Prevention of Crises Based on the Creation and Usage of Simulation Models

PETR ŠNAPKA
MARIE MIKUŠOVÁ
Department of Management
Technical University
Sokolská tř. 33, Ostrava
CZECH REPUBLIC
petr.snapka@vsb.cz
marie.mikusova@vsb.cz

Abstract: - The article is focused on the issues of crisis prevention with the help of the simulation model and the use of production functions. The aim is to explain a simulation model presenting a management system adequate enough for crisis prevention requirements (an early warning system). The presented simulation model and the utilization of production functions are related to coal mining but they can be used in other sectors, too. The starting points, such as the functional characteristics and structure of the elements of linkage and behaviour, i.e. the characteristics which determine the dynamics of the coal mining process, are characterized. The simulation model is structured as functional blocks and their linkages with regard to the organizational and temporal hierarchy of their actions. Then the production function characteristics and their utilization in a dynamic simulation are presented. In conclusion, the article emphasizes the direct relationship of the simulation model and preventive crisis intervention. The creation of the presented simulation model is based on the theoretical findings of regulation, and a knowledge of a dynamic behaviour, hierarchical systems and optimization.

Key-Words: - block, coal mining, crisis prevention, dynamic simulation, model, production function

1 Introduction

In understanding and accepting the approaches in solving crises (crises management) in an organization, the priority is represented by the system of in-advance executed measures, i.e. prevention. This prevention can stop the inception of a crisis, or more precisely reduce possible crises development or at least bring attention to possible crises inception, and with the necessity of the further creation of measures, e.g. to stop crises inception (if these measures really exist).

A significant tool with the possibility of detecting possible crises inception within the framework of given production process is a model simulation for realizing this process at various levels of input, and the external and internal factors influencing this realization. A model simulation can be executed by utilizing the well-designed production process simulation model [14]. Therefore, formation of the simulation model for production process modeling in a company with mass production is one of the cardinal objectives when solving a grant task in the connection to dealing with crises prevention in an organization. Prevention is understood as a significant part of an organization's company chain [13]. It is dealing with one objective: how to solve the problem of a company crises, and as it was already mentioned, with a connection to crises prevention aimed at organization production process (processes).

The model simulation of this process, apart from other things, enables the authors to determine in what production process situations the fulfillment of the goals are threatened for a particular process. Based on this knowledge it is then possible to take preventive measures to solve a potential crises situation and verify it by a model to see if the suggested measures enable a solution to the crisis, or rather if there is not any crises inception at all.

2 Problem Formulation

One of the problems of making production-business activity in mining organizations more efficient is the intensification of the coal extraction process in the coalface by creating and applying a flexible management system, which would be adequate to meet the new requirements of crisis prevention. This issue is often associated with environmental issues and environmental responsibilities [4]. In an effort to achieve sustainability there are applied new underground mining methods reflecting different natural and economic environments [6].

It is pertaining mainly to the accomplishment of a higher level of concentration parameters by increasing the level of work productivity, the time and production utilization of equipment, staff savings, the relative savings of physical work, the determination of the optimum parameters of mining workplaces connection to economic decision criteria (cost optimization, expenses, profit etc.). The achieved level of these parameters indicates the competitiveness of the company [2] [5]. They are also the basis for forecasting, in a wider context, the classification of resources [9]. The economic and mathematical methods have an irreplaceable position in these considerations [7] [8].

2.1 Goals, introductory considerations and methodology

This article aims to present the created dynamic model, its structure and behavior with regard to organizational hierarchy and temporal relationships within the specified blocks of monitored process. Another aim of this article is to highlight the possibility of production functions used both in searching for the optimal level of the production system performance and also as a part of an early warning system.

The modeling of managing actions will be carried out by the application on a production business entity able to be structured from two subsystems in terms of modeling and system, specifically from a managing and managed subsystem [3]. From the systems theory of management it is known that the managing subsystem materialises a purposeful action on the managed system in a generalized specification..

The production function will be then understood in terms of the model as an instrument enabling us to quantify the output from the managing subsystem [10] that the authors have generally indicated as purposeful action. This purposeful action can have two different forms: managing action and/or regulating, which is actually managing an action with a negative feedback. With regard to this fact the regulating action will also be simply indicated as a managing action.

To create the considered management system it is necessary to have a knowledge of dynamic behaviour and the characteristics of a production system and its management [11].

Under the term of dynamic behaviour the authors consider reactions, i.e. with what changes of output levels in time does the production system react to the changes of the values of its inputs, while the dynamic behaviour of the system is dependent on its dynamic characteristics [1]. One of the possibilities on how to solve the problems of analysis and the creation of systems with the required dynamic behaviour is to explore it with the use of dynamic models for the simulation of various situation development [12].

This approach was used for the analysis and projection of the dynamic behaviour system of mining production in the process of coal extraction in a coalface. The created dynamic model was worked out based on the theoretical findings of regulation, hierarchical systems and optimization. It was systematically tested by using software.

