Risk Assessment for Coalbed Methane Development using a Structural Equation Model

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***Abstract* — A successful risk assessment of coalbed methane development project can help managers monitor the risk in a timely manner, which can reduce the loss of business. The goal of this study is to determine the risk factors and to establish an assessment framework for the risk assessment of coalbed methane projects in order to meet the needs of managers for risk monitoring and control. In this paper, including policies and regulations, social environment, geological resources, core technology, organization and management, economic operation and safety guarantee of seven broad categories risk factors have been identified through literature survey and interaction with industry experts. Through the structural equation modeling approach, data attained from a questionnaire survey was analyzed and a model was developed to examine the relationships between different assessment factors and the risk consequences of coalbed methane projects. And it verifies the feasibility and applicability of the proposed model through an example. The results showed that economic operation is a key risk factor forming the hub of the system, while geological resources indeterminacy has maximum influence, followed by technical factors. The results were also of importance for decision-making to understand the relative importance of the assessment factors and establish a comprehensive framework to assess the risk of coalbed methane projects.**

Keywords – CBM; expert analysis; structural equation model; risk factor identification; risk assessment method

I. INTRODUCTION

With the industrialization and utilization of coalbed methane (CBM) resources, China has made substantial progress in recent years. Chinese Academy of Engineering has forecasted China's CBM production will reach 80 billion squares in the next 20 years, about 8 times the current extraction volume. Due to the complexity of geological conditions of coal seam, low pressure, low permeability and low saturation problems of coal reservoirs, Chinese CBM project lifecycle is long [1]. The high risk and low profit of CBM industry curbs the CBM projects investment and seriously affects the development of CBM industry [2]. In order to ensure the implementation of CBM projects, risk aversion, and the maximum economic benefit [3], it is of vital importance to conduct the CBM development projects assessment and analysis. Taking into all risk factors account for the risk assessment model would increase the assessment difficulty and workload and single variable were considered resulting in affecting the accuracy of assessment [4]. Therefore, Identifying the main risk factors from a lot of uncertainty factors was the primary task of risk assessment [5-6].

The paper begins by an introduction of the research method and modeling technique adopted in this research. It is followed by reviewing the factors for risk assessment of CBM projects and the ways in which success is measured for this type of schemes. The framework derived from the structural equation modeling (SEM) approach is then presented with the validation outcomes reported. The paper concludes by discussing the implications of the research findings. It is hoped that the present research on risks in CBM projects will address the gap in the existing literature. It may be useful to managers in the CBM projects to identify and quantify risk factors. Based on the findings, further decisions can be taken on the responses to a particular risk. This may be either mitigation/avoidance of a particular risk or a decision to accept the risk by accepting a possibility of a lower profit or by developing a contingency plan to be implemented on the risk materializing.

II. METHODS

Risk assessment of CBM projects was complicated system engineering [7]. With respect to the assessment of many factors, the properties of each factor were divided into different categories and levels [8]. At present the most frequently used methods are fuzzy comprehensive assessment method [9], decision tree, expert analysis method [10], analytic hierarchy process [11] and Monte Carlo simulation method for projects risk assessment [12]. The previous study found that the decision tree weight design required considerable skill, and failed to investigate the relationship among the dependent variables and had the shortcomings of lack of overall perspective [13]. The analytic hierarchy process and fuzzy comprehensive assessment method were used to test the reliability and validity as well as the lack of risk factors [14]. The expert analysis method is mainly used to qualitative data in risk analytics [15]. Monte Carlo method can't reveal the formation process of risk. In this study, SEM was used to determine the risk factor from the latent variables during the process of CBM development and interaction and variable relationship analysis. The SEM approach was used to unveil the relationship between risk factors and the overall risk consequence of CBM projects as it is considered as an effective method for establishing the structural relationships among the latent variables.

