MINISTRY OF EDUCATION AND TRAINING

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PHAM TUAN ANH

RESEARCH ON APPLYING SOME MATHEMATICAL - GEOLOGICAL MODELS TO ASSESS THE RELIABILITY OF COAL EXPLORATION IN KHE CHAM MINE, CAM PHA CITY, QUANG NINH PROVINCE.

Major: Geological Engineering

Code: 9520501

SUMMARY OF DOCTRINE THESIS

Hanoi, 2023

Work was completed at: **Department of Prospecting and Exploration Geology, Faculty of Geological Sciences and Engineering, Hanoi University of Mining and Geology**

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The thesis can be found at:

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INTRODUCTION

1. Urgency of the thesis

Khe Cham mine, Cam Pha city, Quang Ninh province is one of the mines with large coal reserves and relatively favorable mining conditions. Like some mines in Quang Ninh coal basin, the exploration network carried out at Khe Cham mine is theoretically sufficient for mining design. However, in reality, although the reserves have been explored at a high level, when implementing mining investment projects, geological documents still need to be supplemented and adjusted. The PhD student proposed and was allowed to carry out a PhD thesis in geological engineering with the topic: "Research on applying some mathematical - geological models to assess the reliability of coal exploration in Khe Cham mine, Cam Pha city, Quang Ninh province."

2. Project objectives

Research and apply a number of mathematical and geological methods to evaluate the reliability of exploration work conducted at Khe Cham mine; from there, propose directions for mine exploration and development and applicability to coal mines with similar properties.

3. Objects and scope of the research:

Coal seams of Khe Cham mine; focus on representative seams of the mine.

4. Research content

- Detailed study on morphological characteristics - coal seam structure; serving as a basis for the application of appropriate geological-mathematical models;

- Research and apply computer software to build and manage data for research steps; contributing to modernization in the management and exploitation of geological data;

- Statistical quantification and spatial structure analysis of research parameters (using structural functions and trend functions), in order to fully evaluate the three aspects of variation of coal seam industrial geological parameters;

- Apply suitable Kriging method to interpolate documents, evaluate coal reserves and resources at Khe Cham mine;
- Compare the results of applying mathematical models with traditional methods in previously developed geological reports; from there, evaluate the reliability of the exploration work performed; contributes to orienting the exploration and development of coal resources in Khe Cham mine and its applicability to coal mines of similar nature.

5. Research Methods

The PhD student uses a combination of methods: (i) Traditional geological methods combined with systems approach. (ii) Modeling (mine geometry and some geological mathematical methods). (iii) Geostatistics. (iv) Apply some specialized software to solve the research content. (v) Experts combine practical experience.

6. New points of the thesis

6.1. Selectable mathematical and geological methods include: Statistical mathematics, trend function and structure function to fully evaluate the 3 aspects of variation for the main industrial geological parameters of the coal seams of Khe Cham mine.

6.2. Three relatively high-level homogeneous blocks with different geological structure, distribution characteristics and coal seam morphology and structure have been clarified: The Central block (between the F.E fault and the F.L fault) belongs to exploration mine group II, the southwest block of the F.E fault and the northeast block of the F.L fault belong to the exploration mine group III. This is the basis for assessing the reliability of the exploration work, explaining the shape and exploration network and choosing a method to calculate the reasonable reserves, resources for Khe

Cham mine.

6.3. Along with geological factors and exploration systems, the level of variation of coal seam industrial geological parameters; mainly the parameters of seam thickness and slope angle are the basic parameters that affect the reliability of exploration work and calculation of coal reserves at Khe Cham mine.

6.4. Using the popular Kriging method to interpolate documents with the help of computer software is reliable in assessing coal resource reserves for exploration and mining design.

7. Scientific significance and practical value

7.1. Scientific significance: Contribute to perfecting the exploration methodology in the direction of modern math - information. Provide the theoretical basis, the ability to deploy applied math - information methods for managers, exploration and mining units. Provide scientific arguments in interpreting the exploration system; the method of assessing coal resource reserves is consistent with the geological structure characteristics of Khe Cham mine and other coal mines with similar properties.

7.2. Practical significance: Provide practical solutions in orienting exploration networks, the ability to use the popular Kriging method to calculate coal resource reserves in Khe Cham mine and coal mines with similar properties; is a valuable reference for managers and businesses in coal mine exploration and development.

8. Thesis defense arguments

Argument 1: Using traditional geological methods, combined with trend function analysis, 3 relatively high-level homogeneous blocks can be clarified; in which the Central block (between F.E fault and F.L fault) belongs to exploration mine group II, the southwest block F.E fault and the northeast block F.L fault belong to exploration mine group III.

Argument 2: Thickness parameters and seam slope angle play an important role in assessing the reliability of exploration work and calculating coal reserves in Khe Cham mine.

Argument 3: Using the Kriging method with the help of computer software ensures reliability in assessing coal resource reserves for mine exploration and development and is especially effective in mine design, construction and exploitation.

