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Research on the Risk Factors of Power Coal Supply in China's Shanxi Province Based on ISM

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Abstract: The stability of power coal supply is of great significance for coal base construction and the focus of thermal power enterprise investment in Shanxi province. This paper analyzes the risk factors of power coal supply chain, builds up the power coal supply risk identification model based on ISM and identifies the major power coal supply risks. It is found that the key power coal supply risks for Shanxi's thermal power enterprise are coal enterprises business risk, the coal price fluctuation, coal supply contract risk etc. And then put forward the risk prevention measures.

Keywords: Power Coal Supply Risk, Interpretative Structural Modeling (ISM), Thermal Power Enterprise, Risk Prevention

1. Introduction

Shanxi province is rich in coal resources, and coal-fired electric industry is suitable for large-scale development. According to China's 12th five-year, Shanxi will be built three million kilowatts modern large-scale coal bases in northern, central and southern. Many power generation companies will invest in Shanxi province to build power plants and expand scale. Therefore, maintain long-term stability of coal supply is essential for the sustained and healthy development of Shanxi coal and electricity base. Aimed at the actual situation of Shanxi's coal resources and coal-fired electric enterprise development, we will use the interpretation structure model (ISM) to analyze the risk factors for a stable power coal supply, recognize the key risk factors and provide certain reference for Shanxi's power coal supply chain risk management.

This paper is organized as follows: Section 2 analyzes the risk factors from coal supply for electricity generation in Shanxi province. Section 3 establishes the Interpretative Structural Modeling(ISM) to determine the relationship between risk factors. Section 4 identifies the key risk factors from coal supply for electricity generation based on the risk conduction mechanism. Section 5 puts forward risk prevention and control measures. Section 6 concludes this paper.

2. Risk Factors Analysis

For Shanxi's power coal supply uncertainty in the production, sales, transportation and other areas, we believe that the power coal supply risks affecting the stability are divided into four aspects: external environment risk, production risk, transportation risk, and coal enterprise risk.

External environment risk mainly includes natural environment risk, policy environment risk and economic environment risk. Natural environment risk mainly comes from the natural disasters. Shanxi province, located in the Loess Plateau of northern China, is one of the Chinese disaster areas, and earthquakes, landslides, landslides, hail, frost and other natural disasters occur usually. Policy environment risk mainly refers to the risk factors from the national and local policies change related to power coal supply. Economic environment risk includes macroeconomic operation risk, international market risk, etc. As China's important energy base, Shanxi's coal supply is closely related to Chinese economic growth trend. When the economy is in a high-speed development stage, the coal-fired power plant and other energy-intensive enterprises will increase coal consumption, which will give the power coal supply of coal some risks.

Production risk comes from the mine production, which includes a substantial fluctuation of coal quality, production equipment failure or maintenance, mine safety accidents. In the process of coal mining, mining area changes, mining coal tectonic fault can cause the variety and quality of coal changes. When mining process changes, equipment troubleshooting or mine safety accidents may occur, the mining area of coal production will decline, leading to the shortage of coal supply.

The coal transportation relies on the highway and railway in

Shanxi. The transportation risks include transportation equipment malfunction, transportation safety accidents, shortage of transport capacity and transportation costs rise, etc. In railway transportation, Chinese railway transport capacity constraints, the train wagons are difficult to fully meet the power coal transportation. Coal railway facilities are aging, which causes transportation accidents. As the railway transportation equipment upgrade, the transportation costs rise year by year. In road transport, the transport capacity is limited, traffic accidents frequently occur, and transportation costs are also increasing.

Coal enterprise risks include the coal-fired power plants profit risk, coal price fluctuation, coal supply contract risk, peer competition risk and business risk. The profitability of power generation enterprises can significantly affect the bearing capacity of the coal price. Coal prices can significantly affect the coal supply and demand, and then influence the stability of power coal supply. In order to ensure a reliable power coal supply, thermal power enterprises usually sign the power coal supply contracts with the coal suppliers. Due to market coal price fluctuations, coal suppliers maybe break the contracts for seeking maximum benefits, thus the normal operation of thermal power enterprises will be at risk. Numerous coal enterprises in Shanxi Province maybe cause the peer competition risks. Unfair competition within the power coal industry will damage the lawful rights and interests of the most coal enterprises and thermal power enterprises, and influence the stability of power coal supply. Business risk refers to investment risk, financial risk and operational management risk from the coal enterprise interior.

