Environmental Science and Engineering

Long Quoc Nguyen
Luyen Khac Bui
Xuan-Nam Bui
Ha Thanh Tran *Editors*

Advances in Geospatial Technology in Mining and Earth Sciences

Selected Papers of the 2nd International Conference on Geo-spatial Technologies and Earth Resources 2022

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Environmental Science and Engineering

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Preface

This book comprises a series of selected high-quality peer-reviewed papers delivered at the 2nd International Conference on Geospatial Technologies and Earth Resources (GTER 2022). The event will be held during October 14–15, 2022, at Hanoi University of Mining and Geology (HUMG), Hanoi, Vietnam, which is co-organized by HUMG and the International Society for Mine Surveying (ISM) to celebrate the 55th anniversary of the Department of Mine Surveying (HUMG). The conference is financially supported by the Vietnam Mining Science and Technology Association (VMSTA), the Vietnam Association of Geodesy, Cartography and Remote Sensing (VGCR), Vietnam National Coal-Mineral Industries Holding Corporation Limited (VINACOMIN), and Dong Bac Corporation (NECO).

The conference is believed to be an excellent opportunity during the COVID pandemic for the authors and participants to discuss advanced technologies and scientific directions in the fields of geospatial technologies and earth resources. Additionally, via this conference, a chance to exchange new ideas, innovative thinking, and application experiences both virtual and in-person will be provided, by which research or business relations and partner finding for future collaborations would have been established.

Totally, 205 manuscripts have been submitted to the organizing committee. Subsequently, after screening by the selection committee and reviewing by at least two blind reviewers, 34 research and review papers have been selected to be presented at the conference. The selected papers will be delivered over four planned sessions covering different topics of geospatial technologies, earth sciences, water resources, and environmental systems. These 34 papers were also selected for publication in this book with Digital Object Identifier (DOI) references. We believe that this book will provide the readers with an overview of recent advances in the fields of geospatial technologies and earth resources.

We would like to thank all members of the organizing and selection committees, all blind peer reviewers, all chairpersons, and invited speakers for their invaluable contributions. We are also thankful to (i) Mr. Phuong Kim Minh—President of Dong Bac Corporation, (ii) Assoc. Prof. Tran Xuan Truong—President of the HUMG University Council, Assoc. Prof. Trieu Hung Truong—Vice-Rector of HUMG for their administrative work and financial supports. Special thanks are also to Doris Bleier and Viradasarani Natarajan at Springer Nature for supporting book production procedures. Finally, all authors are thankful for their manuscript submissions regardless of whether or not their manuscripts were selected.

Hanoi, Vietnam
June 2022

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Contents

Evaluation of Coal Reserve Reliability in the Nui Beo Mine, Quang Ninh Province Based on the Statistical and Stable Random Function Methods

Khuong The Hung, Vu Thai Linh, Pham Thanh Tinh, and Nguyen Khac Duc

Abstract The Nui Beo is a famous coal mine in the Hon Gai coal zone, Quang Ninh province, where contains many coal resources in Vietnam. In this study, synthesizing and processing data of the mining geological parameters by using the stable random function and statistical methods are used to evaluate the coal reserve reliability in the Nui Beo mine. The results show that the coal reserve reliability depends on geological conditions, especially in the distances between exploration works and parameters of calculating coal reserves (i.e., thickness, density, and declination angle on coal seams). Most exploration efforts in the Nui Beo mine satisfy the suitable pattern exploration grid for reserve level 122, according to the stable random function used to calculate the affected range. Statistical models based on a confidence probability of 0.95 are used to evaluate coal reserve dependability in the research region, resulting in $\pm$ 10.12 $\div$ $\pm$ 16.46% of coal reserve errors. Estimating coal resources during the exploratory process is sufficient for the exploitation design. The findings also give an overview of the parts of coal resource dependability that have been impacted and a foundation for assessing the coal resource error in the Nui Beo mine. These can be used on other coal resources with general comparable geological and mining conditions.

Keywords Coal reserves · Statistical method · Stable random function · Nui Beo mine

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1 Introduction

The orientation exploration grid is frequently used at the start of any mineral exploration based on geological similarities [1–4]. However, ore bodies are generally seldom the same size, thickness, internal orebody structure, etc., and implementations of this approach have considerable limitations. As a result, the use of stable random function and statistical methods in research-exploration data processing is the most effective approach for determining the most appropriate exploration grid for each mineral item and mining group of deposits [4–6]. Using statistical approaches to set up an exploration grid, numerous projects have had great success in geological research [2, 4, 7], meanings that this step is essential.