9. Document basis: Research works, domestic and foreign scientific articles on the geology of Quang Ninh coal basin. The reports on the results of the investigation, assessment, and exploration of coal conducted on Khe Cham mine have been published from before to 2015. The basic document is the report on coal exploration results of Khe Cham mine - Cam Pha - Quang Ninh in 2015.

10. Dissertation implementation place: The thesis was completed at Department of Prospecting and Exploration Geology, Faculty of Geological Sciences and Engineering, Hanoi University of Mining and Geology under the scientific guidance of Prof. Dr. Truong Xuan Luan, Assoc. Prof. Dr. Nguyen Phuong.

The PhD student would like to respectfully express his deep gratitude for the guidance and dedicated help of the scientific instructors; The attention and facilitation of Hanoi University of Mining and Geology and the following units: VINACOMIN, VITE. Thanks to the scientists, geologists, and colleagues who allowed the PhD student to consult, use, and inherit previous research materials to complete this thesis.

Chapter 1
OVERVIEW OF RESEARCH AREA

1.1. Geological position of Khe Cham mine in Quang Ninh coal basin structure: Khe Cham mine is the eastern part of the Hon Gai graben, limited by two faults A-A in the south and Bac Huy fault in the north, belonging to the eastern part of the Central Cam Pha anticline complex.

1.2. Level of coal research and exploration on Quang Ninh coal basin: In general, the coal basin area that has had investigation, evaluation and exploration works is quite large; but not evenly.

1.3. Overview of Khe Cham coal mine: The mine belongs to the fourth level architectural block - Cam Pha architectural block (Tran Van Tri et al., 1990); has an area of 16.2 km^2.

1.3.1. Features of geological structure and coal minerals

a. Stratigraphy: Participate in the mine structure with formations; Mezozoic Kingdom (MZ), Triassic Formation (T), Upper (T_3), Nori - Reti Stage (T_{3n-r}), Hon Gai Formation ($T_{3n-r}hg$). The formations are distributed throughout the mine, about 1,800m thick, divided into 3 sub-formations: *The lower subsystem* ($T_{3n-r}hg_1$) is mainly a coarse-grained sediment that does not contain coal. *The middle subsystem* ($T_{3n-r}hg_2$) has a petrographic composition including layers of cobblestone, sandstone, siltstone, claystone, coal clay and coal seams. *The upper sub-formation* ($T_{3n-r}hg_3$) is located on top of the Hon Gai formation ($T_{3n-r}hg$), consisting of coarse-grained sediments that do not contain coal. Cenozoic Kingdom (KZ) - Quaternary System (Q).

b. Structural and architectural features: The geological structure of the mine is quite complex, consisting of folds that develop consecutively, most of which are limited by faults that cut through them.

c. Characteristics of coal seams: The coal seams of Khe Cham mine are divided into 3 sets: *Lower seam set*: from V.1 to V.8, mainly distributed below -350m, there are not many control works. *Middle seam set*: from V.9 to V14-5, distributed throughout the mine area, including coal seams of great thickness, of industrial value, accounting for most of the coal resource, reserves of the mine and also the object of main study of the thesis. *Upper seam set*: From V.15 to V.22, distributed mainly in the Northeast region, the seams have partial industrial value.

1.3.2. Some shortcomings need to be researched and solved in the exploration work

- The problem of the shape and density of the survey network: As a result of synthesizing documents, the PhD student found that the fluctuations in geological data during coal mining mainly appear in the locations of the reservoirs with complex structures (bulging, splitting, merging, ...), or places where folds and small faults (high-level) develop which cannot be controlled in the exploration stage. Therefore, it is necessary to research and evaluate the appropriateness of grouping exploration mines; from there, choose the shape and density of the exploration network as well as the method of interpolation of documents carried out at the mine; especially when exploring deep (below -350 m).

- Determination of coal reserves: The actual exploitation and the assessment of mine geologists, the Secang method is still the dominant method and is quite consistent with the morphological and structural features of the coal seam, the exploration network has been conducted and the results have been obtained reliable results; especially for large-scale calculation blocks, the seam has simple or relatively simple structural morphology. However, the reliability of the achieved reserve results depends largely on many factors: scale, uniformity, morphological-structural characteristics; variation of industrial geological parameters (thickness, slope angle, etc.); especially the fluctuation of coal seam pillars within the range between exploration works.

Chapter 2
THEORETICAL BASIS AND RESEARCH METHODOLOGY

2.1. Mineral coal and fields of use

2.1.1. Overview of mineral coal: Coal is a solid, combustible, sedimentary mineral that is a modified product of the coalification process of plant and microbial residues.

2.1.2. Types of origin of mineral coal

- In the world: In the history of geological development of the earth's crust, 5 main periods of coal production have been discovered: Carbon (C), accumulating over 25%; Late Permian (P_3), Triassic - Jurassic (T_3-J_2), which accumulated over 20%; Jura - Cretaceous (J_3 - K) and Paleogene - Neogen (E - N), the latter two periods accumulated coal over 54% of the total potential of coal resources in the world.

