij} = [N_{L_I}, N_{L_{II}}, N_{L_{III}}, N_{L_{IV}}]$ and $N_{L_I} + N_{L_{II}} + N_{L_{III}} + N_{L_{IV}} = N$, N_{L_I} being the number of experts who assessment risk is in level levels I, $N_{L_{II}}$ being the number of experts who assessment risk is in level levels II, etc. N is the experts number; then a normalized secondary factors risk membership function is obtained, as shown in

$$R_{ij} = \left[\frac{N_{L_I}}{N}, \frac{N_{L_{II}}}{N}, \frac{N_{L_{III}}}{N}, \frac{N_{L_{IV}}}{N} \right] \quad (1)$$

(2) First-Level Factors Risk. The first-level factors risk membership function $R_i = W_i \times \begin{bmatrix} R_{i1} & R_{i2} & \cdots & R_{ij} \end{bmatrix}^T$ are determined based on the secondary factor weights W_i and the matrix constructed by membership function of each secondary factor risk relative to the upper level risk.

(3) Total Risk. The total risk membership function $R = W \times \begin{bmatrix} R_1 & R_2 & \cdots & R_i \end{bmatrix}^T$ is determined based on the first-level factor weights W and the matrix constructed by first-level factor risk membership function.

3.2. Delphi and Set-Valued Statistics-Triangular Fuzzy Weight Determination Method. Delphi method usually consists of two iterations of initial opinions and revised opinions based on discussion of the experts [41]. The experts should have experience on MPO project and the number should at least seven. Because MPO is a new trend in China, so our experts selected here are all in the academia or work in coal service enterprise (clients and contractors). A two-round Delphi exercise was adopted in step (2) of set-valued-triangular fuzzy number method to get upper and lower bounds for more accurate weights [42].

Figure 1: Index system of MPO service risk factors.

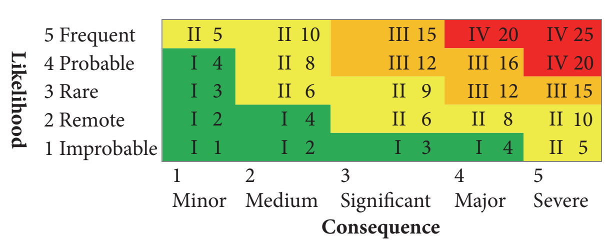

Figure 2: Risk Grades for MPO.

Zhang and Qi (2016) studied the use of the set-valued-triangular fuzzy number method in coal mine emergency management; therefore, based on this research, the set-valued statistics-triangular fuzzy number method is used to determine the weight over three steps:

(1) The evaluation index set $X = \{X_1, X_2, \ldots, X_n\}$ is determined in which n is the number of evaluation factors;

(2) Based on the range for index i given by experts j, the trigonometric fuzzy evaluation value $\widetilde{P}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ is calculated using the set-valued statistics-triangular fuzzy number method;

In the traditional fuzzy triangular weighting method, to calculate the index weight, it is necessary to obtain the fuzzy number $\widetilde{P}_{ij} = (l_{ij}, m_{ij}, u_{ij})$. As it is generally difficult for experts to determine exact values for each index, it is easier for them to provide an interval. The mean for the statistical distribution of the interval set, m_{ij} is calculated and the lower and upper limits of the interval are set (l_{ij}, u_{ij}). For m_{ij}, k experts are invited to propose a range for the importance of each factor on an $[0, 10]$ interval. For example, when expert j gives the interval for index i as $[y_i^{(j)}(1), y_i^{(j)}(2)]$, these

Table 2: MPO risk index system.