In Vietnam, mineral coal distributed on the mainland occurs in six major coal basins: Quang Ninh, Thai Nguyen-An Chau, Da River, Red River, Nghe Tinh, Nong Son, and scattered in small coal-bearing bands and areas. The Quang Ninh coal basin has an arc shape extending a length of 250 km from the Linh Duc mine in the west of Tam Dao mountain range (Tuyen Quang province), through Dong Trieu to Hon Gai, Cam Pha, and Ke Bao areas (Quang Ninh province). It is filled with Norian-Rhaetian coal-bearing sediments of the Hon Gai formation. The Nui Beo mine belongs to the Hon Gai coal zone of the Quang Ninh coal basin, where many coal resources have been estimated.

According to the report on summarizing and recalculating the coal resources of Ha Lam, the Nui Beo coal mine has been additionally explored to $-$ 350 m with the networks in level 122, and level 333 are 75 $\div$ 100 m $\times$ 120 $\div$ 150 m and 250 m $\times$ 250 m, respectively [8, 9]. Exploration results have provided necessary documents on the quality, coal reserves, and mining conditions for mining for recent years. Currently, the open-pit method exploits the mine to the level of $-$ 350 m. Analysis of exploratory documents shows that detailed research mainly focuses on the outcrop to the -300 m level. The study is still preliminary from -300 m to $-$ 500 m levels. Only a few works have drilled controlling the coal seams. Therefore, it is necessary to evaluate the reliability of exploration documents in general and coal reserves in the exploration areas as a basis for deep exploration orientation. The stratigraphy of the Nui Beo area contains coal seams from V4 to V14 seams and some associated lenticular sub-seams. Furthermore, the V11, V10, V9, and V7 coal seams are considered promising for exploitation, and in fact, most the mining pits are currently focusing on these seams. Wherefore, the paper will focus on the coal seams, as mentioned earlier.

In real exploration, the reliability of mineral reserves can be assessed by various methods; in which statistics, geostatistics, or stable stochastic function are methods of the geological mathematical model applied indirectly to determine the reliability of the reserve through evaluating the reliability of the exploration grid and the errors of the parameters affect the reliability of the reserve calculation. All reserve calculation errors are divided into three primary groups: geological, technical errors, and errors related to selecting reserve calculation methods [4, 10–14]. The geological error is mainly related to the extrapolation of actual documents collected in the exploration work to neighboring areas (method of zoning mineral bodies, relating sections according to the linear exploration system), determining the spatial distribution of beneficial and harmful components, etc.). The geological error is often the largest in the reserve calculation, but it is of little interest. According to many researchers [4–6, 11–16], the geological error in the reserve calculation can be up to 10 ÷ 15%. Technical errors are mainly related to measuring techniques and determining initial parameters (thickness, sample analysis results, etc.) to calculate reserves, such as thickness measurement, chemical analysis, determining contents of valuable ingredients, weight density, measuring area, etc. The technical errors related to the reserve calculation include: The error in determining body weight density (Δ_d) ranges from 5% [16] to 10% [11], and the plot's error of area determination (Δ_s) is from 2 to 3%. Moreover, the thickness measurement error (Δ_m) varies depending on the thickness of the ore body (coal seam), type of exploration work, and measurement method. According to Vasiliev [16], the thickness error is usually from 2 to 3%. However, Kreige et al. [11] argued that the error of measuring the thickness of the ore veins in the excavation work and the borehole is usually from 2 to 10% and 20 to 30%, respectively. The largest error is mainly related to the ore veins with small thickness. The average allowable random error in the chemical analysis (Δ_c) of the coal ash content usually ranges from 1 to 20%, sometimes up to 30%. In the general case, this error is generally in the range of ± (2 ÷ 5%) and up to ± (25 ÷ 30%) for coal seams with low ash content and high ash coal seams, respectively.

This study aims to evaluate the coal reserve reliability of the Nui Beo mine based on the statistical and stable random function methods.

2 Overview of the Nui Beo Coal Mine

The Nui Beo mine is located in Ha Long city, Quang Ninh province. The mine is about 4 km far from the southwest of Ha Long city center, on the left side of National Highway 18A from Ha Long to Mong Duong (Fig. 1a).