- In Vietnam: Three periods of coal mine formation have been discovered and identified: Late Permian, Late Triassic and Paleogene- Neogen

In the world, there are many systems for classifying and labeling coal according to origin and technology with different evaluation parameters. Usually according to the State Standard of the Russian Federation (ГОСТ 25543-88) or American standard (ASTM 388-98a).

2.1.3. Fields using mineral coal

Mineral coal is currently used mainly as fuel; chemistry,...

2.2. Research methodology

2.2.1. Traditional geological methods combined with systems approach

- Traditional geological method: Collecting, selecting documents, data from exploration works; then evaluate and select the types of documents to serve the research content of the thesis.

- System approach: Being conducted from the study of general documents of the mine, the Quang Ninh coal basin, assessment methods of the mine group and exploration network, etc.

2.2.2. Modeling method

- Traditional mine geometry method: Modeling linear cross-sections with different azimuths, especially characteristic cross-sections and iso-cylindrical maps for some main reservoirs to evaluate morphological characteristics; rules and structure of coal seam pillar transformation.

- Statistical method: Analyze and evaluate statistical distribution characteristics. Exploit and determine the statistical characteristics of coal seam geotechnical parameters; mainly the parameters of thickness (m) and coal seam slope angle (α), as well as assessing the influence of these parameters on the complexity of morphology and structure of coal seams in Khe Cham mine that are quantified through the values of mean ($\overline{X}$), variance (σ^2) and coefficient of variation (V,%) of the parameters to be studied.

- Trend analysis model: Used for the purpose of separating the information on the map in a certain research area into two components: Components are regional in nature and components are locally variable.

2.2.3. Geostatistical method

- Structural function (Variogram function) analysis: To describe the change law for each geological parameter in space. The empirical Variogram consists of discrete points representing the variability of geological parameters in space with different distances, calculated by the formula:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \left[Z_{(x)} - Z_{(x+h)} \right]^2 \quad (1)$$

In which: N(h) - Number of pairs of calculated points for each interval.

The structural function model helps to explain the variability, isotropy, anisotropy of the industrial geological parameters of the coal seam; is the basis for choosing the shape and size of the block to calculate the resource reserve.

- Kriging method: The PhD student uses the Kriging method to interpolate, build surface models, volume models and calculate coal reserves; establishing iso-cylindrical, iso-thickness, and iso-slope contours. The content of the Kriging problem is summarized as follows:

Suppose there are n values $Z_{(x1)}$, $Z_{(x2)}$, ... $Z_{(xn)}$ at the observation/sampling points: x_1, x_2, x_n are distributed in the vicinity of the point or block to be estimated. The linear estimate for x_o (or for V_o) has the form:

$$Z^*_{(xo)} = \sum_{\alpha=1}^{N} \lambda_\alpha Z_{(x\alpha)} \quad \text{or} \quad Z^*_{(Vo)} = \sum_{\alpha=1}^{N} \lambda_\alpha Zv_{(x\alpha)} \quad (2)$$

In which: λ_α- The αth weighted amount; $Z_{(x\alpha)}$ - Known parameters nearby X_α of the point (or block) to be estimated.

2.2.4. Expert method: It is used by the PhD student in selecting parameters to evaluate the characteristics and variability of coal seam industrial geological parameters; at the same time, it also helps the PhD student to exploit the computer software and interpret the calculation results.

2.3. Application software and database setup: In the thesis, the PhD student used MS Excel, Surpac, Surfer software to support building models, calculating statistical quantities, and calculating coal resource reserves. The PhD student focused on processing data from coal seam drilling and cutting projects under the research object. Exploration data was compiled and calculated into a data table in MS. Excel software.

Chapter 3
ASSESSMENT OF RELIABILITY OF KHE CHAM COAL MINE SURVEY

3.1. Factors affecting the reliability of study results

The reliability of exploration work, the ultimate goal is the accuracy of coal seam structure and morphology in space and the reliability/error of mineral resource reserves depends on many factors, in which, geological - mineral factors, industrial geological parameters, exploration system (shape and exploration network) are basic.

3.2. Analyze the reliability of exploration work using traditional modeling methods

3.2.1. Analysis with traditional mine geometry

Based on modeling using a geological cross-section system and cylindrical space model of coal seams, it allows an overall assessment of distribution characteristics, morphology - structure, as well as the visual relationship between coal seams and surrounding rocks, is the basis for further research steps. The research results draw some conclusions:

- Detailed analysis of isocylindrical plans allows identifying some additional folds and predicting the possibility of small faults cutting through them that have not been done during the exploration stages and are difficult to detect.

- Geometric anisotropy characteristics; the isometric variability of coal seams (through the shape of isometric lines) is quite clear and basically quite similar; coal seams have a general tendency to extend in the sub-parallel direction and are relatively stable in the center of the mine (from fault F.L to F.E). *This is important information in orienting the layout of exploration routes in the next stages.*

- The natural thickness of coal seams has a relatively regular and continuous level of change within each high-level homogeneous block.