SEM is a multivariate analysis technique that encompasses various statistical methods, including the confirmatory factor analysis, multiple linear regression, path analysis, analysis of variance, etc. [16-17]. SEM has been used in the engineering and management domain to examine, for instance, the relational bonding in inter organizational collaborations [18-20], factors affecting disputes between owners and contractors [21], satisfaction of construction project participants [22], and effectiveness of project planning. SEM is able to investigate not only the observable variables, but also the variables that are unable to directly measure [23]. SEM has the advantages both in exploring the direct and indirect effects among the variables. Unlike the traditional exploratory factor analysis, SEM generates a specific factor structure which could be used to test the feasibility in terms of the data. By analyzing structural equation groups, whether the relationship among the variables in different groups still had similar attributes was investigated, and simultaneously, whether the average value of each factor had significant differences was also examined. Because of its superiority in many aspects, SEM has become a popular analysis technology and has extensively applied in social science field [24]. A SEM consists of the measurement and structural models. The relationship between the latent and observed variables was obtained by measurement models [25]. And the formula is:

$$y = \Lambda_y \eta + \varepsilon \quad (1)$$

$$x = \Lambda_x \xi + \delta \quad (2)$$

Where Λx is the factor loading matrix that reflects the relationship between exogenous variables and exogenous latent variables, Λy is the factor loading matrix that reflects the relationship between endogenous variables and endogenous latent variables, η is endogenous latent variables, ξ is exogenous latent variables, ε is the error term of endogenous index y, δ is the error term of exogenous index x.

The relationships among latent variables can be determined by as follow:

$$\eta = \mathrm{B}\eta + \Gamma \xi + \varsigma \quad (3)$$

B is path coefficients between endogenous latent variables, Γ is the path coefficient that reflects the variable effects of exogenous latent variables on endogenous latent variable, ς is residual item [26].

SEM was employed as a risk function in order to identify the critical path and the path to the utility analysis. It was utilized to identify the key risk factors and verify the hypothesis for CBM development. Through the combination of related research results and the specific circumstances of CBM development, risk path CBM relation model was developed. The framework adopted in this research is illustrated in Fig. 1.

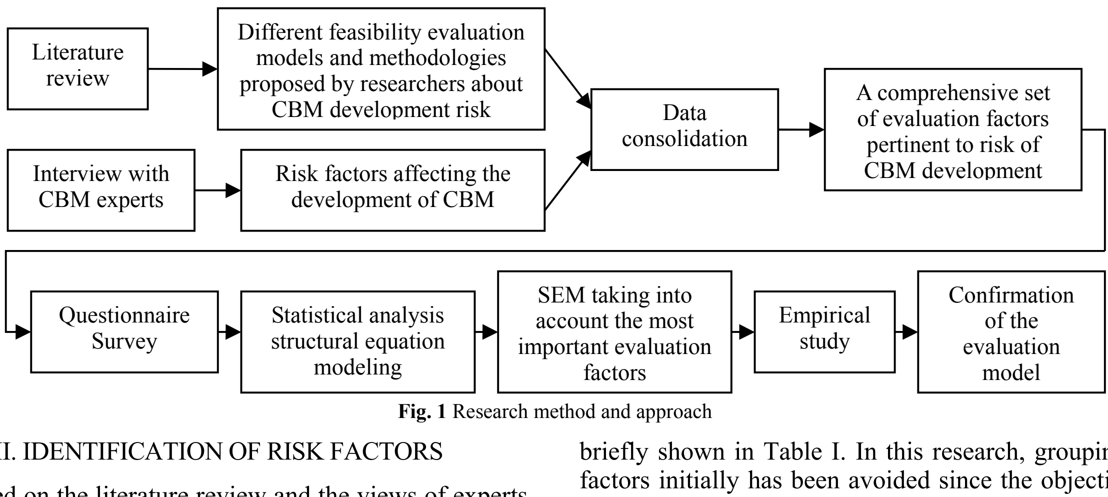

Fig. 1 Research method and approach

III. IDENTIFICATION OF RISK FACTORS

Based on the literature review and the views of experts a list of risk factors applicable in CBM projects referred to in the study summed up 46 analysis factor and formed six risk consequences of measurement scale [27-29]. They are briefly shown in Table I. In this research, grouping of risk factors initially has been avoided since the objective of the study is to analyses the risk factors using various tools that are available, and present to the practitioners: the interrelationships between the risk factors; a classification or grading of the risk factors; and a quantified measure of the importance of the risk factor, so that the more important risk factors get greater management attention.

