GOSPODARKA SUROWCAMI MINERALNYMI

Tom 27 2011 Zeszyt 4

ROMAN MAGDA*

Modelling the mine production process in terms of planning the output volume with regard to the aspects of uncertainty and risk

Introduction

The decision making process, involving the determination of the output volume of the hard coal mine is an element of the investment activities. In this process, the analysis and assessment of the economic efficiency of the investments, aiming at maintaining or increasing the output volume, became increasingly important. The methodology of developing and assessing the economic aspects of the investment projects, developed by the United Nations Industrial Development Organization, commonly known as the UNIDO method, thanks to its wide popularisation, became the world standard (Behrens, Hawranek 1993). This methodology is so general and universal, that it can be applied to evaluate every investment, including the investments completed in hard coal mines.

For the enterprise, the completion of investment projects usually means various types of benefits; of which only some can be expressed in terms of determining their value; it is also possible that the entire effect of the investment could not be subjected to quantification. Thus, it is important that when assessing the project, the outcome, which can be obtained as an effect of its completion, was expressed in monetary units. The effectiveness balance is not the only instrument of the complex evaluation of the investment activities. The important part of this evaluation is the financial analysis, which shall determine, whether there will be a sufficient reserve of financial resources, for both the completion of the investment project and later, for financing the exploitation activities. The balance of economic efficiency and the financial – economic analysis are the mutually complementary elements of the efficiency

* Professor, AGH University of Science and Technology, Kraków, Poland; e-mail: magda@agh.edu.pl

analysis and evaluation of the investment projects. Jointly, they form a basis for making the investment decisions.

The adoption of a specific efficiency measuring device for the investments in the mining industry influences the method of conducting the project assessment. The most precise efficiency indicators include the indicators which take into consideration the balance of the financial streams update in time; allowing to distribute in time the required outlays and expected benefits associated with the particular investment and specific for the spatial and time related factors, influencing the completion of the production process.

1. The essence of modelling

Modelling of the spatial, engineering and time related aspects of the completion of the production process and associated with this process streams of financial output and benefits can be done with the use of the so called integrational method of the mine production process modelling and estimating its economic efficiency in the underground hard coal mine, which was described for the first time in (Magda 1985a), and which basically involves the following:

1. An analysis of the structures of the mine production process.
2. The determination of the elementary models of representation of financial outputs and benefits in relation to the determined elements of the structures of the mine production process and the derivation of formulas describing those models.
3. Integration, in space and time, of those elementary representation models, in accordance to the assumed direction of the deposit exploitation and the rules and regulations for conducting mining activities.
4. The development of numerical software for the derived formulas; the preparation of the set of input data; completion of the calculations and analysis of the obtained results.

The spatial structure of the mine production process involves the distribution and mutual relations of the spatial elements; thus it comprises of the specific elements, for example longwall face, maingate, tailgate, main entry, bleeder entry, main crosscut, ventilation drift, downcast shaft, upcast shaft, etc.

The engineering structure of the mine production process involves the system and mutual relations between the elements of the technical, technological and organisational character. It is a very broad term and its elements can be both whole mining processes, such as cutting or transportation, and the machinery and equipment used for this, and individual basic and auxiliary operations contributing to the whole mine production process.

The time structure of the mining process involves the system and mutual relations between the elements having the specific dimensions in time. It comprises of the specific elements, which can be for example, time periods necessary for the completion of the particular mining operations, time periods necessary for the completion of the longwall exploitation, time periods necessary for the completion of the removal works, etc.

The time structure of the mine production process stems from its spatial and engineering structures, as the time required for the completion of each activity or process stems from the relation: spatial volume – rate of construction. The spatial volume corresponds to the material scope of the specified element of the engineering structure of the mine production process; thus it depends on the applied technical and organisational equipment and is also dependent on the spatial structure.

The synthetic description of the integrational method of the mine production process modelling and estimating the economic efficiency can be found in (Magda 1999; Magda et al. 2002).

The completion of the exploitation process in a hard coal mine always involves the appropriate financial outlays, which can assume the form of values constant in certain periods of time or the form of concentrated values. The intensity of financial outlays, understood as financial outlays per a unit of time is time variable and depends on the spatial structure and the engineering structure of the mine production process.