First-level factors	Second-level factors	Description
Policy risk	Industrial policy	Changes in coal industry regulatory policies, such as "reduce excessive production capacity" and "changing fuel from coal to natural gas", and other industrial layout and structural adjustment policies.
	Taxes policy	Changes in taxes and fees
Economic risk	Macroeconomic condition	Impact of macroeconomic fluctuations
	Coal prices	Coal price fluctuations.
	Market demand	MPO demand changes
	Market competition	Change in service provider number, competitiveness, competition strategy.
Management risk	Organizational structure adaptation	Organizational structure does not meet the specialized mine service model
	Internal communication	Lack of coordination and communication between the proprietor and the service provider.
	Workflow normative	Poor workflows may cause adverse effects.
	System and implementation	System is not perfect or poorly implemented.
	Plan and implementation	Low level of planning and implementation.
Technical risk	Professional service technical level	Specific technical level for specialized mine services.
	R & D innovation capabilities	R & D innovation capacity of the new service.
Resource risk	Human resources	Lack of appropriate human resources
	Funds	Insufficient funds or irrational funding structure.
	Equipment	Equipment selection, maintenance, material supply, etc.
	Information system	Information platform is ineffective.
	Resource endowments	Exploration differences in resource reserves, quality, and geological and coal seam conditions.
Safety risk	Safety management system	Safety management system failures.
	Input	Poor safety equipment, facilities and training input
	Incidents	Direct losses and derivative risks caused by safety incidents.
Environmental risk	Environmental protection system	Environmental protection management system failures
	Input	Poor environmental protection equipment, facilities and training input
	Pollution	Direct losses and derivative risks
	Resource Recycling and Utilization	Poor recovery and utilization of coal and related resources
Contract risk	Contract	Contract signing process is not standardized and low contract text quality.
	Performance	Failed to perform the contract in terms of progress, quality, cost and safety.

intervals then form the sample for the set-valued statistics: $[y_i^{(1)}(1), y_i^{(1)}(2)], [y_i^{(2)}(1), y_i^{(2)}(2)], \ldots, [y_i^{(j)}(1), y_i^{(j)}(2)]$. The interval distribution on $[0, 10]$, which is stacked by interval samples of each expert, can be expressed mathematically as

$$y_i^{\wedge} = \mu(y_i) = \frac{1}{k}\sum_{j=1}^{k} x\left[y_i^{(j)}(1), y_i^{(j)}(2)\right](y_i) \tag{2}$$

$$x\left[y_i^{(j)}(1), y_i^{(j)}(2)\right](y_i) = \begin{cases} 1 & y_i \overline{\in} y_i^{(j)}(2) \ ](y_i) \\ 0 & other \end{cases} \tag{3}$$

Equation (3) is a characteristic function, in which $y_i^{\wedge} = \mu(y_i)$ is the covering frequency function for the random set to y_i, which reflects the degree of fuzzy superiority or inferiority. As function $y_i^{\wedge}$ is actually a convex membership function y_i for the factor i, the average value for y_i can be obtained from $E(y_i) = \int_{b_1}^{b_{L=1}} \hat{y}_i y_i dy_i / \int_{b_1}^{b_{L=1}} \hat{y}_i dy_i$, where $b_1, b_2, \ldots, b_{L+1}$ is the ascending order of the end points for each evaluation interval y_i, L is the number of intervals in the sequence, and $a_l$is the interval frequency $[b_l, b_{b+l})$. Therefore, the average value for y_i can be expressed as

Table 3: Risk probability classification standard.

Level	Description	Probability
1	Improbable	Once every ten years or more
2	Remote	Once every five years-ten years
3	Rare	Once every five years
4	Probable	Once a year
5	Frequent	Multiple times a year

$$E\left(y_i\right) = \frac{\int_{b_1}^{b_{L=1}} \widehat{y}_i y_i dy_i}{\int_{b_1}^{b_{L=1}} \widehat{y}_i dy_i} \qquad (4)$$

As the interval samples add up to a distribution in the interval $[0, 10]$, then $E(y_i)$ is the expert's most probable value for the importance of evaluation index i; therefore, the closer the experts evaluate factor i to $E(y_i)$, the higher the accuracy. The variance in the sample distribution can be expressed as $\sigma^2 = \int_{b_1}^{b_{L=1}} \widehat{y}_i[y_i - E(y_i)]^2 dy_i / \int_{b_1}^{b_{L=1}} \widehat{y}_i dy_i$. σ^2 is then substituted into the formula to calculate the confidence interval for $E(y_i)$ at a 95% confidence level, where $Z_{\alpha/2}$ is equal to 1.96.