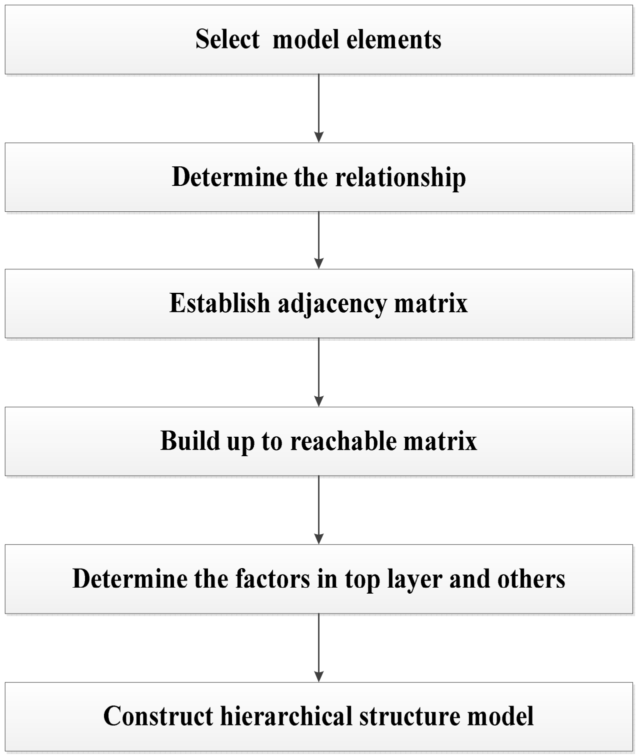

Figure 1. *ISM model analysis processing.*

Table 1. *Power coal supply risks and their relationship in Shanxi.*

risk sources	risk factors	name	factor relationship
	Natural environment risk	S_1	$S_5,S_6,S_7,S_8,S_9,S_{13},S_{14},S_{16}$
External environment risk	Policy environment risk	S_2	S_{13},S_{15},S_{16}
	Economic environment risk	S_3	$S_{11},S_{12},S_{13},S_{14},S_{15},S_{16}$
	Mining process change	S_4	S_5,S_{13},S_{14}
Production risk	Substantial fluctuations of coal quality	S_5	S_{13},S_{14}
	Production equipment failure or maintenance	S_6	S_4,S_5,S_{13},S_{14}
	Mine safety accidents	S_7	$S_4,S_5,S_6,S_{13},S_{14}$
	Transportation equipment failure	S_8	S_9,S_{10}
Transportation risk	Transportation safety accidents	S_9	S_8,S_{10}
	Shortage of transport capacity	S_{10}	$S_{13},S_{14},S_{15},S_{16}$
	Transportation costs rise	S_{11}	$S_{12},S_{13},S_{14},S_{15},S_{16}$
	Coal-fired power plants profit risk	S_{12}	-
	Coal price fluctuation	S_{13}	$S_{12},S_{14},S_{15},S_{16}$
Coal enterprise risk	Power coal supply contract risk	S_{14}	S_{12},S_{15},S_{16}
	Peer competition risk	S_{15}	S_{12},S_{13},S_{16}
	Business risk	S_{16}	S_{12},S_{14},S_{15}

3. ISM Establishment

Interpretative Structural Modeling (ISM) is a qualitative analysis model, mainly used to analyze the relationships between the various entities in economic society. The modeling steps include selecting model elements, determining the relationship between each other, establishing adjacency matrix, building up to reachable matrix and constructing hierarchical structure model. According to the hierarchical structure model, the levels of the risk factors can be determined. ISM model analysis process is shown in Figure 1. There is certain relevance between each risk. We construct the power coal supply risk identification model based on ISM, in order to find the main risks.