The intensity of financial outlays is a complicated process, spread over time – however it can be assumed that the time of expenditure is divided into intervals, during which the intensity of financial outlays can be approximated and substituted with a linear model. The assumed in such way intervals of the linear characteristic of financial outlays was called the function of the substituted intensity of financial outlays. Thus, the so called elementary time interval, characterised by the linear function of the substitute intensity of financial outlays can be defined. This can form an elementary model of imaging the mine production process, together with the associated financial outlays. In the same way can be formed an elementary model of imaging the mine production process, together with the associated financial benefits.

The elementary models, integrated in accordance to the method of mining exploitation can be used for imaging the course of the mine production process in time and in space and the streams of financial outlays and benefits associated with its execution. The methods of integrating the elementary models were described in (Magda 1985a, b, 1994a, b, 1999; Magda et al. 2002).

2. Indices measuring the economic efficiency

The indices used to measure the economic efficiency of the investment can be divided into two groups:

1. Measuring indices taking into consideration the change of the value of money in time (dynamic).
2. Measuring indices, which do not take into consideration the change of the value of money in time (static).

The following indices can be included in the first group: the net present value (NPV), internal rate of return (IRR), external rate of return (ERR), profitability index (PI). The following indices can be included in the second group: accounting rate of return (ARR), payback period (PbP), break-even point (BEP).

The specified above criteria for assessing the profitability of the planning solutions do not exhaust the complete list of criteria, however those are the most commonly used criteria. In the UNIDO method, the net present value and the internal rate of return are preferred as the basic indices, fully considering the update of the account of expenditure and income streams; as well as the analysis of the sensitivity of the project, determined on the basis of the break-even point for the initial assessment of the design solutions.

The basic method of assessing the investment projects is the method based on the net present value (NPV). The method allows to assess the updated (present) value of the financial incomes and outlays, associated with the completion of the specific project.

The next criterion, widely used in the developed market economies is the internal rate of return (IRR). It can be determined as a measure of the final efficiency of the capital. The internal rate of return is the interest rate, for which the updated value of financial outlay streams equals the updated value of the financial income streams, thus it is the interest rate for which: NPV = 0.

The internal rate of return, apart from the NPV, is the best index measuring the economic efficiency of the investment projects, and it is specially recommended in the UNIDO method. However in specific circumstances, the use of this index may not give the proper results. Such cases are fairly common when assessing the mining investment projects and are a result of the influence of negative cash flows during the project execution phase (during the project realisation phase the presence of negative cash flows is typical). As a result, after calculations, more than one value of the internal rate of return is obtained and the proper interpretation of this index becomes very difficult.

With the use of the sensitivity analysis, it is possible to determine, how the net cash surplus and the efficiency of the project change, in line with the increase or decrease of the values of particular parameters, such as unit sale price, fixed costs, unit variable costs or output (sales) volume. This is associated with the uncertainty and risk factors, inherently associated with the execution of the investment projects in the mining industry. The sensitivity analysis shall be used at the investment planning stage, when the decisions regarding the most important elements of the project are being made. The element of uncertainty can be then reduced by determining the pessimistic and optimistic variants and next, by determining the most probable variant, which will be likely to be accepted by the investor.

The modern mining enterprise, when formulating its own development strategy, has to take into consideration the status of the surrounding areas (competition, markets, supply and demand) and the system of the internal legal and organisational bonds (companies, holdings, capital groups). The UNIDO method is fully universal, as with the use of the criteria preferred by this method, both the individual investment projects can be assessed and the multi – year, strategic investment program can be developed, through the assessment of various (often mutually exclusive) projects, which can be executed by undertakings comprising the enterprise (or the capital group). This is particularly important when the financial resources, which can be channelled for the investment projects, are limited.

3. Aspects of risk and uncertainty

The specificity of the economic activities in the mining industry, which is characterised by a high degree of uncertainty regarding the geological and mining conditions, is further enhanced by the aspects of risk and uncertainty influencing the decision making process, associated with the circumstances of the economic environment in which the mine operates. Various types of risks, stemming from the market character of the economic environment, on which the enterprise usually cannot control, and which it shall take into consideration when making the investment decisions, are added to the risks involving the uncertainty of the nature and technological conditions of the mining process.

Often the uncertainty and the risk are the terms which are used together and often mistaken or interchanged. There is a large number of bibliography volumes, from various disciplines of science, devoted to those terms, and also in the context of the mining industry, e.g. (Kicki, Saługa 2000). In order to clarify the meaning of those terms for the purpose of this paper, the definitions of uncertainty and risk used in works referring to issues associated with the investment processes were presented below.

