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SELECTED ASPECTS OF THEORY OF MINE PLANNING **

1. Introduction

Modern mine planning and design are usually supported by mathematical modelling and computer technique. During the stage of a new mine planning as well as planning of existing mine elements it is necessary to know the structure of mine production process. Since the mine production process takes place in the space it has a spatial structure. The mine production process includes the means, methods and operations related to winning coal so it also has an engineering structure. The process is conducted in a certain time thus he has a time structure. The time structure of the mine production process results from its spatial and engineering structures because the completion time of any operation originates from the relationship between its spatial dimensions and rate of construction. During the stage of mine planning and design a concept of the future mine production structures must be developed.

Mathematical modelling of production process of an underground hard coal mine can be based on the principles of the so called integrational method of mine production process modelling [1] which involves:

- 1) An analysis of the structure of the production process;
- 2) Determination of the elementary models representing financial outlays and benefits and derivation of formulas describing those models;
- 3) Integration, in space and in time, of the elementary representation models, in accordance to the adopted direction of deposit mining and the procedures for conducting mining exploitation;

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- 4) Numerical programming of the derived formulas, preparation of the base of data, completing calculations and analysis of the calculations' results.

Synthetic description of the the integrational modelling method can be found in [1–4]. Some selected aspects of the method is briefly described below.

2. Modelling the streams of financial outlays and benefits

The execution of the production process in the mine is always associated with the appropriate financial outlays. The intensity of financial outlays, understood as financial expenditures per a unit of time, is time variable and it depends on the elements of the spatial and engineering structures of the production process. The appropriate financial effects, which are also time variable, are achieved as a result of the execution of the production process.

Time periods for spending money streams and gaining financial benefits are relatively long; thus in order to compare those correctly, it is necessary to apply the updating calculations (calculating their present or future values).

The important element of the process of representing the updated stream of outlays and financial benefits is the use of a particular variant of updating account. Application of the specific variant of the updating account to modelling the production process of the underground mine depends on the assumed degree of specificity. If the degree of specificity is relatively high, and it is necessary to use short periods of time, then it is more convenient to use the constant version of the account update. The integrational method is essentially based on the constant variant of the update account, what does not mean that it is unable to also take into consideration the discrete variant.

Intensity of financial outlays is characterised by a complicated course in time — however it can be assumed that the outlay period is also divided into such periods, during which the actual course of intensity of financial outlays can be replaced, with sufficient approximation, with the linear course. The assumed in such way (with the use of linear sections) characteristics of financial outlays was called the function of an approximate intensity of financial outlays. Thus it is possible to define the so called elementary time interval with a linear intensity of financial outlays, which can form the elementary model of representation of the production process in the coal mine, together with the associated financial outlays. In the same way, it is possible to represent the potential financial benefits, associated with the execution of the extraction process in the coal mine.

The elementary representation model (the module) is described by four, so called, characteristic quantities (Fig. 1):

- T — time interval during which the intensity of financial outlays or financial benefits can be approximated linearly, expressed in time units (e.g. a day, month, quarter, year);
- A — initial rate of expenditure (A_o) or benefits (A_e), expressed in financial units per a unit of time (e.g. PLN/day, PLN/month, millions PLN/year);

- B — final rate of expenditure (A_o) or benefits (A_e), expressed in financial units per a unit of time (e.g. PLN/day, PLN/month, millions PLN/year);
- T_a — time difference between the updating of financial outlays or benefits t_a and the start t_p of the time interval T , expressed in time units (e.g. a day, month, quarter, year) and given as:

$$T_a = t_a - t_p \quad (1)$$

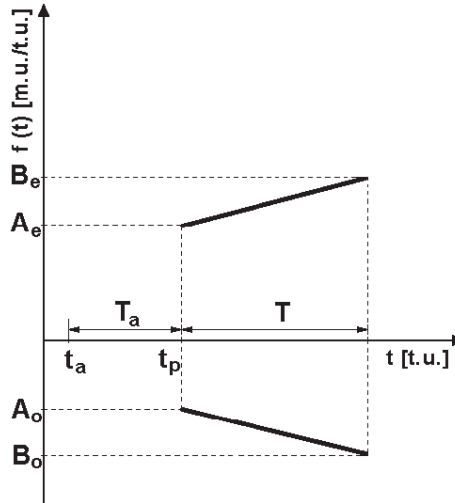


Fig. 1. The elementary representation model

For time period T , when:

$$t_p \leq t \leq t_p + T \quad (2)$$

the appropriate function of financial outlays or benefits intensity $f(t)$ can be described by the formula:

$$f(t) = A + \frac{B - A}{T} \cdot (t - t_p) \quad (3)$$

The function of intensity of the value of financial outlays/benefits $f_a(t)$, updated to assumed time t_a , with the equivalent interest rate ρ_x , corresponding to the assumed unit of time, can be determined using the formula:

$$f_a(t) = f(t) \cdot e^{\rho_x \cdot (t_a - t)} \quad (4)$$

The elementary financial outlay or financial effect F can be determined using the formula:

$$F = \int_{t_p}^{t_p+T} f(t)dt \quad (5)$$

Value of the elementary financial outlay and/or financial benefit F_a , updated for the selected time t_a , can be determined using the formula:

$$F_a = \int_{t_p}^{t_p+T} f_a(t)dt \quad (6)$$

Using the afore described characteristic values, the elementary financial outlay F_o can be determined using the formula:

$$F_o = \frac{(A_o + B_o) \cdot T}{2} \quad (7)$$

The elementary financial benefit F_e can be determined using the formula:

$$F_e = \frac{(A_e + B_e) \cdot T}{2} \quad (8)$$

The values F_{ao} or F_{ae} , updated for the selected time t_a , with the equivalent interest rate ρ_x , for use in continuous functions corresponding to the assumed time unit, can be determined using the appropriate formula:

$$F_{ao} = \frac{e^{\rho_x \cdot T_a}}{\rho_x} \cdot \left[A_o + \frac{B_o - A_o}{\rho_x \cdot T} \cdot (1 - e^{-\rho_x \cdot T}) - B_o \cdot e^{-\rho_x \cdot T} \right] \quad (9)$$

$$F_{ae} = \frac{e^{\rho_x \cdot T_a}}{\rho_x} \cdot \left[A_e + \frac{B_e - A_e}{\rho_x \cdot T} \cdot (1 - e^{-\rho_x \cdot T}) - B_e \cdot e^{-\rho_x \cdot T} \right] \quad (10)$$

In particular cases, when single, concentrated in time t , values of financial outlays/benefits A_o or A_e are being updated, and when the time difference between the update time t_a and time t , equals T_a , the updated value of financial outlays/benefits F_{ao} or F_{ae} can be determined using the appropriate formula:

$$F_{ao} = A_o \cdot e^{\rho_x \cdot T_a} \quad (11)$$

$$F_{ae} = A_e \cdot e^{\rho_x \cdot T_a} \quad (12)$$

In those case, the characteristic value T_a equals:

$$T_a = t_a - t \quad (13)$$

The described above elementary representation models (modules), integrated in accordance to the rules applicable during the mine production process, can represent the course of this process at any structural model of the mine together with the streams of financial outlay and/or financial benefits, associated with its execution. More or less complicated formulas, for shorter or longer periods of time, can be derived for characteristic values, in accordance to the assumed or required degree of precession of the representation model.

Formulas for calculating the characteristic quantities: T , A , B , T_a , can be derived after taking into consideration numerous assumptions or external conditions; e.g. after taking into consideration the bank credit, taken for financing specific mining works; together with its repayment schedule with interest. It is also possible to take into consideration the cycle of rotation of financial outlays and financial benefits. The formulas can also take into consideration the type structure of financial outlays, e.g. outlay streams for wages, materials, energy costs, depreciation, etc. Formulas for calculating the characteristic quantities: T , A , B , T_a , can also be determined as a result of applying the method of statistical analysis and the correlation and regression account.