In the mine site, there are Triassic sediments of Hon Gai formation, middle sub-formation, and loose deposits of the Quaternary system [17] (Fig. 1b). The petrographic composition of the middle Hon Gai sub-formation includes layers of siltstone, sandstone, claystone, coal clay, and coal seams lying alternately, with a stratigraphic thickness of about 1800 m. The middle Hon Gai formation contains industrial coal seams (Fig. 2).

Quaternary sediments directly cover the middle Hon Gai formation, distributed in the lower areas and valleys around the Nui Beo mine. Sedimentary compositions include pebbles, gravels, sands, loose clay, sometimes rolling boulders, and weathering products from pre-existing rocks.

Folds and fault systems are developed in the Nui Beo mine area, making it complicated to identify the seam and mining coal.

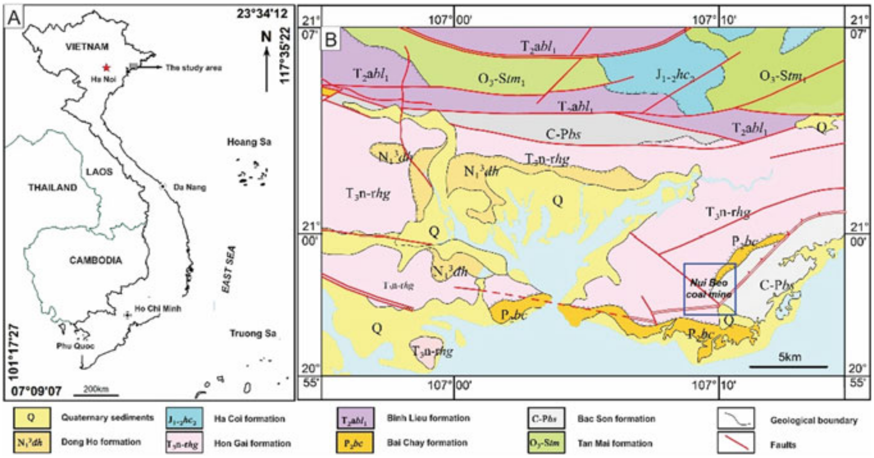

Fig. 1 **A** Sketch map of Vietnam and location of the study area, **B** geological map of Ha Long area showing the location of the Nui Beo mine [17]

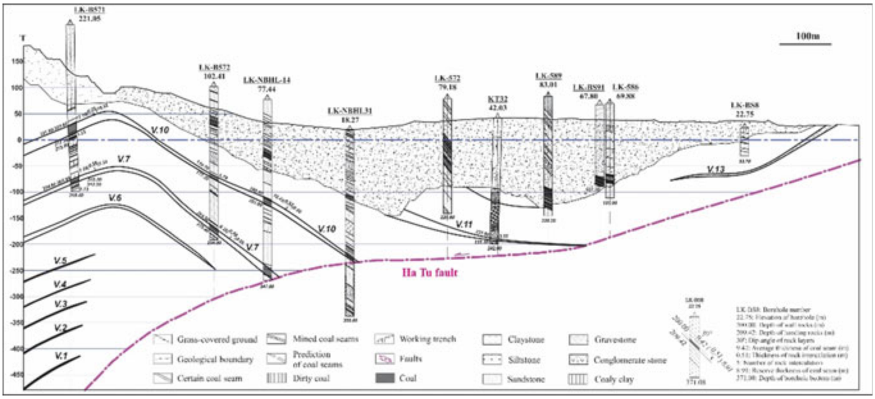

Fig. 2 Geological cross-section of line T.VA showing the coal seams and structure of the Nui Beo coal mine [8, 9]

3 Materials and Methods

3.1 Database

Documents used in this study are mainly from the report on the exploration results of the Ha Lam coal mine edited by Hung [8], Anh [9], combined with new exploratory drilling documents in the greater depth area of the Nui Beo mine recently. In particular, other data collected from the report on exploration results and recalculation of reserves of the Ha Lam coal mine are also used in this paper.

Statistical calculation data and random function construction are based on the data collected from 544 drilling and trenching works that have been constructed through periods and exploration stages within the Nui Beo mine area.

3.2 Reserve Calculation Conventional Method

Based on geological characteristics, distribution, and positions of coal seams, the coal reserve of the Nui Beo coal mine is calculated according to the Secang method [8, 9].