TABLE I. EVALUATION FACTORS FOR STUDYING THE CBM DEVELOPMENT RISK

Potential factors	Risk factors
X1 Policy risk	X11 CBM resources tax increase, X12 Environmental policy increase, X13 The government's new energy policy, X14 Macro economic downturn
X2 Economic risk	X21 CBM price changes, X22 The investment cost is too high, X23 The recovery of funds not timely, X24 The low rate of investment income
X3 Geological resource risk	X31 Resource shortage, X32 Lack of gas content, X33 Permeability is poor, X34 The pressure of coal reservoir, X35 Poor cover, X36 Coal seam area, X37 The thickness of coal seam, X38 The buried depth
X4 Organization management risk	X41 Organization and coordination and communication problems, X42 Organization management problems, X43 Leader ability, X44 The resource allocation problem, X45 The adaptability of organizational structure, X46 Process management, X47 Innovation ability of learning problems, X48 The lack of professional and technical personnel
X5 Technical operation risk	X51 The lack of mining technology and equipment, X52 The recovery rate is low, X53 Mining cost, X54 Production safety accidents, X55 Production material procurement control is lax, X56 The supplier selection, X57 Distribution system
X6 Safety guarantee risk	X61 The lack of safety equipment, X62 Safety technology is not complete, X63 The safety system is not perfect, X64 Safety awareness is not strong, X65 Lack of safety culture construction
X7 risk consequences	X71 Coal bed gas production are not up to expectations, X72 Sales income less than expected, X73 Slower than expected growth in net assets, X74 The higher than expected cost, X75 Earnings below expectations,X76 The deterioration of the social environment

The data determined using the risk factor analysis were to identify the key factors of the premise. Owing to the state key laboratory of CBM resources platform, the data of discrete risk factors obtained from the experts with relevant experience and knowledge was applied in the estimation risk field. In order to make the investigation credible, the collection of the questionnaire survey object mainly were conducted among the senior technical personnel with practical experience, CBM development researchers, projects director and senior management staff of CBM development projects.

In this study, the exploration CBM development risk factors and its results was made up of a series of basic indicators, and each primary index was calculated from the side of a concrete's risk factors. Due to the complexed relationship between basic indicators, there may be a strong correlation between the variables. Therefore, each risk factor and the risk consequences first were analyzed using multiple regression analysis.

Multiple regression analysis method for the regression test indicated that Durbin-Watson statistical value was 2.021, suggesting that there was no serial correlation. The standardized residuals sequences and the independent variable of the absolute value of correlation analysis showed that it was not significant at 0.05 levels between each other, revealing that there were no heteroscedasticity phenomena. VFI test values were less than 10, showing that there was no significant multicollinearity. The correlation coefficient of multiple regression analysis (R = 0.793), the determination coefficient (R2 = 0.605), the decision of the adjusted coefficient (Adjusted R2 = 0.591), and F test of regression model and its significance could be judged, regression model as the overall effect was significant. Table II showed the regression parameter values and its inspections.

TABLE II. REGRESSION COEFFICIENTS AND SIGNIFICANCE TEST

	Unstandardized Coefficients		Standardized Coefficients			Colliearity Statistics	
	B	Std.Error	Beta	T	Sig.	Tolerance	VIF
Constant	-0.037	0.086		0.04	0.681		
Policies and regulations(Y1)	0.163	0.053	0.163	3.89	0.015	0.983	1.351
Social environment(Y2)	0.151	0.068	0.151	1.86	0.33	1.831	1.513
Geological resource(Y3)	0.163	0.056	0.153	3.78	0.008	0.733	1.935
Core technology(Y4)	0.131	0.068	0.131	3.31	0.033	0.531	1.467
Management of organization(Y5)	0.113	0.064	0.105	1.63	0.038	0.671	1.616