3.2.2. Analyze using trend function model

In the thesis, the PhD student used the Trend function in the form of Z = f(x,y) to survey the characteristics of coal seam change (Z); Trend function can be linear or non-linear function of order 2, 3, etc. Trend equation of order 1, 2, 3, which are summarized as follows:

- First order function: $Z = a_1 + a_2y + a_3x$ (3)
- Second order function: $Z = a_1 + a_2y + a_3y^2 + a_4x + a_5xy + a_6x^2$ (4)
- Third order function: $Z = a_1 + a_2y + a_3y^2 + a_4y^3 + a_5x + a_6xy + a_7xy^2 + a_8x^2 + a_9x^2y + a_{10}x^3$ (5)

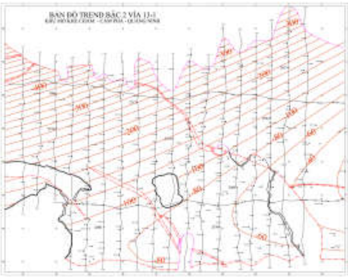
Based on actual data to build the Trend function of orders 1, 2, 3; from there, a Trend map and a Trend deviation map are established; calculate the correlation coefficient ($R_{h(x,y)}$) corresponding to the Trend orders. (Table 1)

Table 1: Summary of the results of the correlation coefficient calculation

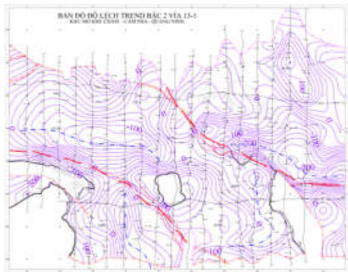
Order of Trend function	Correlation coefficient ($R_{h(x,y)}$)			
	V.10	V.13-1	V.14-1	V.14-5
Order 1	0.83	0.66	0.63	0.63
Order 2	0.84	0.72	0.76	0.73

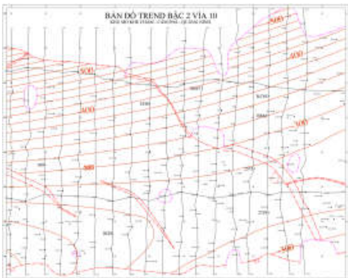
Order of Trend function	Correlation coefficient ($R_{h(x,y)}$)			
	V.10	V.13-1	V.14-1	V.14-5
Order 3	0.65	0.58	0.58	0.56

According to David J. C, R ≥ 0.3 means that there is a Trend; R ≥ 0.7 means that there is an ideal Trend; R ≥ 0.8 means that there is a very ideal Trend. From table 1 and based on the opinion of Davic J. C, the PhD student uses the map and the 2nd order Trend deviation map to analyze and evaluate. Trend map, 2nd order Trend deviation map V13-1, V10 are quoted in Figure 1.



V.13-1





V.10

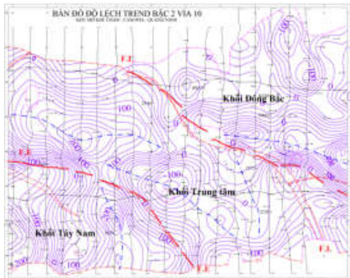


Figure 1. Trend map, 2nd order Trend deviation of seam pillars 13-1, 10

* Based on the analysis using the trend function model (Trend analysis and Trend deviation), the following results are drawn:

- To analyze trends and structural characteristics of coal seams in Khe Cham mine, it is best to use the Trend map and the 2nd order Trend deviation map (R = 0.72 ÷ 0.84).

- Isocontours established by Trend interpolation show clearly and in detail the changes in coal seam pillars (smooth, air-conditioned, etc.), ensuring more objectivity than traditional methods.

- On the Trend map of seam pillars 14-5, 14-1 and 13-1, it can be seen that the coal seams have a general trend toward the North - Northwest; Seam 10 alone tends to dip to the North (Figure 1).

- On the Trend deviation map, the studied coal seams are all folded due to later tectonic activities, the axis of large folds has the Northwest - Southeast and are complicated by high-level folds. The F.E fault is likely to develop from T.VIII to T.VIB and together with the F.L fault divides the mine area into 03 relatively homogeneous blocks of level VI: The southwest block F.E fault, the central block and the northeast block F.L fault. (Figure 1).

- On the second-order Trend deviation maps of seams 13-1, 10: It is possible to clearly identify high-order folds and buckling folds developing on the wings of the major fold in the Northwest - Southeast direction; at the same time, the exact location of the fault noted in exploration reports *(For example: F.G fault from T.XIIIb - T.XIV, F.L from T.XIVb to the East, F.E from T.VIII to T.VI,...).*

3.2.3. Analyze using statistical mathematical model

The coal seams of Khe Cham mine belong to the group of coal seams with medium to thick thickness, the degree of variation ranges from relatively stable to unstable ($40\% < V_m < 100\%$.); most of the ash level (A^d) is distributed in a relatively stable type ($V_A{}^d = 40 \div 75\%$), except for the reservoir V.10 is unstable ($V_A{}^d = 75 \div 100\%$).