Each block's coal reserve/resource is calculated according to the following formula.

$$Q_i = S_i \times m_i \times D = S_b \times \sec\alpha_i \times m_i \times D \quad (1)$$

$$\text{Reserve of seam}: Q = \sum Q_i \quad (1a)$$

where Q_i—coal reserves of the i-th reserve calculation block (ton), Q—total coal reserves of the seam (ton), S_i—actual area in i-th reserve calculation block (m^2), S_b—area of the plan view of seam's cylinder (m^2), α_i—the average angle of the seam in the i-th reserve calculation block (degrees), m_i—the actual average thickness of the i-th reserve calculation block (m), and D—coal weight density ($D = 1.39$ ton/m^3).

However, the method is often limited to calculating steeply inclined seams' coal seam reserver (the angle > 45°). In addition, the process also encounters specific errors due to factors encountered when determining the area, thickness, etc., and not showing the shape of the coal seam in space.

3.3 Research Methods

Stable stochastic function model

Using the stochastic function model allows solving many problems related to exploration and mining. There are two main types of stochastic function models: stable and unstable stochastic functions. The characteristic of a stable stochastic function is that the mathematical expectation M(x) and the variance D(x) is a quantity that is unchanged with any spatial coordinates, i.e., independent of the position of the observation point, the correlation function K(h) depends on the observation step (h) and is a vector depending on the observation direction h. In the scope of this study, a stable stochastic function model is used to assess the reliability of coal reserves by evaluating the grid of exploration works conducted at the Nui Beo mine.

The stable stochastic function is characterized by the correlation function K(h) depending on the observation step h, the observation direction r(h) [4]. The formula determines the correlation function.

$$K(h) = \frac{1}{n-h}\sum_{i=1}^{n-h}[f(x_i) - X][f(x_i + h) - X] \tag{2}$$

where *n*—number of observation points, *h*—distance between observation points is expressed as the number of distances between adjacent points, and *X*—mean value (mathematical expectation) of research parameters.

We often use the norm correlation function r(h) when solving practical tasks.

$$r(h) = \frac{K(h)}{\sigma^2} \tag{3}$$

The norm correlation function allows separating the original variance σ^2 into two parts: spatial correlation variance: $\sigma^2{}_k = \sigma^2 \times r^2(h)$; and the random variance components: $\sigma^2{}_H = \sigma^2 \times [1 - r^2(h)]$.

Formula (3) shows that, as the observation step (h) increases, the spatially correlated variance part decreases, while the random (non-spatial correlation) component increases gradually to the limit σ^2. The observation step where the value of parameter r(h) is suppressed and the random variance coincides with σ^2 ($\sigma^2{}_H = \sigma^2$) is called the auto-correlation limit R. This limit characterizes the size of the influence zone of the observation points.

When the observation step h < R, the parameter's value is a dependent random quantity, and then the coefficient of variation of the research parameter (V_H) is determined by the formula.

$$V_H = \frac{\sigma_H}{X} = \frac{\sigma}{X}\sqrt{1 - r^2(h)} = V\sqrt{1 - r^2(h)} \tag{4}$$

When the step h > R, the correlation coefficient r(h) = 0 and $V_H = V$, the variability is characterized by the normal coefficient of variation, and statistical models can be used to study the characteristics of metallization. In the case, where R(h) > 0 for all h, determine the size of the influence zone H according to the following method.

Make a graph of the norm correlation coefficient.

$$R^*(h) = \mathrm{e}^{-\alpha.h};\ \alpha = \frac{\sum_{i=1}^{m} \ln|R(h_i)|}{\sum_{i=1}^{m} h_i} \tag{5}$$

where *m*—number of observation steps; *h*—the value of observation steps.

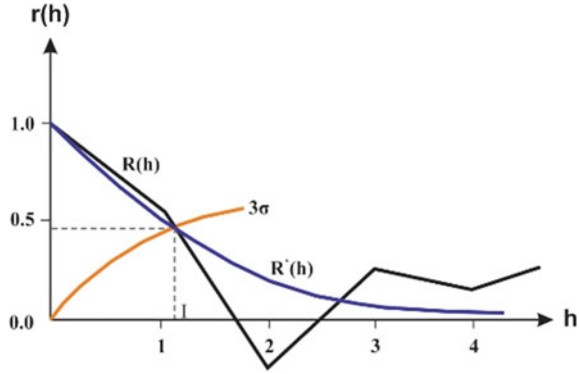

Fig. 3 Spatial correlation function model R(h) [4]

Based on the calculation results $R(h_i)$ và $R^*(h_i)$ build a spatial correlation graph; the horizontal axis represents the observation step distance (h_i), and the vertical axis represents R(h) và $R^*(h_i)$.