If the evaluation range given by experts falls within the confidence interval, the expert opinions are concentrated, with $E(y_i)$ being the most concentrated expert value in the sample interval and the most likely value for the factor. Therefore, each expert needs to compare the estimated factor interval with the final confidence interval. If the evaluation interval $[y_i^{(j)}(1), y_i^{(j)}(2)]$ is included in the confidence interval $y_i^{(j)}(1) \geq [E(y_i) - \sigma/\sqrt{n} \times Z_{\alpha/2}]$, $y_i^{(j)}(2) \leq [E(y_i) + \sigma/\sqrt{n} \times Z_{\alpha/2}]$; that is, if the expert evaluation interval j for index i falls within the range of the set-valued statistical sample interval that constitutes the normal distribution, the credibility of the evaluation interval is considered high and the result is acceptable; if $y_i^{(j)}(1) < [E(y_i) - \sigma/\sqrt{n} \times Z_{\alpha/2}]$ or $y_i^{(j)}(2) > [E(y_i) + \sigma/\sqrt{n} \times Z_{\alpha/2}]$, this indicates that the expert evaluation range falls outside the set-valued statistical sample range that constitutes the normal distribution and the evaluation credibility is low, which means that the experts need to re-evaluate the factors. After the test, the evaluation interval for expert j for index i is expressed as $[l'_{ij}, u'_{ij}]$, and the triangular fuzzy number for expert j for index i is $\widetilde{P}_{ij} = (l_{ij}, m_{ij}, u_{ij}) = (l'_{ij}, E(y_i), u'_{ij})$.

(3) Fuzzy comprehensive evaluation calculation for evaluation index $\widetilde{\mu}_i$.

$$\begin{aligned}\widetilde{\mu}_i &= \left[\sum_{j=1}^{k} l_{ij}, \sum_{j=1}^{k} m_{ij}, \sum_{j=1}^{k} u_{ij}\right] \\ &\quad + \left[\sum_{i=1}^{n}\sum_{j=1}^{k} l_{ij}, \sum_{i=1}^{n}\sum_{j=1}^{k} m_{ij}, \sum_{i=1}^{n}\sum_{j=1}^{k} u_{ij}\right] \\ &\approx \left[\frac{\sum_{j=1}^{k} l_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{k} u_{ij}}, \frac{\sum_{j=1}^{k} m_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{k} m_{ij}}, \frac{\sum_{j=1}^{k} l_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{k} l_{ij}}\right]\end{aligned} \qquad (5)$$

where k is the total number of experts participating in the evaluation and l_{ij}, m_{ij}, and u_{ij}, respectively, represent the lower importance limit, the most likely importance value, and the upper importance limit for each factor given by the experts.

The left and right expected values for $\widetilde{\mu}_i$, $I_L(\widetilde{\mu}_i) = (l_i + m_i)/2$ and $I_R(\widetilde{\mu}_i) = (m_i + u_i)/2$ are calculated as a coefficient, with $\eta < 0.5$ being an optimistic coefficient, $\eta = 0.5$ being a neutral coefficient, and $\eta > 0.5$ being a pessimistic coefficient. Then, the expectation for $\widetilde{\mu}_i$ is $I(\widetilde{\mu}_i) = \eta I_L(\widetilde{\mu}_i) + (1-\eta) I_R(\widetilde{\mu}_i)$, where $0 \leq \eta \leq 1$; that is, a larger $I(\widetilde{\mu}_i)$ results in a larger $\widetilde{\mu}_i$, with the value of η being 0.5 here; therefore, the factor weight is $\omega_i = I(\widetilde{\mu}_i) / \sum_{i=1}^{n} I(\widetilde{\mu}_i)$ and $\sum_{i=1}^{n} \omega_i = 1$.