2.2 Methodology of creating the simulation model:

The solution of the problem of creating a simulation model will be done in the following steps:

1. Determination of the input characteristics of the approach to the creation of a simulation model of managing (the course) the production process, targeting mass production and the analytical reasoning for this approach.
2. Forming (creation) the simulation model’s system structure on the basis of structuring the functional blocks of this model (factors influencing the occurrence of potential crises).
3. Composing the simulation model and its software processing.
4. Determination of possible tasks (decision-making situations), which are solvable by the application of the simulation model – exemplary practical verification of the composed model with the aim to use it as a prevention tool for a crisis situation.

3 Problem Solution

In this section characteristics, structure and behavior of the model are presented.

3.1 Baseline characteristics for creating a dynamic model

When forming the dynamic characteristics of the coal extraction process in a coalface including its modeling design, the following characteristics are considered:

a) the functional characteristics of elements, which form the process dynamics of the coal extraction in a coalface and are presented by special functions of sub-blocks and blocks modeling the dynamic characteristics of the coal extraction process (blocks labeled “RS”, “PSI”, “PSII”, “MAX”, “PR” and “NS”);

b) the structure of its linkage and behaviour, i.e. its dynamic characteristics which are determined by the character of the transformation of the value change of its inputs to its outputs.

Individual functional blocks and sub-blocks model dynamic characteristics on the basis of a discrete linear transformation, furthermore on the basis of non-linearity in the form of time delays and the limitation of an output change of the individual blocks and sub-blocks of the model when changing its inputs and then by the limitation given by the transformation output sign. Functional blocks, their sub-blocks and linkages are functionally determined in a way that it is possible to, by the modelling of its application, express a criteria condition for evaluation the effectiveness of the existing dynamic characteristics of the coal extraction in a coalface process, analyze it and execute a simulation evaluation of the impact of its changes.

The criteria condition of assessing the required level of dynamic characteristics of workplaces (coal faces) in the coal extraction process is based on theoretical knowledge verified in practice, namely, that dynamic characteristics must be such, so that it is possible in case of the existence of unproductive states at a workplace to fulfill mining tasks in the remaining time, i.e. from a certain time to the end of a given period. This requires, apart from securing the mining of the remaining amount of required extraction by the period end, also balancing already existing an undesirable deviation in fulfilling the mining tasks. Concurrently no other deviations should arise in areas of work safety and hygiene, workplace cost effectiveness, qualitative production’s parameters etc. Under the term of unproductive states we will understand such states, in which the extraction of coal from a coalface is not realized or it is limited compared to a given projection.

The time duration of the unproductive state at a workplace influences the productive time in a shift (the time, in which coal is produced). If the projected time t_m is fulfilled, the shift is considered, from the viewpoint of the possibility of fulfilling extraction tasks as normal, if the projection time t_m is not fulfilled, the shift is considered as pessimistic, and if it comes to an extension of time t_m, the shift is considered as optimistic.

The criteria condition for evaluating the required level of dynamic process characteristics of coal extraction in a coalface is possible to write in the formula:

$$Q_{pT}^{max}(T-\tau) = Q_{pT}(T-\tau) + \sum_{t=0}^{t=\tau} \Delta Q(t) \quad (1)$$

where:

$Q_{pT}^{max}(T-\tau)$ – the maximum amount of coal extraction, which is possible to produce in time

$(T - \tau)$ while respecting necessary or limiting conditions (dynamic characteristics) of workplace operation in the process of extraction, such as: productivity of extraction equipment, the productivity of conveying equipment (including extraction out of coalface, capacity of container etc.), the level of requirements for ventilation, safety and climatic conditions at a workplace, admissible level of the cost effectiveness of workplace operation, the required qualitative production parameters, the level of the influence of factors with a mining-geological character influencing the performance of a workplace etc.

Q_{pT} $(T - \tau)$ – required amount of extraction, which should be produced in time $(T - \tau)$

$\sum_{t=0}^{t=\tau} \Delta Q(t)$ – sum of undesirable regulation deviations in the fulfillment of required amount of extraction in the time interval $t=0$ to $t=\tau$

$T - \tau$ - the time when it should come to balancing the arisen deviation at the latest

τ - time in which it comes to finding out the amount of incepted deviation from time $t = 0$, i.e. from the time determined by us as the beginning of monitoring the production progress and a deviation in production.

The criteria condition is determined from the empiric operation management of mining organizations and from the logic of management based on the deviation method (application of regulation principles, management with a closed structure), which is the base of the management process of mining production and therefore also forms the required dynamic characteristics of a production system in a mine.

3.2 Dynamic model structure

The base of the dynamic model structure is formed on the basis of a regulation circumference, since by the regulating the process application it is possible to simulate the fulfilment of the criteria condition of the coal extraction in a coalface management process objective.

Individual functional blocks of the model labelled “PR”, “MAX”, “RS”, “PSI”, “PSII”, and “NS” and the functional linkage and behaviour in a given hierarchical structure (functional, time and organizational decomposition) are set in the analogy of process management with a feedback (by regulation – application of the structure of the regulation circumference), on whose base we are able to test the level of the required dynamic characteristics of the coal extraction process in a coalface.