Uncertainty is a property of the reality, which stems from "a large number, complexity and changeability of subjects and the dependencies between those subjects and in their surroundings and from a limited ability to control by people the factors, which shape the reality" (Kultys 1985). It is then said about the uncertainty of nature, which is objective, independent of the enterprise and external with regard to the enterprise and the source of which are the processes, which cannot be precisely forecasted, thus cannot be controlled.

The risk is associated with the decision making process, which even in case of the identical levels of uncertainty, can be made or not; depending on the inclination of the decision makers to make risky decisions. Thus the risk in the investment activities is influenced by two basic factors:

1) the risk stemming from the uncertainty of nature;
2) the risk stemming from the attitude of the investor to making risky decisions.

In theory and in practice, there are two approaches to risk management, looking from the point of view of the effects of the risk:

1) risk, understood as the possibility of sustaining damage or losses, thus regarded as a threat;
2) risk, understood as a possibility of the effect different from the expected one, which can be worse than expected (an unpleasant surprise) or better than expected (a nice surprise); so in this approach, the risk is not only regarded as a threat but also as a chance.

The risk can be measured; the measure of risk is the variance of the specific criterion in the decision making process (from the interpretation point of view, it caused some problems) or standard deviation of this criterion, that is the square root from the variance (easier for the practical interpretation). Both, the variance and the standard deviation assume positive values and the smaller the variance, thus the smaller the standard deviation, then the risk associated with the decision making is lower.

During the recent years many reports and publications were developed in the field of research connected with modelling and optimizing the production process in underground hard coal mines with regard to the aspects of uncertainty and risk. Systematic progress of computer technique creates the new calculating possibilities based on the greater than before quantity of input informations and data, which can be used for evaluating uncertainty and risk (Magda 2004). The book (Magda et al. 2008) presents a most important results of studies, research and analyses aiming at the development of principles of the integrated system supporting the production management in hard coal mines elaborated in the Department of Economics and Management in Industry at the University of Science and Technology in Kraków, taking into account the aspects of uncertainty and risk.

By applying the available mathematical and calculation apparatus, the aspects of uncertainty and risk can be considered in the process of modelling and optimisation of investment activities in the hard coal mining; even with the use of fairly complex models. One of such models can be the model prepared on the basis of the afore described the integrational method of the mine production process modelling and estimating its economic efficiency in the underground hard coal mine (Magda 1994a, b). This model, which takes into consideration the dependencies between the elements of the spatial, engineering and time structures of the mining process in the underground mine and the streams of financial outlays and benefits can be used for assessing the influence of uncertainty and risk in the investment decision making process. This can be obtained by dividing the sets of input data into the determined data and the random (independent) data and next, by determining the appropriate descriptive statistics and probability distribution for the random data, acting on the basis of source data collected from the real life cases (Gryglik 2001).

Thanks to applying the Monte Carlo simulation method, it is possible to conduct the simulation calculations with the use of the existing model, in which runs of the values of the random data are drawn in accordance to the determined earlier distribution pattern (e.g. by using the method of reversing the cumulative distribution function). After completing the large number of draws, the set of values for the selected assessment criterion can be obtained (Magda, Gryglik 2000; Gryglik 2001). By subjecting the obtained values to the statistical analysis, the expected value of the analysed criterion and its standard deviation, which is assumed to be the measure of risk, can be determined. The general block diagram of the process of modelling the output volume, with the consideration of uncertainty and risk factors, was presented in Fig. 1.