4. Jinjie Coal Mine Case

A production and operation general contract was signed by the Guohua Jinjie Energy Company and Shendong Coal Group in 2014; the Jinjie Coal Mine is under the jurisdiction of Shenhua Guohua Jinjie Energy Company. In practical applications, the index system was adjusted as both the Guohua Jinjie Energy Company and the Shendong Coal Group belong to Shenhua and have state-owned enterprise characteristics. In addition, due to the complex calculation process, only part of the results is given.

4.1. Jinjie Coal Mine Risk Index System. The risk index system framework for the Jinjie Coal Mine was determined after a discussion with 15 experts which either work on MPO project of Jinjie coal mine (clients 5 and contractors 5) or have study experience on contract mining in China (academia 5). The policy risk and macroeconomic risk were not considered because of the state-owned characteristics. The coal price risk was not considered because the coal produced in Jinjie Coal Mine is mainly consumed by Jinjie Energy Company itself. The deleted risks were considered to be relatively small. The management factors were combined into three, and the new risk index system was shown in Figure 3.

4.2. Jinjie Coal Mine Risk Assessment Set. With reference to the risk division principles in the Shendong Coal Group intrinsic safety management system, the risk evaluation vector set was determined by 15 experts who scored the risk probabilities and risk losses for each secondary risk factor, as is shown in the security risk example in Table 4.

4.3. Jinjie Coal Mine Risk Weights. The factor weights for all levels were obtained from the 15 experts by two-round Delphi method, which were then input into the set-value statistics-triangular fuzzy number index weighting method (see Tables 8–11). The final results are shown in Table 5.

4.4. Fuzzy Comprehensive Risk Evaluation at the Jinjie Coal Mine. The fuzzy comprehensive evaluation procedure was used to determine the risk assessment vectors on all levels for the comprehensive MPO risk evaluation, the results for which are shown in Table 6.