Functional block “PR” is the block determining controlling quantity, block “NS” is the block of failure state impact simulation (unproductive states), blocks “RS”, “PSI” and “PSII” are the model regulating system connected with the regulated one, including feedback loops.

Time decomposition is based on the fact that the partial subsystems of a given system are activated in different time levels. In the case of the dynamic simulation model, meaning that the model’s blocks and sub-blocks are activated during shifts, in shifts and within the framework of a given period (e.g. month) for fulfillment of the mining tasks given by the market (based on demand).

By internal shifts there are activated the activities of blocks “RS”, “PSI”, “PSII” and “MAX”, possibly block “PR” and in the framework of the time level the period is activated, the activity of blocks “PSII” and “PR”.

The organizational decomposition of a complex system, whose production system is realized considering the organization structure of its creation purpose. In a case of the model it is the structure of the parallel linkage of workplaces (coalface) from the view of its possible production representation and its grouping into hierarchically higher controlling and organization levels.

From the view of functional decomposition, we decompose the system into four levels (layers), namely into following levels:

- stabilizing – regulation with balancing undesirable deviation – activity of block “RS”;
- optimizing – optimization of controlling quantity (quantities) – activity of block “PR”;
- adaptation – adaptation of the regulation process, including optimization of the controlling quantity considering the newly arisen condition of a system’s activity – the activity of block “PR”;
- self-organizing – a system’s structure change, if it is not able to fulfill target behaviour with the given limitations (it is not applied in the model).

Functional block “PR”

This block is modelling the optimal determination of the controlling quantity, such as the market required for the amount of extraction ($T^{(i)}$) from individual coalfaces for the time periods while respecting conditions determining the maximum of the possible dynamics of mining at the workplace considering the limitation of its possible operation: technological, ventilation, safety and transportation. Simultaneously both, the minimum of an operation’s cost effectiveness at the workplace and the fulfillment of the required level of mining qualitative parameters are respected.

Functional block “MAX”

This block is modelling the outcome of the criteria condition of the required dynamic characteristics of a mining process, i.e. such a situation in evaluating the possibility of fulfilling mining tasks at the workplace, when the given time for the whole period is fully used for extraction together with the maximal possible extraction dynamics in a shift.

Functional block “MAX” is a model’s “signalization” of a state of a coalface’s operation, which warns of a situation that it does not have to come to fulfilling the required task in the coalface extraction for a given period and that it is necessary to think about a necessary transfer of mining tasks among workplaces (if it is possible).

Functional block “NS”

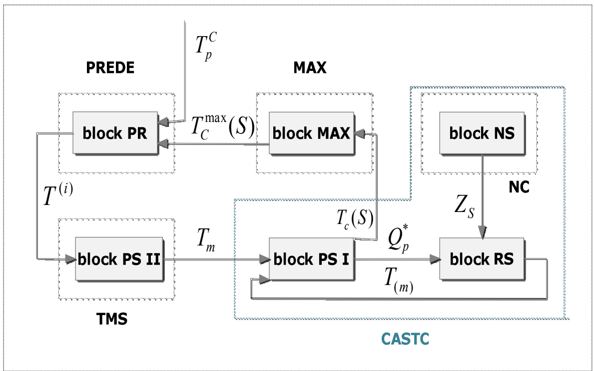
This block is modelling systems of unproductive states (failure/malfunction) in the process of mining in coalfaces on the base of its generating by the usage of a random number system or a deterministic implementation into the process of its simulation, when the unproductive states make a system, which is a relative system in the connection to the real time of a shift, both from the view of time duration and the inception moment of these unproductive states in a coalface. In the model it comes to generating a group of unproductive states expressed by the time of inception, the time duration and the characteristics of its influence on the mining process in the sense that it is the state of stopping or limiting mining at a workplace.

A stochastically determined combination of unproductive states at a workplace in a shift is considered in a model as one of possibly really existing situations at a workplace, from the view of influencing the unproductive states in connection to the length of its duration and the amount of failures of mining resulting from this.

Functional block "RS", "PSI" and "PSII"
They model dynamics of the fulfillment of the task progress in mining from the view of time hierarchy, namely: internal shifts (block RS), shift (block PSI) and shift with the linkage to a determined period (block PSII) for individual workplaces. The outcome of blocks "PSI" and "PSII" is the determination of controlling quantity (expected extraction) for the time level of a shift and an internal shift and its possible change.

Blocks "RS", "PSI" and "PSII" are the regulating and regulated system according to the analogy of regulation circumference. More detailed characteristics of purpose functions and linkage of individual blocks in the dynamic model will be mentioned when describing the behaviour of a model. Linkage of the model's individual blocks is shown in Fig. 1.