Exploitation and utilization(Y6)	0.138	0.061	0.138	3.83	0.003	0.831	1.759
Acquisition of materials(Y7)	-0.078	0.058	0.086	-0.98	-0.079	-0.583	1.589
Economic operation(Y8)	0.089	0.067	0.093	1.37	0.019	0.733	1.333
Safety guarantee(Y9)	0.076	0.055	0.063	1.19	0.011	0.678	1.897

Regression analysis showed that policies and regulations, geological resources and core technology factor for CBM development risk consequences had a strong explanatory ability. The uncertainties in these factors include variables were larger in CBM development and production operations. Material purchasing factors were not standardized with regression coefficient, t value not significant at the 0.05 level. Descriptive information purchasing factor coefficient was not significant different from zero. It could not be introduced into the regression equation.

Material purchasing factor related hypothesis was rejected. The means of production of CBM was the main in CBM development and other production data had little effect on CBM development. Assumptions in the rejected material purchasing factor at the same time also showed the importance of CBM resources for CBM development. The results were in conformity with existing literature research.

IV. MODELLING THE RISKS FACED BY CBM PROJECT

The objective to investigate the evolution of CBM development risk dynamic was to reduce the probability of risk occurrence, control and prevent risk. Risk control reduced the risks or transformation, so as to improve the yield of development projects. Therefore, on the basis of the CBM development key risk factors identification, analysis and review on previous research methods, SEM were proposed to develop a model of the risk assessment of CBM development projects.

The factor analysis which was used to identify the key risk factor is of significance for the risk consequence of CBM development. But not all of the risk factors would directly impact the risk consequences of CBM development. The purpose of CBM development formation path of research was to find out the risk factors and risk consequences, and the role of the relationship between risk factors, as well as explore the risk factors and risk the consequences of various paths.

The study putted forward CBM development risk factors and risk consequence path relation model. Based on the analysis above, this paper proposed the following hypothesis.

H1: The Policies and regulations of risk factors may increase the risk of economic operation.

H2: The Policies and regulations of risk factors have direct significant influence on the risk consequences.

H3: The social environment of risk factors may increases the possibility and effect of economic development of coal bed gas generation operation risk consequences.

H4: The social environment of risk factors has a direct significant effect on the risk consequences.

H5: The organization and management of risk factors may increase the risk of geological resources.

H6: The organization and management of risk factors may increase the risk of core technology.

H7: The organization and management of risk factors may increase the risk of Safety guarantee.

H8: The organization and management of risk factors may increase the risk of economic operations.

H9: The geological resource of risk factors may increase the risk of core technology.

H10: The geological resource of risk factors may increase the risk of Safety guarantee.

H11: The geological resource of risk factors may increase the risk of economic operations.

H12: The core technology of risk factors may increase the risk of Safety guarantee.

H13: The core technology of risk factors may increase the risk of economic operations.

H14: The core technology of risk factors may increase the risk of geological resource.

H15: The core technology of risk factors may increase the risk of organization and management.

H16: The Safety guarantee of risk factors has direct influence on the economic operation of risk factors.

H17: The economic operation of risk factor has direct significant influence on the risk consequences.

SEM and AMOS21.0 software was used to analyze the relationship between paths in order to verify hypothesis above. By applying the SEM method, the interaction and dynamic evolution among the key risk factors in the process of CBM development were analyzed. And finally, the risk factor influence model was obtained (Fig. 2). Effects of among variables including direct effect and indirect effect and total effect from three aspects referred to that the direct effect was the direct path coefficient reaction effect, indirect effect was an independent variable by directly or indirectly affect a third variable to influence, its size by two path coefficient of the product. The total effect was equal to the direct effect and indirect effect. The results showed that CBM development risk was not caused by single factor, and the effect extent of each factor was different. Over all, risk prevention and control system for CBM development should consider the weight of each risk factor and form the path of the risk consequences.