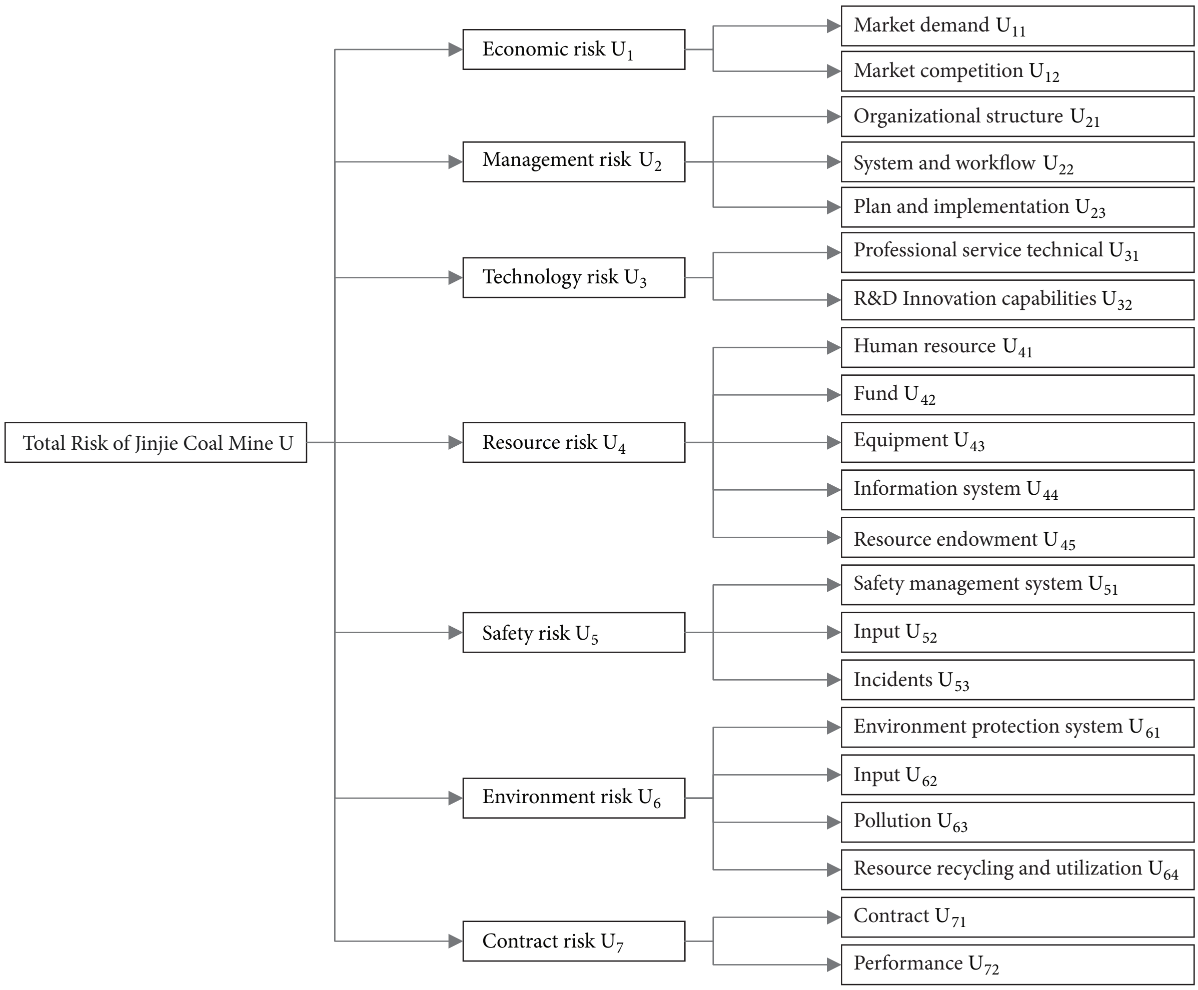

Figure 3: Risk index system for the Shendong Jinjie Coal Mine.

Table 4: Risk assessment of Jinjie Coal Mine.

Risk Level	Leve I	Level II	Level III	Level IV
U_{51}	0.00	0.40	0.53	0.07
U_{52}	0.07	0.80	0.07	0.07
U_{53}	0.00	0.07	0.60	0.33

Table 5: Risk index weights for the Shendong Jinjie Coal Mine.

Risk Weight		W_1	W_2	W_3	W_4	W_5	W_6	W_7
Secondary Factor Weight	W_{i1}	0.49	0.33	0.49	0.21	0.34	0.26	0.48
	W_{i2}	0.51	0.33	0.51	0.21	0.32	0.25	0.52
	W_{i3}		0.34		0.21	0.35	0.27	
	W_{i4}				0.18		0.23	
	W_{i5}				0.19			
First-level factor weight		0.14	0.15	0.13	0.13	0.16	0.15	0.13

From Table 6, it can be seen that economic risks, safety risks, and environmental risks were all found to be level II, and management risks, technical risks, resource risks, and contractual risks were level I; therefore, according to the principle of maximum membership degree, the overall risk at Jinjie Coal Mine was determined to be level II.

While the risk membership identifies each risk level, it is not possible to compare the individual risks. Using a median method and assigning values to each risk level (10, 30, 50, and

Table 6: Risk assessment vectors for the Shendong Jinjie Coal Mine.

Rating Factors	**Risk Level Affiliation**			
	I	II	III	IV
Economic risk U1	0.00	**0.80**	0.17	0.03
Management risk U2	**0.44**	0.42	0.09	0.04
Technical risk U3	**0.56**	0.44	0.02	0.00
Resource risk U4	**0.57**	0.25	0.08	0.10
Safety Risk U5	0.02	**0.41**	0.40	0.16
Environmental risk U6	0.10	**0.58**	0.27	0.05
Contract risk U7	**0.53**	0.30	0.10	0.07
Total risk U	0.29	**0.48**	0.17	0.07

Table 7: Jinjie Coal Mine Risk assessment.