Fig. 1 Linkage of the model's individual blocks



managing programm

Legend of individual quantities (information) used in Fig. 1 is following:

T_p^c- market required mining amount (demand) from a coalface for a given period (t. period $^{-1}$)
$T^{(i)}$ - by calculation determining the optimal amount of required mining for i-th coalface for given period (t. period $^{-1}$)
T_m – required mining amount from a coalface per shift (shift expectation) (t. sm^{-1})
$T_c^{max}(S)$ – maximum amount of mining from a coalface given by simulation for a given period (t period^{-1})
$T_{(m)}$ –shift expectation of coalface mining after having done the correction as the consequence of the undesirable deviation inception in mining (t. sm^{-1})
$T_c(S)$ – determined the mining amount from workplaces, given by simulation, after finishing s-th the shift from the period beginning (for the given time) (t. time^{-1})
ZS – the unproductive state with a maximum amount of its influence in a coalface towards lowering the possible extraction from a coalface (t. min^{-1})

As fundamental input quantities, when a change of their level will, in the process of simulation, influence the level of process dynamics of possible mining task fulfillment in a given period, consider the following quantities: the amount of mining shifts in a given period, the effectiveness of the controlling influence, capacity limitation of mining from a coalface with the consideration to the applied technological system, the limitation in ventilation and transportation connected to coalface transportation, the productive time in a shift for coal production by extraction equipment, the amount of reserves in coalface productive activity and in the amount of productive time in a shift, the required revenue from utility products from the refining process, the cost effectiveness of coalface operation and the occurrence frequency of the so called unproductive states in a coalface, information delay and delays in the possible realization of given measures in workplace operation.

3.3 Dynamic model behavior

Dynamic model behavior is formed by the purpose functional activity of its blocks and sub-blocks and its linkage considering an organization and the time hierarchy of their influence within the framework of already determined feedback loops and the defined linkage.

The linkage structure of the functional blocks including its sub-blocks is shown in Fig. 2 in the Appendix. According to Fig. 2 within the functional block:

"PSI" is activated by sub-blocks: "S1" to "S5"
"RS" : "S6" to "S15"
"NS" : "S16" to "S18"
"PSII" : "S23" to "S26"

The simulation process in terms of the time hierarchy begins from the highest hierarchical time level of simulation, i.e. with the activity of the function block "PR" which is impacting the time level, meaning the period towards the functional blocks impacting at lower time levels.

In terms of organization hierarchy the simulation takes place after each workplace always at all hierarchical time levels for a given workplace until the the final number of workplaces within the given hierarchical organizational level is reached.

The functional activity of block "PR" and therefore the whole simulation process is set off by the implementation of the information input to block "PR", which is the amount of extraction required by the market in given time period (e.g. month).

Based on this information and the described functional activity of block, "PR´s block output is determined. By the output we understand the required amount of extraction for individual workplaces (coalfaces) $(T^{(i)})$ for a given period according to the already mentioned functional activity of block "PR".

Based on this output, in the process of dynamic simulation, the activity of functional blocks "PSII" and later "PSI" is induced, which leads to a determination of controlling quantities (mining tasks) for hierarchically lower time levels. The required amount of extraction per shift (T_m) is determined as well as the average amount of shift extraction expectation (mining minutes) of a workplace (Q_p) considering the limitation of the extracted amount caused by ventilation, transportation and the technological capacity of the workplace. In the case of the workplace being affected by these limitations in the full amount, the shift condition *(Qp)* reaches the maximum (Q_p^{max})

ie $Q_p = Q_p^x = Q_p^{max}$

Afterwards the simulation process, in the interest of the analysis of the dynamic characteristics of coal the process in the coalface, is connected with the induction of activity in the "NS" functional block.

Linkage and reaction of block "RS" at the output of block "NS" (linkage of the unproductive state realization) is implemented in order to determine and execute measures at the workplace which would lead to the solution of unproductive states which stop or limit workplace operation. The reaction of the "RS" block is caused by the inception of undesirable regulation deviation as a consequence of the influence of unproductive states at the workplace which were found out based on the feedback loop called "quick feedback loop (RS)". With the existence of this feedback loop (as an information loop) we find out, based on reciprocal comparison, the required minute amount of extraction (Q_p^x) and by simulation the derived minute speed of an extraction in shift (V_s^1) the regulation deviation *(E)*. If this deviation is negative or zero, the activity of functional block "RS" settles down in the sense of the transformation of inputs to outputs of individual sub-blocks ("S6", "S7", "S8", and "S9") of this block

The workplace is run based on current coal process parameters.

In case of a positive deviation (E^x), the "RS" block as a feedback circumference reacts to this undesirable deviation by the preparation and realization of measures with the aim to balance an incepted deviation. It comes to the reaction of the sub-block of controlling influence ("S6"), i.e. it comes to a change of the quantity value (V_k), and subsequently to a reaction of sub-blocks "S7", "S8" and "S9". The quantity V_k characterizes the minute amount of extraction in the shift with the consideration of th inception of undesirable deviation when fulfilling the extraction task during the shift.

The intensity of the reaction of controlling the influence sub-block (its dynamic characteristics) is expressed in the model as an invariable of its dynamic strengthening, modeling the intensity of the amount change of the quantity (V_k) with a certain level of undesirable deviation in mining (E^x).