The model presented in Figure 1, on the basis of which the formulas (3) to (10) were derived, represents the current financing of financial outlays and current accrual of financial benefits. This is a certain approximation, as compared to real life practical applications, as in real life, both the financial outlays and financial benefits can be affixed independently on the time axis, depending on the economic — financial condition of the mining enterprise and its contracting parties, on concluded commercial agreements and agreements with companies completing the particular works. With the use of model presented in Figure 1. it is possible to represent the potential income and costs, however their placement on the time axis can be assumed in accordance to the specific conditions. Illustration, presented in Figure 2, representing the process of construction the underground roadway in time T , at the average, stabilised rate of construction, was used, in order to explain the representation method. While driving the roadway, the output is also obtained, thus certain amount of useful mineral, which can be sold, is available.

Model presented in the upper part of Figure 2 represents a situation, when outlays are borne systematically and the financial benefits are also registered systematically. In this case it is possible to apply formulas: (7), (8), (9) or (10) to calculate the nominal values and/or updated for time t_a streams of financial outlays and benefits, and the characteristic quantity T_a can be calculated using formula (1). The nominal outlays coincide with the shaded field F_o , and nominal benefits coincide with field F_e .

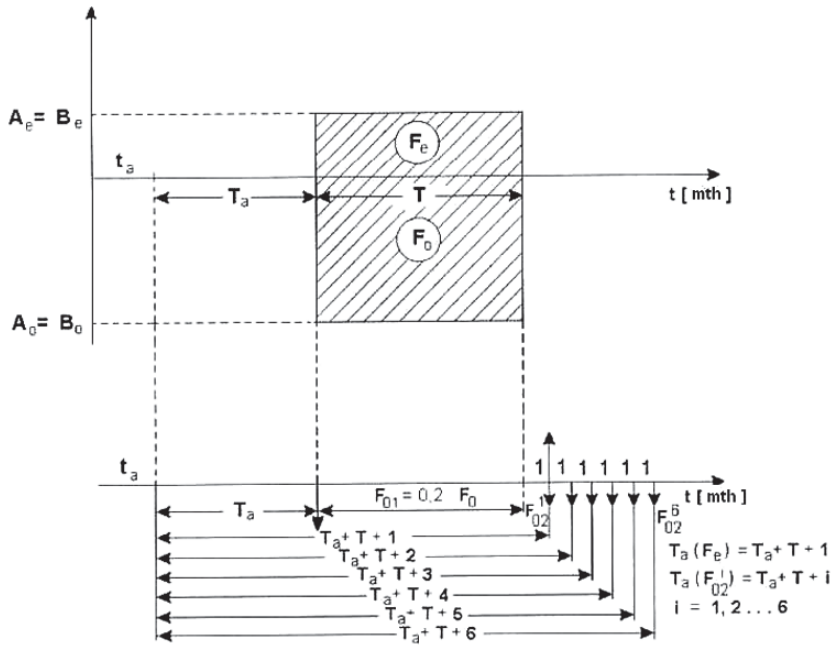


Fig. 2. Illustration of modelling and updating the financial streams [4]

Model presented in lower part of Figure 2 is characteristic due to the following assumptions:

- outlays are borne in two instalments: the first one, in the amount of 20% of the nominal costs of the construction: paid at the time the construction works on the roadway started and financed from the company's own sources; and the second one, in the amount of 80% of the nominal costs of the construction: paid at the time the construction works on the roadway ended; financed from the bank loan, the repayment of which was divided into six equal, monthly instalments, the first of which is due one month after at the time the construction works on the roadway are finished;
- financial benefits are obtained in form of one, concentrated value obtained one month after at the time the construction works on the roadway are finished.