Complexity of coal seam structure: Mainly belongs to the group of stable reservoirs with structures ranging from simple to complex.

Shape characteristics and degree of change of coal seam shape: Mainly belongs to the group of reservoirs with simple or relatively complex reservoir shapes ($1.4 < \mu \leq 1.8$; V12, 10, 9, 8) and relatively complex to complex ($\mu > 1.8$; V14-5, 14-4, 14-1, 13-1). The shape of coal seams mainly belongs to the complex and very complex groups (groups III and IV); the structure and tectonics of the mine belong to the complex group (P_{bv} from 25 ÷ 100).

3.3. Analysis using spatial structural function model

3.3.1. Set up structural functions (Variogam): To solve the task of researching and fully evaluating the spatial variability of coal seams, the PhD student conducted surveys in 4 basic directions (0^0, 45^0, 90^0, 135^0), with a scanning angle of $\pm 22.5^0$. The thesis has investigated the structural function model with natural thickness parameters and coal specific thickness of seams 14-5, 14-1, 13-1 and 10.

3.3.2. The results of the structural function model survey: Figure 2, 3, the PhD student quotes the survey results of the structural function model with natural thickness parameters of seams 14-5, 10.

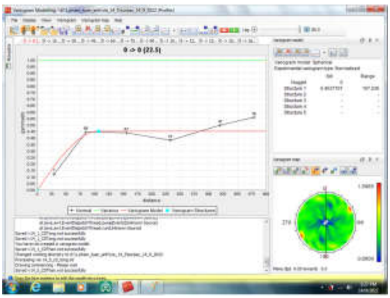


Figure 2. Survey Variogram direction 0^0, scan angle 22.5^0 V14-5

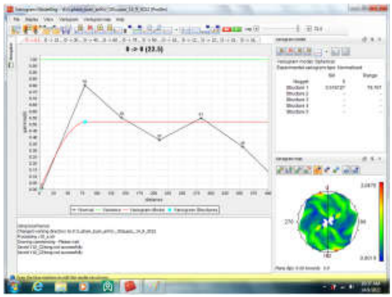


Figure 3. Survey Variogram direction 0^0, scan angle 22.5^0 V10

* From the research results, the PhD student draws the following comments:

- The scan angle value $\pm 22.5^0$ for each survey direction is suitable for the research object, making the most of the research parameters.

- The autogenic effect (Co) that appears is not a true autogenic effect; it would be appropriate to call it a “sample size effect.”

- The natural thickness variation and specific coal thickness of seams 14-5, 14-1, and 10 are similar.

- In the 4 coal seams subject to research, with specific coal thickness: Seams V14-5 and 13-1, the research parameters show the regional anisotropy, the strongest variation in the North - Northwest direction. Seam 10 also shows clear regional anisotropy, with two main directions near North - South. Seam 14-1, nearly isotropic.

- Regional anisotropy shows the complexity of the research parameters and one can think about the heterogeneity of industrial geological parameters right in each reservoir; It can be said that the formation of the four coal seams studied also has certain differences.

3.4. Set up mine groups and exploration networks

3.4.1. Set up group of exploration mines: Research results show that, in order to establish a group of exploration mines in Khe Cham mine, it is necessary to focus on evaluating 2 basic parameters: (1) Thickness variation coefficient (V_m); (2) Slope angle variation coefficient (K_α, %).

Table 2: Criteria for establishing groups of exploration mines according to each high-grade homogeneous block in the Khe Cham mine area

No.	Block / Parameter	Southwest F.E	Center	Northeast F.L
1	Thickness variation coefficient (V_m, %)	77	68	76
2	Slope angle variation coefficient (K_α)	0.544	0.666	0.557
3	Exploration mine group	III	II	III

Summary of assessment results on morphological characteristics - coal seam structure, geological structural complexity, analysis using traditional mine geometry methods, trend function analysis and results in Table 2, the PhD student stated that: *Khe Cham mine area is divided into 03 relatively homogenous blocks of grade VI with the corresponding group of exploration mines as follow: The Central Block (block between F.E and*

F.L) is classified in Exploratory Mine Group II, the Southwest Fault Block F.E and the Northeast Fault Block F.L are classified in Exploratory Mine Group III;

This affirms: Even within a mine/mine area, it may be necessary to explore at different levels of detail, consistent with the results of structural function research that regional effects exist in the Khe Cham mine area.

3.4.2. Set up exploration network: To establish the exploration network, researchers investigated the structural function model for the thickness parameters of coal seams. The survey results are summarized in Tables 3, 4.