The functional activity of the sub-block of controlling influence is therefore linked to a search and determination of measures, which would lead to fulfillment of the required change in the amount of quantity (V_k).

Looking for a measure which would be lead to a change or at least keep the extracted amount in a shift stable, for a shift, per day etc. is possible, ex ante apart from other things, to execute in the connection with knowledge deriving from the utilization of so called production functions. The application for solving the quantity amount level (V_k) will be discussed later in this article.

The amount of relative reserve in a possible reaction (in behaviour dynamics) of the sub-block of controlling influence is determined first of all by the amount of possible quantity change (V_k) from its initial state with the reaction of the sub-block of controlling influence (i.e. at the time of undesirable deviation inception). The amount of change of quantity (V_k) in a way, that it comes to evening up the undesirable deviation, is possible to the level of possible maximum change (V_k), i. e. to level (V_k^x). The amount of (V_k^x) is limited to a restriction in ventilation, transportation and technological capacity.

Further, the relative reserve is determined by the time in which, by the reaction of controlling sub-block influence, the needed level of quantity (V_k) is achieved, possibly up to the maximum of its possible change, i.e. level (V_k^x). It is necessary to take into consideration that from the measure acceptance to its realization in operation some time will go by, it comes to a delay, which is modeled by the "S9" sub-block.

The amount of this time delay is implemented and it is obvious that the bigger the time delay is, the slower and less effective will be the reaction of block "RS" and the process of regulating the undesirable deviation in mining at the workplace during the shift will be less operative.

Reaction in the first line of sub-blocs "S7", "S8" and "S9" in the sense of the transformation of the value change of its inputs to outputs is realized in the duration time (existence) of the undesirable deviation (E_x) in mining, if the quantity value (V_k) does not reach a possible maximum, i.e. level (V_k^x).

The invariability of the input level of block "RS" and in the first place its sub-block "S6" and "S7" will come in a time when the amount of undesirable regulation deviation (E^x) reaches the maximum possible minute extraction at a workplace. This will happen in case that (Q_p^x) as a maximum value of controlling quantity of regulation process reaches the value (Q_p^{max}).

Transmission of information about continuation of an unproductive state at a workplace and from this deriving the inception of undesirable deviation within the functional block "RS" is realized through the feedback of information loop "RS" with the value of derived minute speed of a workplace's mining in simulation. Transmission of this information is happening through the sub-block "S10", whose function in the simulation process is to show a delay of information transmission for the determination of the regulation deviation *(E)*.

The sub-block of controlling influence does not detect immediately the real level of regulation deviation, but after some time passes, in simulation time (T_d) in minutes. The output of the "PSI" block activity in the simulation process is to determine derived mining from workplace per minute (V_s) and in a simulation of the determined amount of mining *(T(m))* from the beginning of a simulated shift to the simulation of monitored time in shift.

The output *(T(m))* is then the entry for activity induction of functional block ("PSI"), which enables integration into the process, in simulation, higher hierarchical controlling level due to the necessity to change controlling quantities (Q_p – required minute extraction from a workplace).

The activity of this loop is induced in a time level within the shift after a certain number of multiples of the time step of feedback loop "RS", i.e. always after a certain time during the simulated shift.

If there are undesired deviations in fulfilling the required mining amount at the workplace during the shift, based on the activity of this loop, a new projection of mining within the shift Q_p' of a workplace during the shift (new controlling quantity (Q_p)) is determined. This assumption comes from the ratio of remaining required extraction until the end of the shift and the remaining productive time until the end of the shift.

And because the correction of controlling quantity (Q_p) to value Q_p' happens after a certain time (in time of functional block "PSI" activity), therefore it leads to a simulation of delay in the reaction for the necessary changes of the controlling quantity, which is dependent on the time of reaction of the information feedback loop "PSI" in connection to the time of the reaction of the feedback loop "RS".

The higher the multiple of time steps of loop activity "RS", when it comes to the reaction of feedback loop "PSI" is, the higher the delay in determining and misrepresentation of the deviation level *(E)* is.

In case of undesirable deviation it comes to misrepresentation and the delay of a possible reaction of controlling sub-block influence within block "RS" in the final realization of the change of the coal amount produced per minute from the workplace (coalface).

By the activity of feedback information loops "RS" and "PSI" within the functional blocks "RS" and "PSI" of simulation model it is determined its behaviour on a hierarchical level during the shift and until the shift ends. After the extraction process simulation on a hierarchical time level during the shift, the activity feedback information loop "PSII" is induced; it influences the time level of the shift in the connection to the time level of the period (this is given by the number of mining shifts per period). The activity of block "PSII" determines the output of block "PSII", which is the required mining amount from a workplace for following a shift with a connection as the input for functional block "PSI" – the simulation of new shift during the shift.

Before the simulation of the following shift process, after finishing a certain shift, it comes to a workplace inspection, if it is able to ensure the fulfillment of a required task until the end of the period, or if a situation of fulfilling this task is in danger. This inspection, as it comes from the description of functional blocks of the simulation model, is realized by block "MAX".