3.1. To Determine the Risks and Their Correlation

According to the power coal supply risks analysis, we select the 16 risks as the model elements and determine the interaction relation, as shown in Table 1.

3.2. To Establish the Adjacency Matrix

According to Table 1, we establish the adjacency matrix of power coal supply risks, $A=(a_{ij})_{16\times16}$, and $a_{ij}=\begin{cases}1 & \text{There is relationship between } s_i \text{ and } s_j \\ 0 & \text{There is no relationship between } s_i \text{ and } s_j\end{cases}$. The adjacency matrix A is shown in Table 2.

3.3. To Build up to the Reachable Matrix

We construct the A+I matrix, where *I* is the unit matrix, and use the Matlab7.14 to build up the reachable matrix *T* about power coal supply risk in accordance with the Boolean algebra, as is shown in eq (1)

$$(\mathrm{A}+\mathrm{I})^4=(\mathrm{A}+\mathrm{I})^3\neq(\mathrm{A}+\mathrm{I})^2\neq(\mathrm{A}+\mathrm{I}) \tag{1}$$

Then

$$T=(\mathrm{A}+\mathrm{I})^3 \tag{2}$$

The reachable matrix *T* is shown in eq (3).

$$T=\begin{bmatrix}
1&0&0&1&1&1&1&1&1&1&0&1&1&1&1&1\\
0&1&0&0&0&0&0&0&0&0&0&1&1&1&1&1\\
0&0&1&0&0&0&0&0&0&0&1&1&1&1&1&1\\
0&0&0&1&1&0&0&0&0&0&0&1&1&1&1&1\\
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0&0&0&0&0&0&0&0&0&0&0&1&1&1&1&1\\
0&0&0&0&0&0&0&0&0&0&0&1&1&1&1&1\\
0&0&0&0&0&0&0&0&0&0&0&1&1&1&1&1
\end{bmatrix} \tag{3}$$

3.4. To Determine the Risk Levels

For reasonable risk control, we will divide the power coal supply risks into different levels by the reachability matrix. We need a clear concept of the reachable set and antecedent set. Element s_i reachable set is a collection of the reachable matrix column elements that the elements corresponding to line s_i are 1, R (s_i). Element s_j antecedent set is a collection of the line elements that the elements corresponding to column s_j are 1, P (s_j). As shown in Table 3.

Table 2. *The adjacency matrix A.*

	s_1	s_2	s_3	s_4	s_5	s_6	s_7	s_8	s_9	s_{10}	s_{11}	s_{12}	s_{13}	s_{14}	s_{15}	s_{16}
s_1	0	0	0	0	1	1	1	1	1	0	0	0	1	1	0	1
s_2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1
s_3	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
s_4	0	0	0	0	1	0	0	0	0	0	0	0	1	1	0	0
s_5	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
s_6	0	0	0	1	1	0	0	0	0	0	0	0	1	1	0	0
s_7	0	0	0	1	1	1	0	0	0	0	0	0	1	1	0	0
s_8	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
s_9	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0
s_{10}	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
s_{11}	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
s_{12}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
s_{13}	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1
s_{14}	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1
s_{15}	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1
s_{16}	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0

Table 3. *R(s_i)、P(s_i) and R(s_i)∩P(s_i).*

s_i	The reachable set R(s_i)	The antecedent set P(s_i)	R(s_i)∩P(s_i)
s_1	1、4、5、6、7、8、9、10、12、13、14、15、16	1	1
s_2	2、12、13、14、15、16	2	2
s_3	3、11、12、13、14、15、16	3	3
s_4	4、5、12、13、14、15、16	1、4、6、7、	4
s_5	5、12、13、14、15、16	1、4、5、6、7、	5
s_6	4、5、6、12、13、14、15、16	1、6、7	6
s_7	4、5、6、7、12、13、14、15、16	1、7	7
s_8	8、9、10、12、13、14、15、16	1、8、9	8、9
s_9	8、9、10、12、13、14、15、16	1、8、9	8、9
s_{10}	10、12、13、14、15、16	1、8、9、10	10
s_{11}	11、12、13、14、15、16	3、11	11
s_{12}	12	1、2、3、4、5、6、7、8、9、10、11、12、13、14、15、16	12
s_{13}	12、13、14、15、16	1、2、3、4、5、6、7、8、9、10、11、13、14、15、16	13、14、15、16
s_{14}	12、13、14、15、16	1、2、3、4、5、6、7、8、9、10、11、13、14、15、16	13、14、15、16
s_{15}	12、13、14、15、16	1、2、3、4、5、6、7、8、9、10、11、13、14、15、16	13、14、15、16
s_{16}	12、13、14、15、16	1、2、3、4、5、6、7、8、9、10、11、13、14、15、16	13、14、15、16