At the position $R^*(h)$ intersects the graph $2\sigma_r$ or $3\sigma_r$ ($\sigma_r = \frac{1}{\sqrt{N}} \times [1 - R^*(h)]$) make a perpendicular line to the horizontal axis, assuming the horizontal axis at point i. The distance OI is the size of the influence zone to be determined (H = OI) (Fig. 3).

Based on the size of the influence zone (H), it is possible to determine the anisotropy index and choose the distance to arrange the exploration work.

To characterize the degree of anisotropy, it is possible to use the anisotropy coefficient (A) determined by the formula.

$$A = \frac{I_d}{I_{df}} \tag{6}$$

where I_d—effect size (H) to the dip direction, I_{df}—effect size (H) to the strike line.

Based on the anisotropy index A, select the layout shape of the exploration work. When A ≅ 1) it is best to use a square network, and when A ≠ 1, a rectangular or linear network should be used.

Stable stochastic optimization techniques are fragile, sensitive to stepsize selection and other algorithmic factors, and unstable outside well-behaved goal families. Stable stochastic methods may be rendered stable, provably convergent, and asymptotically optimum with properly precise models; merely modeling that the target is nonnegative is sufficient for this stability. We emphasize the necessity of resilience and precise modeling with experimental evaluations of convergence time and algorithm sensitivity.

Statistical Methods

Statistical approaches have done more than only make it possible to assess the consistency of results. They have provided techniques for testing and made it feasible to create more efficient and thorough trials. Accordingly, statistical and mathematical methods are widely applied in geological research, including evaluating the reliability of mineral reserve calculation.

According to formulas (1) and (1a), the coal reserve of the Nui Beo mine is calculated by the Secang method, so the error of reserve is mainly the error of volume and weight density of coal. Therefore, the overall error of coal reserve assessment in the statistical model corresponds to the total error of the volume of the reserve/resource calculation block and the weight density of coal, where volume error includes the error of thickness and area of the coal seam.

If the parameters comply with the normal distribution or refer to the normal distribution, the formula calculates the error of seam thickness.

$$\Delta_{m} = \frac{tV}{\sqrt{N}} \tag{7}$$

where Δ_m—thickness error, t—the coefficient of probability $t = 1.96$, corresponding confidence probability is 0.95; V—coefficient of variation of seam thickness, and N—number of exploration works.

According to Kazdan [4], the total technical error in reserve calculation in each block is determined by the following formula:

$$\sum \Delta = \sqrt{\Delta_m^2 + \Delta_s^2 + \Delta_d^2} \tag{8}$$

The total error calculated by the formula (8) can account for 12–15% or more.

4 Results and Discussions

4.1 Factors Affecting Reserve Accuracy

The accuracy of calculating mineral reserves in the ground depends on many factors: geological factors, system, the density of the exploration grid, method of interpolation of geological documents, and determining geological-industrial parameters (parameters for calculating reserves).

The geological factors that affect the accuracy of the reserve calculation are quite diverse, including the geological structure of the mine, the type of mineral, the shape, the bedding conditions and the internal structure of the mineral body, the number of ore bodies, and the degree of variation of geological-industrial parameters. If the coal mine (coal seam) is more complicated, then the reserve calculation error is greater, and on the contrary, it is less reserve calculation error.

The system and density of the exploration grid are important factors affecting the accuracy of the calculation of underground mineral reserves. When the exploration system, weight density, and orientation of the exploration grid are selected inappropriately, it can lead to a misperception about the geological characteristics of the mine, shape, depth of position, and minerals' distribution law; as a result, this is the cause of increasing errors in reserve calculation. In general, if the structural coal mine and quantity of reserves are determined more precisely, then the density of the exploration grid is higher, and coal exploration cost is also greater. Therefore, in order to improve the efficiency of exploration work and the accuracy of reserve calculation, it is necessary to rationally select the system and shape of the exploration grid based on a complete analysis of the group of exploration mines, the space homogeneity, and anisotropy of minerals (coal seams).

The methods of interpolating geological data include zoning the mineral bodies, relating the cross-sections according to the exploration line system, and determining the spatial distribution of useful and harmful components. The interpolation results of geological data are the basis for determining all the initial documents for the reserve calculation: area, thickness, weight density, and content of useful components. Therefore, interpolating geological data is considered one factor that generates errors and decreases or increases the determination of underground mineral reserves. Geologists need to analyze and select suitable interpolating geological data for the exploration object to solve this problem.