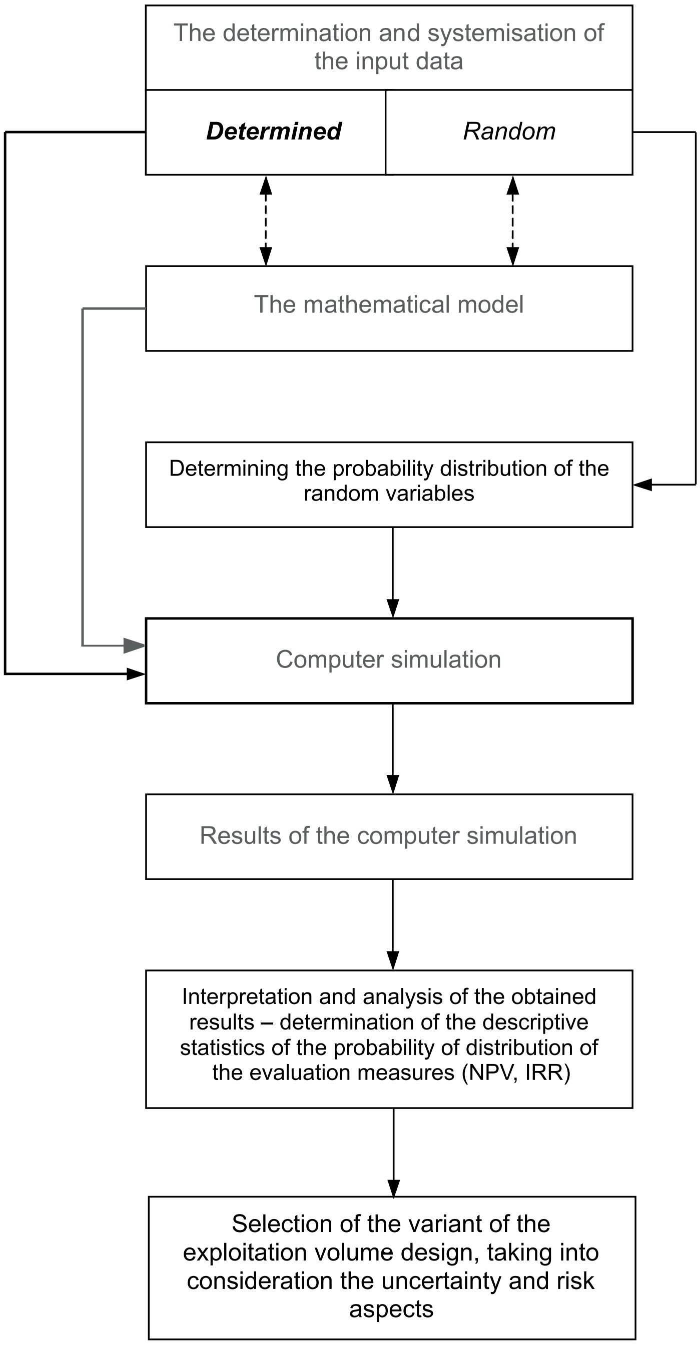

Fig. 1. General block diagram of the modelling the mine production process in terms of planning the output volume with regard to uncertainty and risk

Rys. 1. Ogólny schemat blokowy modelowania procesu produkcyjnego kopalni w aspekcie projektowania wielkości wydobycia z uwzględnieniem niepewności i ryzyka

4. Synthetic characteristics of the example of the calculations

A computer application, functioning under the name of NAKŁADY-KOSZTY-EFEKTY (Łoś, Kozek 2001), was developed for the purpose of modelling the exploitation process of the mine, with regard to designing the output volume with the consideration of uncertainty and risk factors. This application, together with the STATISTICA package (Luszniewicz, Słaby 2001), was used for simulation calculations and statistical analyses on specific examples, taken from the actual mining practice.

The example of the calculations applied to a working, single horizon mine, for which the variants of the daily outputs of 18 000 and 20 000 Mg/d of raw coal was assumed. Obtaining such output was possible from longwalls located in three exploitation panels (I, II and III).

The input data for the calculations were prepared for each of the panels and were set in form of tables (4 large tables) containing respectively, for each of the panels: the geological and mining data, the data regarding the geometry of the exploitation panels, the technical and organisational data and the economic and financial data. In addition, the set of data concerning the mining processes realised outside the exploitation panels, associated with underground deliveries and transport, ventilation, work of electrical and mechanical departments, hoisting and processing, were included in form of indicators.

Also, the specific number of work days per year, the average coal selling price, the discount rate and the income tax rate were included.

The following parameters were specified as the random data: the thickness of the coal deposit, the mining advance rate of: gates, longwall faces, cross-cuts; as well as the number of production cycles in the longwalls.

The statistical analysis of the actual data regarding the thickness of the coal deposit showed that its distribution is within the standard range, of the following parameters: the expected value 2.84 m; standard deviation: 0.54 m, the number of production cycles in the longwalls is also characterised by a standard distribution; e.g. the distribution parameters equalled respectively:

— for the longwall of 250 m: expected value: 3.72 m; standard deviation: 0.88 m,
— for the longwall of 275 m: expected value: 3.38 m; standard deviation: 0.80 m,
— for the longwall of 300 m: expected value: 3.10 m; standard deviation: 0.73 m.