We divide the risk factors into different levels according to Table 3.

If s_i satisfies the condition (eq (4)), it is the highest element set.

$$R(s_i)\bigcap P(s_i) = R(s_i) \quad (4)$$

So the first level system is $L_1 = \{s_{12}\}$ .Then we remove the row and column corresponding to the element of L_1 in the reachable matrix, and get the new reachable matrix T. According to the above steps, we can obtain the second level system $L_2 = \{s_{13}, s_{14}, s_{15}, s_{16}\}$, the third layer system $L_3 = \{s_2, s_5, s_{10}, s_{11}\}$, the fourth layer system $L_4 = \{s_3, s_4, s_8, s_9\}$, the fifth layer system $L_5 = \{s_6\}$, the sixth layer system $L_6 = \{s_7\}$ and the seventh layer system $L_7 = \{s_1\}$.

3.5. To Construct Hierarchical Structure Model

Based on the above layer systems of power coal risk, we can get a multi-level hierarchical structure model, as is shown in Figure 2.

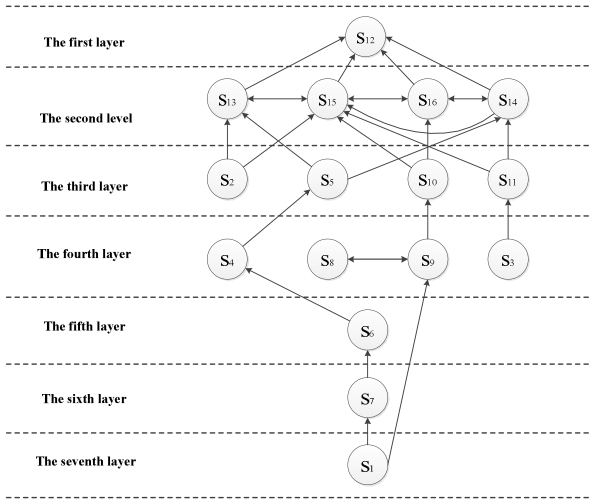

Figure 2. *Hierarchical directed structure.*

4. Power Coal Risks Identification

According to the Figure 2, we can get the relationship between each risk and the transmission mechanism. There are five risk transmission paths.

Path 1 Natural environment risk $\rightarrow$ Mine safety accidents $\rightarrow$ Production equipment failure or maintenance $\rightarrow$ Mining process change $\rightarrow$ A substantial fluctuation of coal quality $\rightarrow$ Coal price fluctuation $\rightarrow$

$$\begin{cases} \text{Coal} - \text{fired power plants profit risk} \\ \text{Business risk} \rightarrow \text{Coal} - \text{fired power plants profit risk} \\ \text{Peer competition risk} \rightarrow \text{Business risk} \rightarrow \text{Power coal supply contract risk} \rightarrow \text{Coal} - \text{fired power plants profit risk} \end{cases}$$

Path 2 Natural environment risk $\rightarrow$ Transportation safety accidents $\rightarrow$ Shortage of transport capacity $\rightarrow$ Business risk $\rightarrow$

$$\begin{cases} \textit{Coal} - \textit{fired power plants profit risk} \\ \textit{Power coal supply contract risk} \rightarrow \textit{Coal} - \textit{fired power plants profit risk} \\ \textit{Peer competition risk} \rightarrow \textit{Coal price fluctuation} \rightarrow \textit{Coal} - \textit{fired power plants profit risk} \end{cases}$$