In case the criterion "MAX" was fulfilled (evaluation of fulfillment was mentioned in the description of the functional block "MAX") it comes to the simulation completion of the possible extracted amount at a workplace, where there was found a situation that endangers the fulfillment of a required extracted amount for a given period. Then a correction linkage is induced which helps to divide the required extraction into each workplace for a given period according to determined and described rules for the activity of functional block "PR" (if the redistribution can be done).

It means that at the workplace where, by a dynamic simulation, the situation of danger is detected (in terms of the fulfillment of the required task of extraction for a period), the activity of functional block "PSII" is activated based on the influence of the information feedback loop "PSII" with the determination of a new required task (in mining for the following shift), which is a new input for functional block "PSI".

The simulation of the extraction process at the workplaces where the situation of danger was detected continues this way until the end of the period (in the simulation process there are activated connections among blocks and sub-blocks in a way, which was already mentioned in the simulation model behaviour description).

After simulating the findings of (at a given workplace) the possible extracted amount after the period end, i.e. with regards to the mining possibilities simulated by block "RS" (the linkage to production function characteristics), depending on the frequency and the time of the unproductive states at the workplace and its character (stopping or limiting workplace operation or its combination), with regards to delay in the reaction of the controlling influence system, depending on the information misrepresentation of activity of blocks "PSI" and "PSII", the mining redistribution to individual workplaces is executed.

At the same time, the workplace where the fulfillment of an initially required task in extraction for a given period was detected as in danger, the extraction which is considered as the required one, is the one found in simulation.

It comes to the activity of correction linkage "PR" within the activity of block "PR", which output determines extraction ($T^{(i)}$) for a given workplace, which should be sustained for a period. In case that the workplaces are able to fulfill the required tasks within the end of the period, their initial tasks do not change until the end of the period.

After the de-simulation of a given shift, we have to determine again the inputs for blocks "PSI" and "RS" for the following shift (original values are zero).

The simulation process of dynamic model application for other workplaces, which are part of the considered organization framework continues the same way.

After finishing the dynamic simulation of fulfilling the required task in the extraction of a given workplace, this amount is added to the extraction of other workplaces with the objective to determine the final amount of extraction for all workplaces of a given organizational unit in shifts and after period ending.

3.4 Production function characteristics and their utilization in a dynamic simulation

It was already mentioned that the functional activities of the sub-block of controlling influence is connected to searching and determining a measure, which would lead to the accomplishment of change or sustaining the value of quantity *(V_k)*.

For the search to go in the way of the targeted decisions within the controlling influence, it is possible to use the findings of the production function analysis, which are in the macroeconomic area represented for example by the Coob-Douglas function:

$$Y = \alpha K^{\alpha} L^{\beta}, \tag{2}$$

where

Y – gross national product
K – fixed capital
L - labor
α - production elasticity to fixed capital
β - production elasticity to employment

Different types of production functions are possible to apply also in the area of microeconomics, as it is for example with the function which is modelling amount of a shift's extraction T_{sm} from the coalface in the form:

$$T_{sm} = \frac{t_m}{\frac{L-l_v}{V_{ef}} + t_A} hmL\rho_0(t/sm) \quad (3)$$

where:

t_m - mining productive time in shift (min)
L - length of coalface (m)
l_v - length of niche (if they are made) (m)
v_{ef} - efficient preliminary speed of a mining combine (m.min^{-1})
t_A - time of the operation in dead center
h - width of swath
m - average weight (m)
ρ_0 - volume weight of coal (t.m^{-3})

From this function we are able to determine the amount of extraction per minute per shift *(V_k)* in the form:

$$V_k = \frac{T_{sm}}{480} \ (\text{t.min}^{-1}) \quad (4)$$

After putting the formula in (3) into formula in (4) we get:

$$V_k = \frac{1}{480} \frac{t_m}{\frac{L-l_v}{V_{ef}} + t_A} hLm\rho_0 \quad (5)$$

From the relation (5) it is evident, that the change of quantity *(V_k)* can by analyzed in the connection to an analysis of production functions linked to parameters t_m, L, v_{ef}, t_a, h, if we consider the relation (5):

$$\frac{1}{480} m\rho_0 = invariable\ K$$

and at the same time the length of niche (I_v) will also be constant.

Parametres m and ρ_0 are given by the natural conditions. In this situation, the connection (5) can be modified to (6):

$$V_k = \frac{t_m}{\frac{L-l_v}{v_{ef}+t_A}} hLK \quad (6)$$

In terms of simulation processes we can analyze the production functions and apply them for decisions about changes within the simulation of quantity value *(V_k)*, first in the form of the so called incremental effectiveness *(s')* of individual factors (quantities) of the production function (also we can say the incremental measure of substitution among considered factors) and secondly on the basis of the so called production function elasticity *(S'_{xi})*.

Incremental effectiveness *(s')* of individual factors (coefficients) of production function enables discovery of the level of necessary change of one function's factor in a way, that this change must be equivalent to a change of another factor and the level (amount) of the production function output must be maintained (without a change). In our case it considers maintaining the reached level of simulated quantity *(V_k)*.