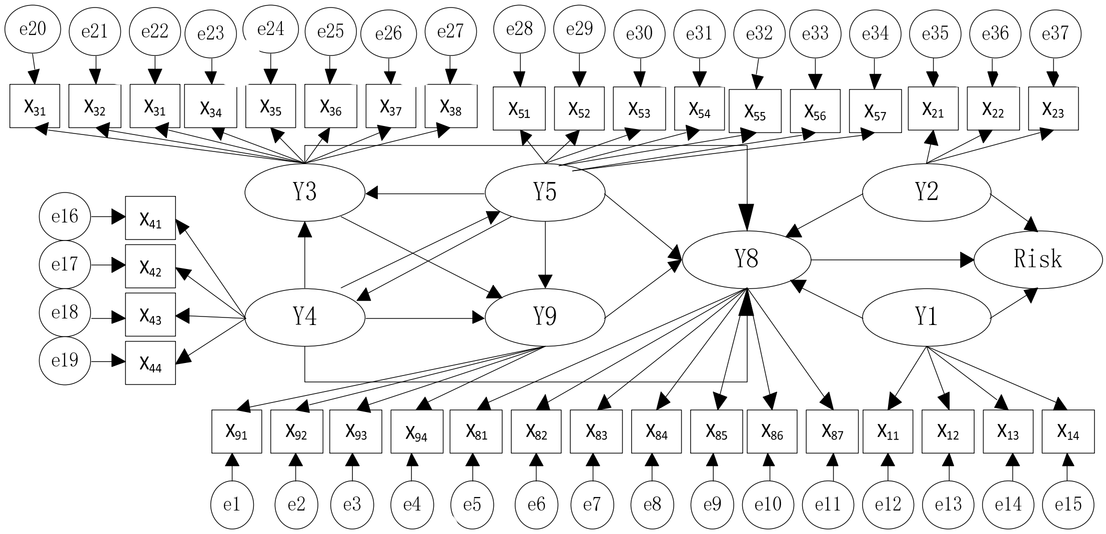

Fig. 2 Influence mechanism structural equation model of CBM project risk

V. SIMULATION AND ANALYSIS

Shizhuang southeast area of CBM development demonstration project is located in the southern Qinshui basin in China. By the end of 2013, CBM development completion number has reached 1138 wells in Shizhuang, including have been put into production 464 wells and has been producing 307 wells, CBM production has reached 62 million m3. The CBM blocks of Shizhuang in Taiyuan group 15# coal seam are studied in this paper.

A questionnaire protocol was first designed based on the assessment factors as previously identified. Six industry practitioners who have more than five year experience in carrying out CBM projects, together with four researchers selected from the CBM institute were invited to pilot the questionnaire, and they were asked to comment on the questionnaire design and to rate the identified assessment factors. Altogether 100 questionnaires were administered, out of which, 61 valid responses were received representing a response rate of 61 percent.

Descriptive analysis was then carried out on the collected data, using the statistical software SPSS19.0 in which the means and standard derivations (s.d.) were computed. The results show that the questionnaire Cronbach 'α is 0.865, more than 0.7 of the standard requirements indicating that they are meet the requirements of consistency description. In general, all assessment factors have a mean rating higher than four (i.e., above the midpoint along the 7-point Likert scale) indicating that they are critical to the success of a CBM project.

Finally, a framework was developed through the SEM approach to unveil the relationships between various risk assessment factors pertinent to CBM projects. Several fit indexes were adopted to assess the fitness of the SEM models. The fit indexes adopted include the Tuker–Lewis index (TLI=0.915>0.9), root mean squared error of approximation (RMSEA=0.038<0.05), normed fit index (NFI=0.912>0.9), and comparative fit index (CFI=0.961>0.9). All the fit indexes fall within the recommended intervals, solidifying the reliability of the model. Effects between risk factors and pathways coefficient were shown in Fig. 3.