The statistical analysis, conducted on the basis of the real life data also showed that the advancement of the drilling works is characterised by the standard distribution of the following parameters:

— cross cut: expected value: 5.63 m/d; standard deviation: 1.76 m/d,
— maingate entry: expected value: 9.96 m/d; standard deviation: 2.34 m/d,
— main roadway: expected value: 9.25 m/d; standard deviation: 2.60 m/d,
— inclined gate roadway: expected value: 5.32 m/d; standard deviation: 1.34 m/d,
— longwall face advance: expected value: 6.98 m/d; standard deviation: 1.96 m/d.

As the output capacity of three simultaneously active exploitation panels would significantly exceed the assumed output level, also based on its output abilities; thus two variants of mining sequence, in two streams, were assumed:

1. Sequence variant A1 – in the first stream, of the maximum capacity two panels are active (Panel I and after that Panel II); in the second stream (supplementary) – Panel III.
2. Sequence variant A2 – in the first stream, of the maximum capacity two panels are active (Panel II and after that Panel I); in the second stream (supplementary) – Panel III.

A set of 4 calculation variants, containing the combination of the output volume of the mine (2 variants) and the sequence of the panels mining (2 variants) was created and marked respectively:

- W_01 – mining sequence variant A1, mine output 18 000 Mg/d,
- W_02 – mining sequence variant A1, mine output 20 000 Mg/d,
- W_03 – mining sequence variant A2, mine output 18 000 Mg/d,
- W_04 – mining sequence variant A2, mine output 20 000 Mg/d.

The appropriate simulation calculations of the NPV and IRR economic efficiency indices, on the basis of the prepared earlier sets of input data and with the use of the Monte Carlo method (100 draws were assumed), were conducted with the use of the NAKŁADY-KOSZTY-EFEKTY application. Presentation of the obtained results is beyond the frames and volume of this paper. The descriptive statistics of the analysed indices and their probability distribution were determined with the use of the STATISTICA package. The descriptive statistics of the analysed indices and their probability distribution were presented in Table 1.

After comparing the obtained results of the simulation calculations, the following main conclusions can be derived:

- all calculation variants show economic efficiency with regard to the assumed assessment indices NPV and IRR,
- the expected value of the NPV and IRR increased together with the increase of the mine output (advantage) but the standard deviation (risk level) also increased (disadvantage),
- the best results of the NPV and IRR are obtained for the calculation variant W_04 (mining sequence variant A2, mine output 20 000 Mg/d); for this variant mean values of the assumed indices are equal respectively: NPV = 318.3 Mil PLN and IRR = 44.3%; according to the mean values of the NPV and IRR the calculation variant W_04 can be recommended for practical application,
- if we take into consideration the mean values and the standard deviations of the NPV (in minus and in plus) we can obtain the following intervals for the calculation variants:
  - W_01 – from 175.5 to 316.7 Mil PLN,
  - W_02 – from 205.4 to 375.2 Mil PLN,
  - W_03 – from 230.9 to 348.5 Mil PLN,
  - W_04 – from 244.2 to 392.4 Mil PLN,

TABLE 1

Descriptive statistics of the results of simulation calculations of the analysed indices: NPV [Mil. PLN], IRR [%]

TABELA 1

Statystyki opisowe wyników symulacyjnych obliczeń analizowanych mierników: NPV [mln PLN], IRR [%]

Index	Variant	Mining sequence	Mine output [Mg/d]	Number of draws	Mean	Confidence interval		Sum	Min.	Max.	Range	Variance	Standard deviation	Skewness	Kurtosis
						–95%	95%								
1	2	3	4	5	6	7	8	9	10	11	12	13	14	16	18
NPV	W_01	A1	18 000	100	246.1	232.1	260.2	24 614.6	46.1	417.4	371.3	4 989.8	70.6	–0.1	0.5
	W_02		20 000	100	290.3	273.5	307.2	29 031.2	73.5	773.1	699.6	7 206.8	84.9	1.7	9.7
	W_03	A2	18 000	100	289.7	278.0	301.3	28 965.2	110.1	430.3	320.3	3 432.0	58.6	–0.4	0.6
	W_04		20 000	100	318.3	303.6	333.0	31 829.7	99.3	519.3	420.0	5 485.2	74.1	–0.1	0.7
IRR	W_01	A1	18 000	100	31.0	29.5	32.5	3 099.2	11.1	48.2	37.1	56.7	7.5	0.0	–0.1
	W_02		20 000	100	34.9	33.3	36.5	3 487.7	13.1	53.3	40.2	64.1	8.0	0.0	–0.1
	W_03	A2	18 000	100	40.8	38.9	42.6	4 076.1	17.8	61.5	43.7	89.8	9.5	0.0	–0.2
	W_04		20 000	100	44.3	42.2	46.5	4 434.3	17.0	74.4	57.4	119.9	10.9	0.1	0.0

the common part of these intervals are values between: 244,2 to 316,7 Mil PLN; only the mean value of the NPV for variant W_04 (318,3 Mil PLN) is greater than upper value of this interval so this variant can be considered as advantageous from the point of view of risk level,