The size of the streams of updated financial outlays is in this case calculated using formula (11), and size of the streams of updated financial benefits is calculated using formula (12). The characteristic quantity T_a is calculated using formula (13).

Calculation scheme of the integrational method can be used not only for modelling, taking into consideration economic categories. With the use of the diagram presented in Figure 1 and characteristic quantities T, A, B it is possible to model various quantities, not having the economic character (e.g. the output volume). In this case the characteristic quantity T_a is omitted

and the update is not performed, as there are no logical grounds for doing so. Such scheme can be used for representing numerous parameters of the technical — organisational character, e.g. the scope of roadway construction works, crewing the coal face, etc.

For example, in the model representing the examined parameter, the characteristic quantities T, A, B are determined in the following way:

- T — time period of a linear characteristic of the analysed parameter (e.g. output volume), expressed in time units (e.g. a month);
- A, B — values of the analysed parameter (e.g. output volume), respectively at the beginning and at the end of the time period T , expressed in units specific for the particular parameter per unit of time (e.g. Mg/month).

The integrational method is used mainly for modelling and multi — criteria optimisation of the production process in the underground coal mine; and the criteria can be formulated in the economic or technical — organisational categories as e.g.: unit, nominal cost; unit, updated cost; net present value, NPV ; internal rate of return, IRR ; profitability index, PI ; work efficiency and other, adopted depending on the individual situation.

The methodical scheme of the integrational method of production process modelling of coal mines and their elements is simple and involves entering formulas for calculating characteristic quantities T, A, B, T_a , and next the determination of their values and substitution to the appropriate formula (7 to 12). Those formulas are valid for all levels of integration, what makes programming the calculations easier.

The integrational method is characterised by a wide scope of research abilities, as it covers the dependencies between structural elements of the production process, thus allowing to examine the influence of any structural on shaping the optimisation criterion, using the computer simulation.

The methodical scheme is elastic, and it can be made more complicated or simplified — as required — as a result of the appropriate management of shorter and longer, elementary time intervals T .

3. Integration of the elementary models

Representation of the entire production process of the mine can be obtained through the appropriate, multi — step integration of the representations of structural elements of this process, while maintaining certain, stemming from the specificity of the production process, mutual time and spatial relations between those elements.

The division into consecutive stages of integration of the model representing the production process can be more or less elaborate. However it shall be developed in such way, that the next stage of integration includes the integrated elements of the previous stage, as well as representation of the processes, characteristic for the specific stage of integration. For every stage of integration of the representation model, the moment of updating the financial

outlays and financial benefits is determined. Processes proceeding within the development workings giving the access to the elements of the represented spatial structure at the previous stage of integration, and not included in the process of modelling the previous integration stage, are modelled with the use of elementary representation models, described by the characteristic quantities: T , A , B , T_a , taking into consideration the determined update time. As a result of model integration, the integrated stream of financial outlays and financial benefits for the specific integration stage, updated for the specified update time, is obtained. Such integrated stream, at the specific stage of integration, is the starting point for modelling the production process at the next stage of integration.

For example, considering the coal face to be the basic element of the spatial structure of the production process of the mine, the following stages of integration of the model can be presented in the following way:

- 1) Representation model of the production process in the longwall panel, encompassing the representation model of the processes in the coal face and representation of the processes in development headings, separating the longwall panel.
- 2) Representation model of the production process in exploitation panel, encompassing the integrated representation models of the extraction process in the longwall panels and representation of the processes in the development headings within the exploitation panel.
- 3) Representation model of the production process at the horizon interval, encompassing the integrated representation models of the production process at the exploitation panels located within the horizon interval and representation of the processes at the headings giving access to the exploitation panels.
- 4) Representation model of the production process of the mine, encompassing the integrated representation models of the production process at the horizon intervals and representation of the processes within the shafts and surface objects of the mine.