Determining geological-industrial parameters (reserve calculation parameters) directly affects the contouring of the coal seam shape and the number of coal reserves in the ground. Their influence is especially large when systematic errors occur during the sampling, processing, and analysis of samples or the determination of other parameters. These errors can only be overcome by completing the method and technique of sampling, measuring thickness, area, and anomalous processing samples.

According to Hung (2019) [8], the assessment of the remaining reserves for the Nui Beo coal seams by the end of 2019 is summarized in Table 1.

Table 1 Remaining coal reserves are in the Nui Beo mine [8]

Name of seams	Reserves (ton)		Resources (ton)		
	122	Total	333	334a	Total
V13	150,825	854,219	1,005,044	532,442	532,442
V11	2,284,517	8,235,274	10,519,791		
V10	2,056,707	11,440,714	13,497,421	5,847,015	5,847,015
V9	1,497,738	5,565,200	7,062,938	4,968,159	4,968,159
V7	2,504,758	4,759,936	7,264,694	8,033,175	8,033,175
V6		409,727	409,727	542,478	542,478
V5				3,635	3,635
Total	8,494,545	31,265,070	39,759,615	19,926,904	19,926,904

4.2 Assessment of the Reliability of the Nui Beo Mine Exploration Grid

The Nui Beo mine has a synclinal structure; exploration lines are arranged on the map in azimuth 10–190°, 130 m apart, and drilling works on the defined route are 80 m apart on average [8, 9]. There are longitudinal and transverse lines concepts because the coal seams are located in the Nui Beo synclinal structure. Therefore, to determine the distance between the exploration works along the line in the azimuth 80–260°, linking the works were carried out on the exploration lines in the azimuth 10–190°. Thus, the dimension of actual exploration work on the network map is 80 m × 130 m.

To evaluate the reliability of the exploration grid, a stable stochastic function model is applied to the exploration lines with the number of works crossing the seam V11, V10, V9, and V7.

Calculating the stable stochastic function along the exploration lines for some selected seams is presented in Figs. 4 and 5.

Summary of survey results of stable stochastic function along exploration lines with azimuths of 80 ÷ 260° and 10 ÷ 190° corresponding to some coal seams are presented in Table 2.

From Table 2, it can be seen that the size of the influence zone to the strike direction varies from 65 to 208 m, the size of the dip direction varies from 32 to 56 m, and has obvious anisotropy (A = 0.41). Thus, the exploration grid applied (80 m ×

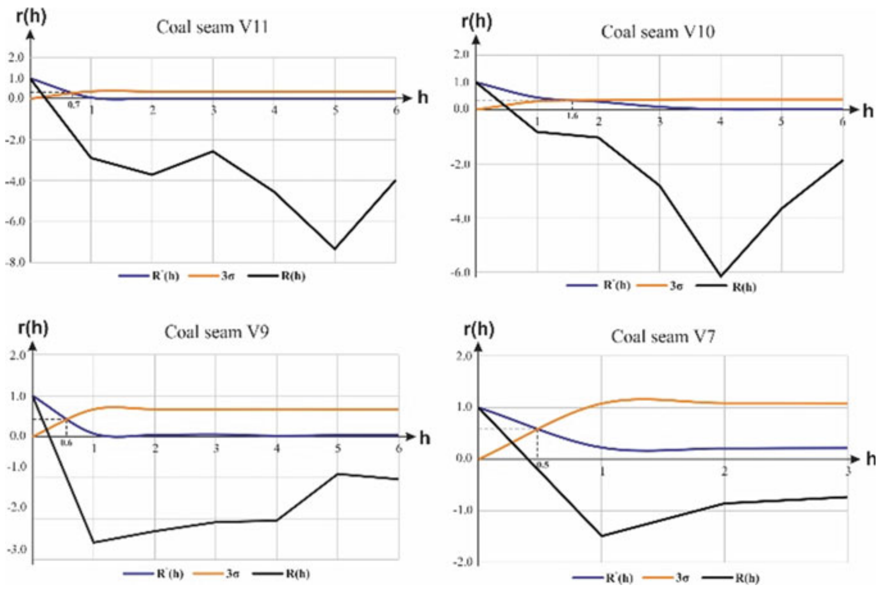

Fig. 4 Graph of stable stochastic function along strike direction of the coal seam V11, V10, V9, and V7