The incremental effectiveness of individual factors of the production function will be expressed by partial derivations $\partial V_k/\partial_{xi}$, where x_i are considered factors t_m, L, l_v, h, v_{ef}, t_A. Relations among the increase of individual factors for invariable value *(V_k)*, the so called isoquant is given (with invariable m, ρ_0, l_v) by this formula:

$$\frac{\partial V_k}{\partial t_m}\Delta t_m + \frac{\partial V_k}{\partial h}\Delta h + \frac{\partial V_k}{\partial L}\Delta L + \frac{\partial v_k}{\partial \upsilon_{ef}}\Delta \upsilon_{ef} +$$

$$\frac{\partial V_k}{\partial t_A}\Delta t_A = 0 \quad (7)$$

which left side is the total differential of function (6). For illustration we are considering only two factors, e.g. t_A and L, the others we will be left as invariables

$$\frac{\partial V_k}{\partial t_A}\Delta t_A + \frac{\partial V_k}{\partial L}\Delta L = 0 \quad (8)$$

Deriving from this there is the following relation (9):

$$\frac{\Delta L}{\Delta t_A} = -\frac{\frac{\partial V_k}{\partial t_A}}{\frac{\partial V_k}{\partial L}} = s', \qquad (9)$$

where *(s')* is the incremental level of substitution among considered factors, i.e. the inclined length of coalface *(L)* and the time of work duration in dead centers *(t_A)*. Similarly, it is possible to calculate the incremental level of substitution in other combinations of the proportion between coefficients (factors) and create a matrix of the incremental rate of substitution. The incremental rate of substitution *(s')* depends on the combination of two factors and represents an additional range of factor x_2, which is necessary for preservation of the extracted amount when it comes to the reduction of factor x_1.

Furthermore, elasticity is a very important quantity for analysis of production function. In general we define the function elasticity as the ratio of relative change of a dependent variable and the relative change of independent variables. Let's use the function:

$$Q = f(x_1,\ x_{2\ldots}x_n) \qquad (10)$$

then

$$S'_{x_i} = \frac{\frac{\partial Q}{Q}}{\frac{\partial x_i}{x_i}} = \frac{x_i}{Q}\ \frac{\partial Q}{\partial x_i} = \frac{\partial(\ln Q)}{\partial(\ln x_i)}, \qquad (11)$$

where S'_{x_i} is the function elasticity in a point $(x_1,\ x_{2\ldots}x_n)$ relating to factor x_i.

In our case the production function elasticity quantifies a relative change of quantity *(V_k)* during the relative changes of the value (size) of individual input production factors (dealing with small enough changes of these factors, e.g. 1 %). So in our case we can say, that

$$S'_L = \frac{\frac{\partial V_k}{V_k}}{\frac{\partial L}{L}}; S'_{tA} = \frac{\frac{\partial V_k}{V_k}}{\frac{\partial t_A}{t_A}} \text{ and so on}$$

With the analysis of incremental effectiveness *(s')* and production function elasticity *(S_{xi})* we are able to acquire information about, how to search for and orient the measures in the production process (coal mining in a coalface) within the framework of individual production factors in a way that the required amount of quantity *(V_k)* is reached with the aim of possibly achieving the required extraction amount for a given period based on market demands, in a needed quality and at the mining process realization costs.

For illustration let's present some examples. Let's assume an initial situation, which is given by the following input values:

t_m	=	420 minutes
L	=	120 m
H	=	0.8 m
l_v	=	8 m
v_{ef}	=	0.5 m . min^{-1}
t_A	=	70 min. cycle^{-1}
κ	=	0.004 t.m^{-2}

After putting these numbers in the formula (6) we receive the minute extraction per shift V_k = 0.55714 t.min^{-1}. Function elasticity in a point determined by initial situation characterized by above mentioned input data and considering the coalface length is as follows:

$$S'_L = \frac{t_A v_{ef-\,l_v}}{L + t_A v_{ef-\,l_v}} = \frac{70\ x\ 0.5 - 8}{120 + 70\ x\ 0.5 - 8} = 0.18.$$

If we consider the change of coalface length by 1% as small enough, than we can interpret the result in a way, that in case of extending the coalface by 1% the minute extraction will increase by 0.18%. The same result we will get if we put the above mentioned input information with the only change of coalface length to 120.20 m (increase in coalface length by 1 %) into the formula (6), from the result we subtract the initially counted minute extraction in a shift (0.55816 – 0.55714 = 0.001018) and we determine the percentage.

$$\frac{0.001018}{0.55714}\ x\ 100 = 0.18\ \%.$$

Inaccuracy forms at further decimal places and can be explained. 1% is not an infinitely small quantity. Similarly we can proceed with other coefficients. The results of calculation showed that in the initial situation which was given by the above stated input data

a) prolonging the coalface by 1% will increase the minute extraction amount in a shift by 0.18 %;
b) increasing the speed of a mining combine by 1% will increase the minute extraction amount in a shift by 0.76%.
c) decreasing the length of operations in dead centers by 1% will increase the minute mining in a shift by 0.24%.