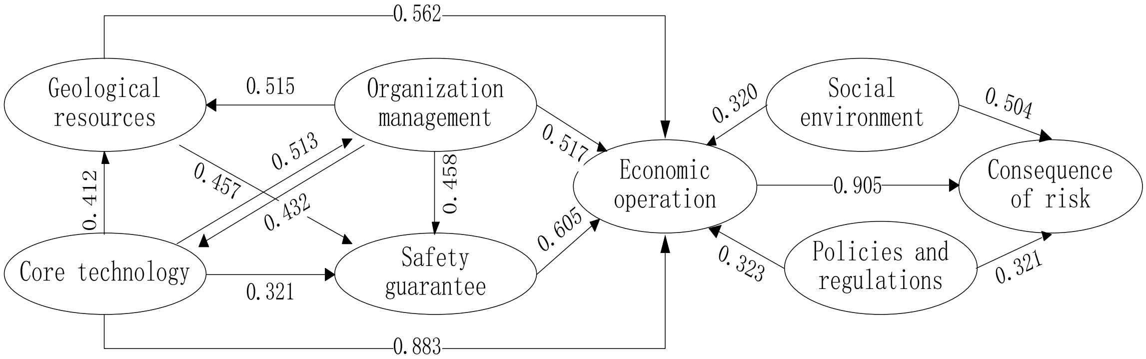

Fig. 3 Standardized regression weights of CBM project risk structural equation model

Fig. 3 showed that in terms of the total effect, geological resource was the greatest effect of risk consequences, with a value of 1.651, following by core technology, economic operation and safety guarantee, with the values of 1.216, 0.965, and 0.782, respectively. In contrast, the effects of organization management, social environment and policies and regulations on the risk consequences were relatively little, with the value of 0.615, 0.582, 0.503, respectively. Among the seven key risk factors, which the effect extents of each factor on CBM development in descending order: geological resources, core technology, economic operation, safety guarantee, organizational management, social environment, policies and regulations.

The results of the SEM showed that the geological resources and core technology are crucial to the controlling risks of CBM projects when the managements are taken into account. In fact, we can see that safety guarantee and organization management are ranked fourth and fifth in risk model. These are the very important factors and need maximum management attention since they can influence other factors to the maximum extent and are themselves amenable to be influenced.

From the point of the test results of exploration and development, Taiyuan group of 15 # coal seam has many problems, such as coal seam structure is loose, easy to collapse, low permeability, low gas saturation, producing water is bigger. Although the geological resources is the most important influencing factor, but in the actual development of its controllability is low. Based on risk impact mechanism model, it can through the technology improvement to reduce the effects of geological resources factors.

VI. CONCLUSION

To establish a comprehensive assessment framework for decision makers to assess the development risk of CBM projects, a model was developed by taking into account the mechanisms risk of CBM projects. Through a questionnaire survey conducted and the SEM approach, seven risk factors likely to be faced by CBM undertaking development projects have been identified. These risk factors were first subjected to structural analysis using the SEM method. The inputs for the analysis were drawn up by seeking the opinion of China CBM industry experts, as suggested in the SEM method. The SEM model shows the risk factors in a structured pathway showing their interrelationships. Economic operation emerges as a key risk factor forming the hub of the system. Geological resources indeterminacy is the most influential risk factor, followed by poor technology, weak safety guarantee, poor organizational management, force majeure social environment, and policies and regulations instability.

The SEM analysis also highlighted counterintuitive results, such as poor organizational management. The change in influence and dependence of a factor when viewed directly and under the influence of indirect relationships has also been brought out, with financial capability of investor and weak safety guarantee showing the greatest increase in influence.

The research would be useful for practitioners in the CBM industry and to academicians undertaking research in this field, since it is a new approach to the study of CBM project risks. Although the study was conducted in the China context, the method adopted here could be applied in similar studies in other countries and regions as well to understand and analyse the risks involved in CBM projects. Furthermore, the essential features of the risk of CBM project as identified in this paper can help decision makers to formulate management strategies to improve the implementation of CBM projects.

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