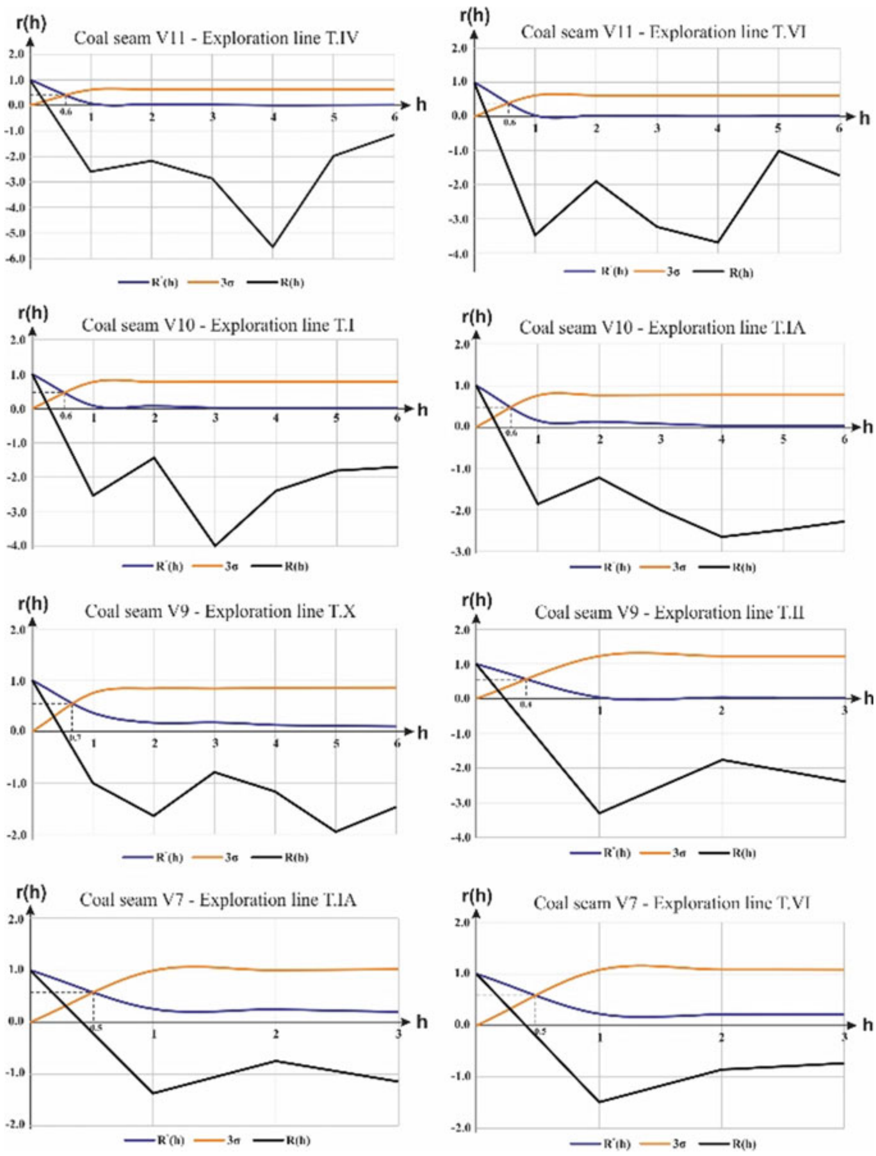

Fig. 5 Graph of stable stochastic function along dip directions of the coal seams name V11, V10, V9, and V7

Table 2 Survey results of the stable stochastic function

Name of seams	Route	Azimuth (deg.)	Value h	Dimension of influence zone (m)		Mean anisotropic coefficient (A)
				To the strike direction (I_{df})	To the dip direction (I_d)	
V11	T.NT	10–190	0.7	91		45:110.5 = 0.41
	T.IV	80–260	0.6		48	
	T.VI	80–260	0.6		48	
V10	T.NT	10–190	1.6	208		
	T.I	80–260	0.6		48	
	T.IA	80–260	0.6		48	
V9	T.NT	10–190	0.6	78		
	T.X	80–260	0.7		56	
	T.II	80–260	0.4		32	
V7	T.NT	10–190	0.5	65		
	T.IA	80–260	0.5		40	
	T.VI	80–260	0.5		40	

130 m) for the Nui Beo coal seams is consistent with the anisotropic properties of the coal seams and meets the Nui Beo coal mine exploration grid's requirements belonging to the group of relatively complex mines (mining exploration group III) [18, 19]. However, to reach the mining process requirements, the exploration period for coal mining needs to conduct a detailed analysis of the structural elements of the coal seams based on thickness contour diagrams. This one helps for additional exploration works satisfying the distance between exploration works along the dip format of coal seam does not exceed 32 m for reserve calculation block code 122. The distance between exploration works along strike format is less than 208 m for reserve calculation block code 122, respectively.