Table 3: Influence size shall be according to structural function survey results on natural thickness of coal seams

Coal seam name	Survey direction 0^0		Survey direction 90^0		Note
	Ceiling (including Nuggets)	Influence size (m)	Ceiling (including Nuggets)	Influence size (m)	
14-5	0.45	110	0.43	235	
14-1	0.69	90	0.60	90	
13-1	0.57	180	0.36	180	*108^0*
10	0.51	80	0.35	150	

Table 4: Influence size shall be according to the structural function survey results on the specific thickness of coal seams

Seam name	Survey direction 0^0		Survey direction 90^0		Note
	Ceiling (including Nuggets)	Influence size (m)	Ceiling (including Nuggets)	Influence size (m)	
14-5	0.54	110	0.52	210	
14-1	0.79	90	0.60	90	
13-1	0.39	210	0.38	330	*108^0*
10	0.49	80	0.41	150	

* From Tables 3 and 4 it is found that:

- With natural thickness: Seams 14-1, 13-1 show isotropy, anisotropy index I ≈ 1. Particularly for the 14-5, 10 reservoirs, the size of influence in the 90^0 direction (according to the seam direction) is much larger than the 0^0 direction (in the slope direction), showing regional anisotropy with anisotropy index I = 2.14 (V.14-5) and I = 1.88 (V.10).

- With specific thickness of coal: V14-5 and 13-1, the research parameters show the regional anisotropy, the strongest variation in the North - Northwest direction (I = 1.9). V10, also show clear regional anisotropy (I ≈ 2), but the dominant direction is near North - South (direction of slope). V.14-1, nearly isotropic.

Thus, for both natural thickness and specific thickness of coal seams 14-5, 13-1, 10 there is a much greater degree of complexity variation in the slope direction (≈2 times) than in the vertical of the seam.

According to Section 10, Article 19 of Decision No. 25/2007/QD-BTNMT dated December 31, 2007 Regulations on exploration and decentralization of coal reserves and resources: *"In case of applying geostatistics to process geological data, coal quality and reserve calculation, the location of machine drilling works is not required to be arranged according to the geometric network and on geological routes. Density and distance of exploration drill holes are determined by structural functions (Variogram) of typical geological parameters and coal quality.*

According to exploration geologists in the world and in Vietnam, the selected exploration network must ensure the following requirements: *(i)* Level 121 reserve calculation blocks, the distance between the alignments and the alignment does not exceed 2/3 of the affected size in the direction of least variation; the distance of works on the route does not exceed 2/3 of the affected dimension in the direction of the most complex variation. *(ii)* Level 122 reserve calculation blocks, the distance between the alignment and the size of the influence in the direction of least variation; distance of works on the route ≤ the size of influence in the direction of the most complex variation.

From the principles and results of determining the size of the effects mentioned above, the PhD student proposes the most reasonable mine exploration and development network for Khe Cham mine as shown in Table 5.

Table 5: Network of proposed coal exploration in Khe Cham mine

Reserves level 121		Reserves level 122	
Line distance (From - To, m)	Construction distance (From - To, m)	Line distance (From - To, m)	Construction distance (From - To, m)
100 - 125	50 - 75	125 - 150	75 - 125

To integrate the results of determining the exploration network according to “Regulations” and determined by structural functions, the PhD student recommends applying table 5 as follows: The value “From” is the recommended exploration network for areas/blocks with complex geological, morphological and structural characteristics and the degree of variation in geological characteristics of unstable coal seams, corresponding to Exploration Mine Group III; the value “To” is the proposed exploration network distance from the areas/blocks of Exploration Mine Group II. The numbers given are suggestions, maybe ±10 meters.

* From the research and analysis results, some conclusions are drawn:

- Geomathematical methods are used to quantitatively evaluate the complexity of the mine geological structure, the morphological - coal structure, combining the mine geometry method and the Trend analysis method allows a more comprehensive understanding of the three changing aspects of the coal seam industrial geological parameters. This is the scientific basis for establishing mine groups and selecting alignments for mine exploration and development projects.

- Results of analyzing Trend maps and Trend deviations of seams 14-5, 14-1, 13-1, 10 show: The exploration route being carried out in the Khe Cham mine in the North - South direction is not really consistent with the geological structure of the mine and the changing characteristics of the morphology and structure of the calculated coal seams. Therefore, when additional exploration or upgrade exploration, it is necessary to adjust the alignment to suit the coal seam structure in each established high-level homogeneous block (best to apply a nonlinear exploration network).

- With the morphological and structural characteristics of coal seams in the mine being quite complex and changing in each high-level homogeneous block, in exploration it is necessary to apply a parallel linear network, combined with non-parallel. Some blocks and coal seams with relatively stable insertion direction and gentle slope angle (central block) can use a rectangular or diamond-shaped network. Nematode direction and insertion direction vary most complexly.

- To determine a reasonable exploration network for the Khe Cham mine and other coal mines with similar properties, it is necessary to analyze a structural function model with appropriate scanning direction and angle to quantify the effect size. From there, determine the exploration network according to the principles presented above.