— if we take into consideration the mean values and the standard deviations of the IRR we can obtain the following intervals for the calculation variants:
  - W_01 – from 23.5 to 38.5%,
  - W_02 – from 26.9 to 42.9%,
  - W_03 – from 31.3 to 50.3%,
  - W_04 – from 33.4 to 55.2%.

  the common part of these intervals are values between: 33.4 to 38.5%; the mean value of the IRR for variant W_04 (44.3%) is higher than upper value of this interval and mean value of the IRR for variant W_01 (31.0%) is less than lower value of this interval so the variant W_04 can be considered as advantageous and variant W_01 can be considered as disadvantageous from the point of view of risk level,

— the results of simulation calculations can be useful for decision makers but the final selection of the variant will depend on their inclination to make decisions, while taking into consideration the risk levels.

Summary

The volume of the paper does not allow to present in full the input data and the results of the simulation calculations. Only the most important information regarding the methodology of modelling the exploitation process in the hard coal mine, in terms of determining the output volume, taking into consideration the uncertainty and risk aspects and the final results of the calculations were presented. This methodology is universal and it can be applied for any hard coal mine. In the original version, the methodology is fairly labour intensive, especially during the stage of preparing the input data for the simulation. The sets of input data can also be prepared in a simplified version, applying longer time intervals in the elementary models of projecting the course of the mining process in time and in space and associated with this process streams of financial outlays and benefits.

This publication was prepared as a part of the statutory activity No: 11.11.100.279

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MODELOWANIE PROCESU PRODUKCYJNEGO KOPALNI DLA POTRZEB PROJEKTOWANIA WIELKOŚCI WYDOBYCIA Z UWZGLĘDNIENIEM ASPEKTÓW NIEPEWNOŚCI I RYZYKA

Słowa kluczowe

Górnictwo podziemne, projektowanie kopalń, modelowanie procesu produkcyjnego kopalni, niepewność i ryzyko

Streszczenie

W pracy scharakteryzowano metodykę modelowania procesu produkcyjnego podziemnej kopalni węgla kamiennego oraz związanych z nim strumieni wydatków i efektów finansowych opracowaną dla potrzeb analizy i oceny ekonomicznej efektywności przedsięwzięć inwestycyjnych w aspekcie projektowania wielkości wydobycia kopalni. Nawiązano do integracyjnej metody odwzorowania i oceny ekonomicznej efektywności procesu produkcyjnego kopalni podziemnej, na bazie której zbudowano model procesu produkcyjnego i związanych z nim strumieni wydatków i efektów finansowych. Scharakteryzowano pokrótce mierniki oceny ekonomicznej efektywności inwestycji przyjęte jako funkcje celu. Poddano dyskusji aspekt niepewności i ryzyka w procesie projektowania wielkości wydobycia kopalni. Przytoczono najważniejsze informacje i dane przyjęte do przykładowych obliczeń, które wykonano zgodnie z opracowaną metodyką, a także najistotniejsze wnioski wynikające z obliczeń.

MODELLING THE MINE PRODUCTION PROCESS IN TERMS OF PLANNING THE OUTPUT VOLUME WITH REGARD TO THE ASPECTS OF UNCERTAINTY AND RISK

Key words

Underground mining, mine planning, mine production process modelling, uncertainty and risk

Abstract

In this paper, the methodology of modelling the production process of the underground hard coal mine together with the streams of financial outlays and benefits is characterised. The method was developed for the purpose of analysis and assessment of the economic efficiency of the investment works in terms of determining the output volume of the mine. The reference to the integrational method of the mine production process modelling and estimating its economic efficiency in the underground hard coal mine was made. On the basis of this reference, a model of the production process and associated with this process streams of financial outlays and benefits were built. Economic efficiency indices of the investment, as the objective functions were shortly characterised. The aspect of uncertainty and risk, associated with the process of planning the output volume of the mine were discussed. The most important information and data, assumed for the exemplary calculations, conducted in accordance to the developed methodology and the most important conclusions drawn from the calculations were also instanced.