Calculating variation of coal seam thickness along different directions by stable stochastic function model shows that most coal seams are explored with the system and density of the exploration grid, ensuring an approximately reliable method for reserve calculation 122. This means that the factor of system and density of the exploration grid in calculating coal seam reserves in the Nui Beo mine is insignificant and acceptable.

4.3 Assessment of the Reliability of Reserves by Statistical Methods

Statistical methods are widely applied in geological research, including reliable and accurate assessment of mineral reserves. As mentioned above, the coal reserves of the

Table 3 Coal seam thickness error

Number	Name of coal seam	Work numbers	V_m (%)	Thickness error (%)
1	11	91	46.79	9.61
2	10	88	50.84	10.62
3	9	50	58.02	16.08
4	7	48	45.82	12.96

Nui Beo mine are calculated by the Secang method, implying the error of the reserve is mainly the error of the seam volume and the weight of coal. According to formula (7), the error of seam thickness is evaluated based on the calculated parameters, as shown in Table 3.

The error of seam area (Δ_s): Because coal seams rarely show wavy folds, when determining the area on the planar projection by isometric lines, there are usually small thanks to the application of specialized software (such as AutoCAD or Mapinfor programs) to measure the area of the coal seam. Therefore, in the case of the Nui Beo mine, the research team chose an error of 3% on the map.

The weight error of coal calculated for each seam is applied according to the formula (7), similar to the thickness error. The calculation results are summarized in Table 4.

To determine the error of coal reserves in the detailed areas, the formula (8) was applied, and reserve error ΔQ (%) was calculated and summarized in Table 5.

The calculated data show that with a reliability probability of 0.95, the reserves' error varies from ± 10.12 to ± 16.46%, which is reasonable and acceptable for reserves class 122 for the mining exploration group III, such as the Nui Beo mine [7, 15].

Table 4 Error on coal weight density

Number	Name of coal seam	Work numbers	V_d (%)	Weight density error (%)
1	11	91	4.67	0.96
2	10	88	5.03	1.05
3	9	50	6.57	1.82
4	7	48	6.30	1.78

Table 5 Error on coal reserves

Number	Coal seam number	*t*	Δ_m	Δ_s	Δ_d	ΔQ (%)
1	11	1.96	9.61	3.0	0.96	± 10.12
2	10		10.62	3.0	1.05	± 11.09
3	9		16.08	3.0	1.82	± 16.46
4	7		12.96	3.0	1.78	± 13.42

The assessment results of geological-industrial parameters of coal seams, such as thickness, area, and weight density of the Nui Beo coal seams, are within the allowable error threshold of reserves of grade 122, mining exploration group III. Thus, the statistical method's application shows that the coal seams' geological-industrial parameters have little influence on the reliability of the Nui Beo mine reserve calculation. Therefore, the Nui Beo mine estimate of reserves meets the feasible design and exploitation reliability shortly.

Evaluating the reserves reliability of the Nui Beo coal mine based on statistical and stable stochastic function methods shows that the factors affecting the reliability of coal reserves are within the allowable limit. Therefore, the assessment of coal reserves of the remaining mine in the range from − 350 to − 500 m is sufficient for the next underground mining design. However, to ensure objectivity and comparability with computer-aided modeling and simulation methods in the near future, the modeling of coal seams in a three-dimensional model should be implemented. Modeling the ore body in a 3D model is also a method widely applied in mining worldwide because of its intuitiveness and ability to update the reservoir parameters quickly and conveniently.

5 Conclusion

Some conclusions are drawn from the data collecting, analysis, and reliability assessment of coal reserves in the Nui Beo mine, Quang Ninh province.

According to exploration lines with azimuth 80–260° and 10–190° for coal seams as the V11, V10, V9, and V7 seams, survey results show that the coal seams have anisotropic properties with properties an anisotropy coefficient of 0.41. Therefore, in the exploration process for mining, it is necessary to adjust the exploration grid of the Nui Beo coal mine to ensure that the distance between the exploration works in the dip direction is 0.41 times the distance between the exploration lines.

The error assessment of coal reserves in the exploration areas of the Nui Beo mine shows that with a reliability probability of 0.95, the error in the reserve varies from ± 10.12 to ± 16.46% is acceptable. Within the allowable threshold for reserves of 122, the calculated reserves in the basic exploration phase meet the reliability for exploitation.

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