- The coal exploration network proposed by the PhD student for Khe Cham mine is shown in Table 5. In addition, during the exploration process, it is necessary to have 10 ÷ 15% of the works arranged in nonlinear form, especially in the direction where this function is difficult and impossible to reduce to a certain standard structural function.

3.5. Assessment of coal reserves and resources

3.5.1. Subject: including seams 14-5, 14-1, 13-1 and 10, which are coal seams selected for detailed study (Trend analysis, Structural function).

3.5.2. Prepare data

- Build a map of the location of drill holes in space: The PhD student uses Surfer software to display and perform research tasks.
- Interpolation model number of piers, thickness and slope angle: Use the popular Kriging method to interpolate the numerical model for coal seam pillars, coal specific thickness, and seam slope angle for reserve calculation blocks; parameters such as scan radius are oriented to the effect size determined by the structural function model.

c. Building a surface space model: The numerical model of isocylindrical surface space of 4 coal seams is shown in Figure 4.

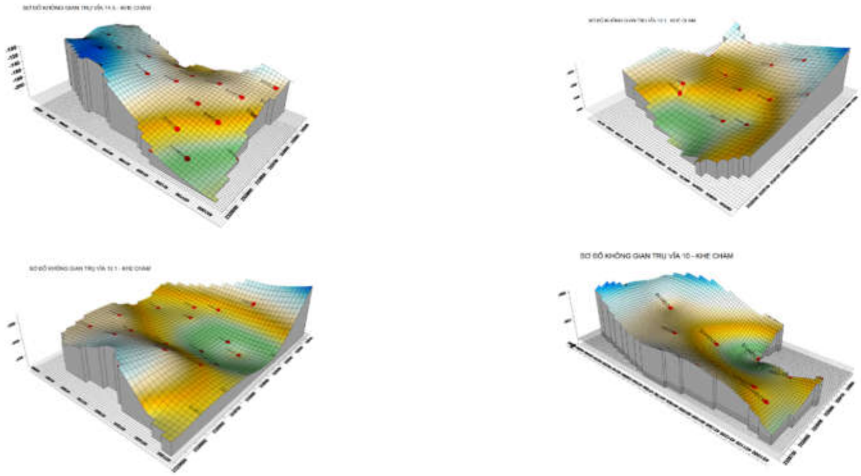


Figure 4. Spatial model of cylindrical surface of seams 14-5, 14-1, 13-1, 10

- Building block models of coal seams: To determine the appropriate microblock size, the PhD student tested options with exponentially reduced sizes (1/2) h. Accordingly, the dimensions of the tested microblocks are (50x50) m, (20x20) m or (20x15) m x [m] - seam thickness (choose the minimum seam thickness of 0.8m).

The results of building the block model in the space of coal seams (by

Surfer software) are shown in figure 5.

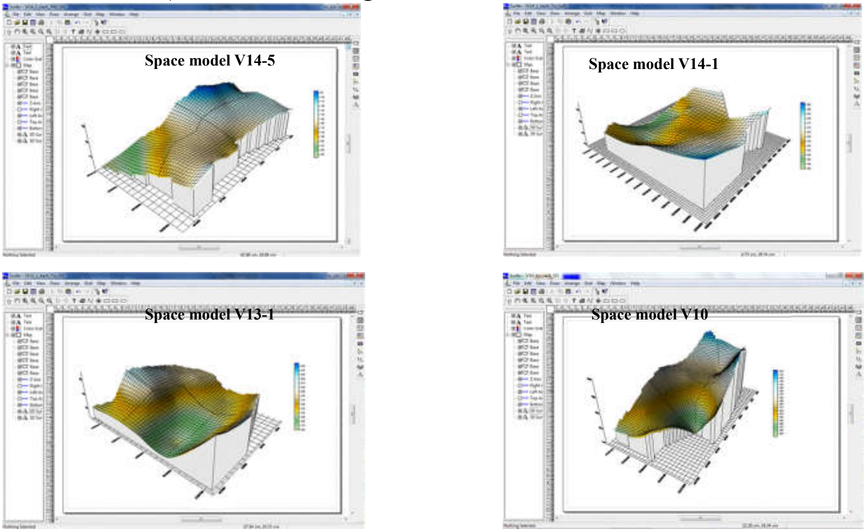


Figure 5. Spatial model of seams 14-5, 14-1, 13-1, 10.

3.5.3. Results of calculating coal reserves according to the Kriging method:

The results of calculating coal reserves using the Kriging method (spatial block model) are summarized in Table 6.

Table 6. Results of calculating coal reserves by the Kriging method

Coal seam name	Coal reserves (tons)		Difference	
	Microcube size 50x50x[m]	Microcube size 20x20x[m]	Ton	Percentage (%)
14-5	5 167 000	5 304 929	137 929	2.67%
14-1	804 000	804 490	490	0.06%
13-1	2 764 000	2 849 516	85 516	3.09%
10	7 460 000	7 471 385	11 385	0.15%
Total	16 195 000	16 430 320	235 320	1.45%

* From the above calculation results, the conclusions can be drawn: The reserve calculated by Kriging method with 2 sizes of microblock has a

difference of 235 320 tons (1.45%), this difference is not large. However, in specific blocks, coal reserves vary significantly.