Risk	Leve I	Level II	Level III	Level IV
U_{11}	0.00	0.80	0.20	0.00
U_{12}	0.00	0.80	0.13	0.07
U_{21}	0.07	0.73	0.13	0.07
U_{22}	0.67	0.27	0.07	0.00
U_{23}	0.60	0.27	0.07	0.07
U_{31}	0.73	0.27	0.07	0.00
U_{32}	0.40	0.60	0.00	0.00
U_{41}	0.53	0.33	0.13	0.00
U_{42}	0.60	0.13	0.07	0.20
U_{43}	0.53	0.27	0.00	0.20
U_{44}	0.67	0.27	0.07	0.00
U_{45}	0.53	0.27	0.13	0.07
U_{51}	0.00	0.40	0.53	0.07
U_{52}	0.07	0.80	0.07	0.07
U_{53}	0.00	0.07	0.60	0.33
U_{61}	0.07	0.80	0.13	0.00
U_{62}	0.13	0.73	0.13	0.00
U_{63}	0.07	0.13	0.67	0.13
U_{64}	0.13	0.67	0.13	0.07
U_{71}	0.53	0.33	0.13	0.00
U_{72}	0.53	0.27	0.07	0.13

Table 8: Expected values.

Expected value	i	1	2	3	4	5	6	7
First-level factor	W_i	7.96	7.04	7.07	8.65	8.29	7.71	7.18
Secondary factor	W_{1i}	7.28	7.57					
	W_{2i}	7.60	7.39	7.67				
	W_{3i}	7.35	7.37	7.50				
	W_{4i}	8.00	8.02	8.09	7.13	7.62		
	W_{5i}	8.27	7.80	8.50				
	W_{6i}	8.15	7.87	8.45	7.41			
	W_{7i}	7.00	7.60					

70), a numerical result for each risk rating was determined to arrange the risks at Jinjie Coal Mine in descending order; safety risks, environmental risks, economic risks, management risks, resource risks, contract risks, and technical risks.

Compared with traditional mine risks, safety and environmental risks were still the most serious, with economic risks and contract risks newly emerging. The technical risks were the smallest, which was also in line with the actual

Table 9: Standard deviations.

σ	i	1	2	3	4	5	6	7
First-level factor	W_i	1.00	0.61	0.54	0.33	1.32	1.22	1.01
Secondary factor	W_{1i}	0.65	0.94					
	W_{2i}	0.80	1.02	0.84				
	W_{3i}	1.27	1.11	0.92				
	W_{4i}	1.03	0.84	0.98	1.10	0.99		
	W_{5i}	1.37	0.79	1.10				
	W_{6i}	1.37	0.81	1.24	0.88			
	W_{7i}	1.00	0.97					

situation because of the technological superiority of the professional services company.

Corresponding risk prevention and control measures were arranged according to the factor weight distributions and the risk assessment results.

5. Risk Treatment

5.1. Emphasis on Safety and Environmental Protection. Safety risk and environmental risk are inherent difficulties in mine production and operation. Mine collapses, gas, dust, and mechanical and electrical accidents are still serious problems for specialized services. Therefore, as the top priority is to establish an intrinsically safe mine, any of these issues can reflect the risk levels associated with the MPO services. Further, mine production environmental problems such as waste water, waste gas, solid waste, and land reclamation are of major concern and were a particular focus of the 19th National Congress; as a result, many relevant laws and regulations have been promulgated or amended, all of which could affect the market competition inherent in the general MOP professional services contracts.

5.2. Establish and Perfect the Service Risk Management System. Standardized risk management is an important part of the establishment and perfection of the risk management system and, therefore, the construction of a risk management system is the basic condition for standardizing risk management. The specialized MPO services risk management system relies on the existing precontrol risk system to provide support for the protection and risk management system of the organization, the system, the cultural construction, finance, and technology. The normative, systematic practicability of the risk management system plays a decisive role in the formation of a risk management system that meets the needs of specialized MPO services and is also the key to improving coal mine safety levels.

5.3. Strengthen Management Contract Risk. Contract risk management should be based on a reasonable sharing of the risk. First, contract management should be established to improve the contract risk prevention and control system. Second, the risk sharing plan in the initial contract developed during the bidding and negotiation stages needs to be optimized. Thirdly, in light of the uncertainty risk, the contract execution process needs to be renegotiated through

Table 10: Confidence intervals.