When interpreting the results it is necessary to distinguish into what level the considered factor can be influenced. If it is the coalface length, it is given by the preparation and information about the effect of its extension on the amount, and is rather significant for production preparation, although the length can change during the lifetime of the coalface which is due to the irregular shape of a coalface block. Mining combine speed and operation time in dead centers are on the contrary factors, where change might be a question of operative intervention within the rationalization of the extraction cycle with the potential possibility of achieving a change of the extracted amount in shifts so that tasks for a given period are fulfilled based on market demands.

From the relation (6) and initial input data, incremental substitution rates among individual factors (coefficients) were calculated. The factors are mentioned in Table 1.

Table 1 Incremental substitution rates

	Δt_m	ΔL	Δh	Δv_{ef}	Δt_A
Δt_m	1	-0.6428	-524.9956	-639.9847	1.4285
ΔL	-1.5557	1	-816.7154	-995.6154	2.2223
Δh	-0.0019	-0.0012	1	-1.2190	0.0027
Δv_{ef}	-0.0016	-0.0010	-0.8203	1	0.0022
Δt_A	0.7000	0.4500	367.044	448.0056	1

Utilization of Table 1:

$$\frac{\Delta t_m}{\Delta L} = -0.6428, \frac{\Delta L}{\Delta t_m} = -1.5557 \ and\ so\ on.$$

We are considering e.g. substitution between the effective advancement speed of combine v_{ef} and the time length of operations in dead centers. From the Table 1 we can find out, that incremental rate of substitution between the two coefficients is:

$$s' = \frac{\frac{\partial V_k}{\partial t_A}}{\frac{\partial V_k}{\partial v_{ef}}} = \frac{\Delta v_{ef}}{\Delta t_A} = 0.0022.$$

Therefore $\Delta v_{ef} = 0.0022\ \Delta t_A$. If for example the operation's length in dead centers increases by one minute, ($\Delta t_A = 1$), then we will get:

$$\Delta v_{ef} = 1\ x\ 0.0022 = 0.0022.$$

This means that when the time of operations in dead centers is prolonged by 1 minute, it is necessary to increase the effective combine advancement speed by 0.0022 m/min, if the minute extraction in a shift is to be kept.

Similarly, as in the case of minute mining in a shift, the microeconomic production functions can be constructed also for other parts of the production process in mining, no matter if they are main, subsidiary or auxiliary processes. Construction and analysis of these production functions have significance especially when searching for the possibility of rationalizing the technological procedures, lowering costs and increasing production effectiveness.

The stated findings from the possible production function analysis which are presented in this article are fully usable for the simulation of production in a coal mining process in coalfaces in connection to searching for measures, which would enable the achievement of necessary minute extraction change (minute extraction V_k) in a shift so that the market demand of mining is fulfilled at the required amount. More precisely – these findings enable an evaluation of situations in which it is no longer possible to fulfill these requirements.

The stated way of analysis of these production functions, in connection with their graphical illustration, enables finding the transition from lower level of production system performance to a higher level and that by the required optimal direction considering the state of the initial system.

4 Conclusion

After reading the article, the question arises: What is possible to solve by the application of the presented dynamic model?

The authors offer the responses: By the application of this dynamic simulation model it is possible:

- to simulate the course of mining and the mining results in the process of extraction for the different dynamic, in simulation determined, characteristics of workplace (coalfaces) operations and for given dynamic characteristics when the value of certain input quantities influencing mining results change, including simulating the possible maximums of these results;
- to determine in advance the situations and times when it would not come to the fulfillment of a workplace´s mining tasks with the necessity to adapt the whole process of mining which is lying in the redistribution of a required workplace's mining tasks with the possibility of fulfilling these tasks within the mining organization or the reorganization of workplace structure (e.g. by operating another workplace or other workplaces), possibly there is a signal for the necessity of its preparation etc.;
- to optimally (sub-optimal) divide the distribution of the required extraction into individual workplaces with regards to the determined objective criteria and considered the limiting conditions of the mining process implementation;
- to clear the creation of an indicator's value level of possible workplace mining and linking indicators for them from the use of average values, which in many cases lead to a misrepresentation of an information base and by this to misrepresentation of a determined indicators' value of a possible mining amount;
- to create a database of mining results achieved for certain technologies operated in certain mining-geological conditions with given limiting conditions and objective requirements on the mining process within a different time, hierarchical levels with the possibility of its utilization for strategic, tactical and operative production management in the mining process.
- to create an early warning system, the creation of an outcome database for a certain model of simulated dynamic features of the production process with the application of limiting conditions in different time hierarchical levels, in this manner the created system is usable for strategic, tactical and operational process management in an organization.

The Dynamics simulation model of mining production in the process of coal mining in coalfaces at given a hierarchical organization level is possible to use in both the process of preparing this production and also during the mining process implementation, i.e. within the framework of operative mining production management and this way contributes to its rationalization.

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Appendix: Fig. 2 Simulation model behaviour