3.5.4. Compare the results of reserve calculation according to the Kriging method with the Secang method: Synthesize and compare the results of calculating coal reserves using the Secang method according to the 2015 Geological Report with the results of calculating the Kriging method (block model) of coal seams and corresponding ranges. The results are summarized in table 7.

Table 7: Comparing the results of calculating coal reserves between the Kriging method with microblock size 20x20x[m] and the Secang method

Coal seam name	Coal reserves (tons)		Difference	
	Secang Method (2015)	Kriging method Microcube size 20x20x[m]	(Ton)	(%)
14-5	5 406 669	5 304 929	-101 740	-1.88%
14-1	803 611	804 490	879	0.11%
13-1	2 772 543	2 849 516	76 973	2.78%
10	6 544 082	7 471 385	927 303	14.17%
Total	15 526 905	16 430 320	903 415	5.82%

In order to have a more specific assessment basis for the reliability of the Secang method that has been used for coal mines, the PhD student uses documents such as cylindrical congruent plan, thickness, slope angle interpolated according to Kriging to calculate reserves by the Secang method. The results of calculation and comparison of reserves are summarized in Table 8.

Table 8. Compare the results of calculating coal reserves between Kriging and Secang methods when documents are interpolated according to Kriging

Coal seam name	Coal reserves (tons)		Difference	
	Secang-Kriging method	Kriging method Microcube size 20x20x[m]	(Ton)	(%)
14-5	5 406 669	5 304 929	-101 740	-1.88%
14-1	803 611	804 490	879	0.11%
13-1	2 807 012	2 849 516	42 504	1.51%
10	7 410 126	7 471 385	61 259	0.83%
Total	16 427 418	16 430 320	2 902	0.02%

* From the research results, draw some conclusions:

- The results of calculating coal reserves according to the traditional method (Secang/Cosecan) in exploration reports at Khe Cham mine ensure reliability corresponding to the reserve level with large-scale calculation cubes on each seam; at the same time, Kriging interpolation can be applied to calculate coal reserves.

- Coal reserves calculated according to the model method with microblock size of 20x20x[m] and the Secang method when the documents are interpolated according to Kriging have a small difference (2,902 tons, accounting for 0.02%); even when comparing individual shapes/small blocks (differences below < ± 5%).

- In essence, using the Kriging method to interpolate the properties of coal seam industrial geological parameters will not be affected by coal seam geological conditions. However, it indirectly affects the results of determining the structural function model. So it can be understood: *When structural function survey results have satisfactory reliability, Kriging can be interpolated.*

- Applying the Kriging method to interpolate with computer software, resource reserves will be accurately calculated for each small block (micro-block), tt will be easier to automate than traditional methods and *has many benefits when using documents, especially for design and exploitation monitoring. This is also a strong point of the Kriging method and the software to calculate mineral resource reserves by the model.*

CONCLUSIONS AND RECOMMENDATIONS

1. Conclusions

1.1. Geological factors, exploration systems, variability of coal seam industrial geological parameters; in which the spatial variability of thickness parameters and seam slope angle are the basic factors affecting the reliability of exploration work and calculation of coal reserves at Khe Cham mine.

1.2. Use a combination of traditional geological methods, trend function analysis has clarified three relatively high-order homogeneous blocks; in which the Central block belongs to exploration field group II, the southwest block F.E fault and the northeast block F.L fault belong to exploration mine group III.

1.3. Geological mathematical methods (including modern geostatistics), combined with modeling methods (mine geometry and Trend analysis) allow a full and comprehensive understanding of three aspects of variation of coal seam industrial geological parameters. This is the basis for establishing mine groups and choosing the alignment of mine exploration and development projects; especially when exploring deep.

1.4. Using a combination of trend function analysis and structural function analysis will clarify the morphological - structural characteristics, effect size, anisotropy/isotropy; from there, select the exploration network (route azimuth and distance of exploration work layout) to ensure closest proximity to the exploration object, limiting the prescribed method currently being used.

1.5. The results of calculating coal reserves according to Secang method in exploration reports at Khe Cham mine to ensure satisfactory reliability corresponding to the delineated reserve level with the large calculated volume on each seam, but there are still many limitations for seams with complex structure, thickness and slope angle vary strongly. To overcome, it is necessary to use a combination of the popular Kriging method with the help of computer software to improve reliability in coal reserve assessment; special for design and mining.

2. Recommendations

2.1. It is necessary to continue to research and apply a combination of trend function model analysis methods, combined with spatial structure function model analysis in mine exploration and development in Quang Ninh coal basin, especially when exploring deep.

2.2. Promote the application of modern information technology methods, mainly the Kriging method with the help of specialized software in interpolating documents and calculating coal resource reserves in the Quang Ninh coal basin.

2.3. Research and develop a database to manage, look up, share, etc. geological data using modern technology./.

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