4. Extension to the probabilistic model.

In underground mining all factors and circumstances that might impact on the mining processes cannot be fully recognised. The model described above referred to as deterministic. It involves functional relationships between the elements of the spatial, engineering and time structures of the mine production process in the coal mine and the stream of outlays and benefits. It is possible to create a probabilistic model which is more adequate to the real conditions of mine production process. The input data can be divided into those that are determined and those that are random (independent). For the random data the probability distributions can be derived on the basis of source data collected in database performed from the mining practice. Database should comprise the information on previous mining activities, covering the geological and mining data as well as technological and financial data. The database can be updated accordingly to account for the progress of mining operations. The

main purpose of the database is to collect information required for stochastic modelling of mining operations taking into account the involved risk and uncertainty [6]. The model can be applied to determine the effects of uncertainty and risk on the specified criteria for the investment decisions. Application of the Monte Carlo method permits the simulations using the analytical model. In each iteration procedure the random variables are drawn accordingly, to fit the probability distribution pattern determined a priori. After a large number of random draws, we get a set of values of the adopted optimisation criterion. Statistical treatment of those values yields the expected value of the investigated criterion and the standard deviation, which is thought to be the measure of risk [7].

The results of the simulation calculations for the longwall panel length 3000 m and the assumed portfolio of variants of the longwall panel width: 200, 225, 250, 275, 300 m are illustrated in Figure 3. Seam thickness and daily number of production cycles of the shearer were taken as random input data for the calculations. Both of them are characterised by normal probability distribution derived on the basis of practical source data [5].

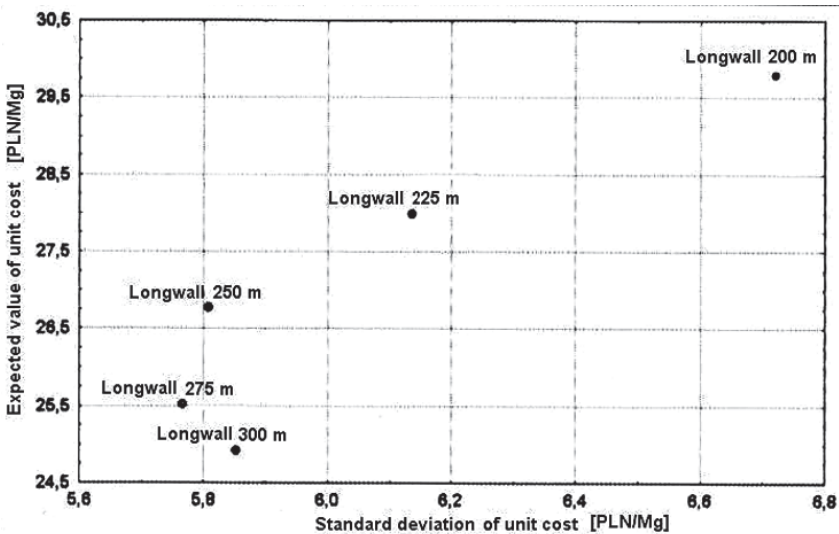


Fig. 3. Illustration of calculation results for different variants of the longwall panel width [4]

The best solution is obtained for the panel width of 300 m when we take into account minimum of expected value of unit cost of production process within the longwall panel.

The best solution is obtained for the panel width of 275 m when we take into account minimum of standard deviation of unit cost of production process within the longwall panel (risk measure). In this case the planning decision concerning the selection of the longwall panel width depends on the inclination to undertaking risky decisions.

5. Summary

The development of the computer technology has created new opportunities for the use of mathematical methods and models in the mine planning and design. Possibility of registration of a large data and information resource about the production process have been opened. This resource can be used for planning future development of the mine production process. New calculation procedures can be implemented taking into account aspects of uncertainty and risk. Data collected during the production process realisation can be used for creating stochastic models useful for future planning and design. Probability distributions of parameters used in stochastic models of mining activities (such as: costs, rate of advance of mining operations, shutdown time, repairs, and other random parameters) as well as correlation and regression functions can be very useful in development of theory of mine planning.

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