Path 3 Economic environment risk $\rightarrow$ Transportation costs rise $\rightarrow$ Power coal supply contract risk $\rightarrow$

$$\begin{cases} \textit{Coal} - \textit{fired power plants profit risk} \\ \textit{Business risk} \rightarrow \textit{Coal} - \textit{fired power plants profit risk} \\ \textit{Peer competition risk} \rightarrow \textit{Coal price fluctuation} \rightarrow \textit{Coal-fired power plants profit risk} \end{cases}$$

Path 4 Transportation equipment failure $\rightarrow$ Transportation safety accidents $\rightarrow$ Shortage of transport capacity $\rightarrow$ Business risk $\rightarrow$

$$\begin{cases} \text{Coal} - \text{fired power plants profit risk} \\ \text{Power coal supply contract risk} \rightarrow \text{Coal} - \text{fired power plants profit risk} \\ \text{Peer competition risk} \rightarrow \text{Coal price fluctuation} \rightarrow \text{Coal-fired power plants profit risk} \end{cases}$$

Path 5 Policy environment risk $\rightarrow$ Coal price fluctuation $\rightarrow$

$$\begin{cases} \text{Coal} - \text{fired power plants profit risk} \\ \text{Business risk} \rightarrow \text{Coa-fired power plants profit risk} \\ \text{Peer competition risk} \rightarrow \text{Business risk} \rightarrow \text{Power coal supply contract risk} \rightarrow \text{Coal-fired power plants profit risk} \end{cases}$$

Business risk, coal price fluctuation, peer competition risk and power coal supply contract risk in the second layer form a loop. There is a mutual influence relationship between the transportation equipment failure and transportation safety accidents.

According to the transmission mechanism of power coal supply risks, we can get the following conclusion.

(1) Natural environment risk, policy environment risk and economic environment risk as the external indexes are the essential factors affecting the power coal supply, without control. They are the priority in the power coal supply risk management.

(2) Business risk, coal price fluctuation, peer competition risk and power coal supply contract risk has a strong correlation and are related to coal-fired power plants profit. They are the key in the power coal supply risk management.

(3) Mine safety accidents, transportation safety accidents, transportation equipment failure and transportation costs rise maybe induce business risk, coal price fluctuation and peer competition risk through risk transmission mechanism. They affect the stability of power coal supply and need to be paid attention by investors.

5. Risk Prevention Measures

5.1. External Environment Risk Prevention Measures

Natural environment risk, policy environment risk and economic environment risk as the external environment risks aren't controllable. Investors should undertake risk prediction based on past experiences and data, and prepare the response plant for ensuring the power coal supply and the coal-fired power plants normal operation in Shanxi.

5.2. Production Risk Prevention Measures

Mine safety accidents as the important production risk should be paid attention by investors. Coal enterprises should monitor the coal quality fluctuation and the change of coal seams structure, timely repair equipment, update the technology and strengthen the mine safety awareness to prevent accidents.

5.3. Coal Enterprise Risk Prevention Measures

Business risk, coal price fluctuation, peer competition risk and power coal supply contract risk as the important coal enterprise risk have certain relevance with coal-fired power plants profit risk. Business risk, power coal supply contract risk and coal-fired power plants profit risk are controllable to a certain extent. Coal enterprises and coal-fired power plants should pay attention to enterprise management status, and guard against business risk. Investors should pay close attention to the power coal supply contracts performance and formulate corresponding measures to prevent the economic loss caused by the contract breach. Investors should also control costs and other measures to improve coal-fired power plants profit and enhance the coal price affordability.

6. Conclusions

There are a variety of power coal supply risks in the process of coal production, transportation, use, storage, etc. The thermal power enterprises need to control the main risk factors in the investment. This paper analyzed Shanxi's power coal supply risks, including external environment risk, production risk, transportation risk, and coal enterprise risk. It studied the relationship among the risks based on the ISM and obtained the hierarchical interpretative structure model. We identified the key risks that affect the stable power coal supply through risk transmission mechanism, including natural environment risk, policy environment risk, economic environment risk, business risk, coal price fluctuation etc. What's more, some suggestions are put forward to control the key risks.

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