Confidence interval			down	up
First-level factor		W_1	7.46	8.47
		W_2	6.73	7.35
		W_3	6.80	7.35
		W_4	8.49	8.82
		W_5	7.62	8.96
		W_6	7.09	8.33
		W_7	6.67	7.69
Secondary factor	W_1	W_{11}	6.95	7.61
		W_{12}	7.09	8.04
	W_2	W_{21}	7.19	8.00
		W_{22}	6.88	7.91
		W_{23}	7.25	8.10
	W_3	W_{31}	7.25	8.10
		W_{32}	6.88	7.91
		W_{33}	7.48	8.52
	W_4	W_{42}	7.59	8.44
		W_{43}	7.59	8.59
		W_{44}	6.57	7.69
		W_{45}	7.12	8.12
	W_5	W_{51}	7.58	8.96
		W_{52}	7.40	8.20
		W_{53}	7.94	9.06
	W_6	W_{61}	7.46	8.85
		W_{62}	7.46	8.27
		W_{63}	7.82	9.08
		W_{64}	6.97	7.86
	W_7	W_{71}	6.49	7.51
		W_{72}	7.11	8.09

a new framework clause or agreement, with special attention being paid to the adjustment mechanism based on a risk redistribution design for geologically complex mine projects and a recognition of the various influencing factors.

6. Conclusions

In this study, an MPO specialized services risk evaluation model was presented based on a multi-level fuzzy comprehensive evaluation method, for which a professional service

Table 11: Triangular fuzzy numbers.

Confidence interval			left	mid	right
First-level factor		W_1	0.13	0.15	0.17
		W_2	0.12	0.13	0.14
		W_3	0.12	0.13	0.14
		W_4	0.15	0.16	0.17
		W_5	0.13	0.15	0.18
		W_6	0.12	0.14	0.16
		W_7	0.12	0.13	0.15
Secondary factor	W_1	W_{11}	0.44	0.49	0.54
		W_{12}	0.45	0.51	0.57
	W_2	W_{21}	0.30	0.34	0.38
		W_{22}	0.29	0.33	0.37
		W_{23}	0.30	0.34	0.38
	W_3	W_{31}	0.18	0.21	0.23
		W_{32}	0.18	0.21	0.23
		W_{33}	0.18	0.21	0.24
	W_4	W_{41}	0.18	0.21	0.23
		W_{42}	0.18	0.21	0.23
		W_{43}	0.18	0.21	0.24
		W_{44}	0.16	0.18	0.21
		W_{45}	0.17	0.20	0.22
	W_5	W_{51}	0.29	0.34	0.39
		W_{52}	0.28	0.32	0.36
		W_{53}	0.30	0.35	0.40
	W_6	W_{61}	0.22	0.26	0.30
		W_{62}	0.22	0.25	0.28
		W_{63}	0.23	0.27	0.31
		W_{64}	0.20	0.23	0.26
	W_7	W_{71}	0.42	0.48	0.55
		W_{72}	0.46	0.52	0.59

risk management index system was established for coal enterprises. The Delphi and set-valued statistics-triangular fuzzy number method was used to determine the weights, and the Jinjie Coal Mine was selected as a representative case.

The combination of both qualitative and quantitative methods gave credibility to the evaluation results, from which it was found that safety risks, environmental risks, and economic risks were the most critical and that there were newly emerging risks such as contract risk and economic risk. Several countermeasures and suggestions were proposed based on the Jinjie Coal Mine risk assessment results: the establishment and perfection of a risk management system, strengthening contract risk management, and emphasizing safety and environmental protection.

This study on the general contract specialized mine production and operation risks can assist the Shendong Coal Group release excess capacity and provide better focused specialized mine services to meet its own production and operational needs to allow it to expand its services across the country and to the rest of the world through China's Belt and Road Initiative.

Appendix

*Jinjie Coal Mine Risk Assessment.*See Table 7 .

Set-Valued Statistics-Triangular Fuzzy Weight Determination Method for the Jinjie Coal Mine case. See Tables 8, 9, and 10.

The experts gave new assessment for the weights in the confidence interval, after which the triangular fuzzy numbers were determined (see Table 11).

Data Availability

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

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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