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SIMULATION MODEL OF UNDERGROUND COAL MINING PRODUCTION MANAGEMENT

This article is focused on the problems of the coal mining process intensification. The aim is the explaining of simulation model which presents management system adequated to new requirements. The knowledge of a dynamic behaviour and features of production system and its management are needed for this model creation. Starting points as the functional characteristics and structure of elements linkage and behaviour, i. e. characteristics which determine the dynamics of coal mining process are characterized. Simulation model is structured as functional blocks and their linkages with regard to organizational and temporal hierarchy of their actions. The creation of presented simulation model is based on theoretical findings of regulation, hierarchical systems and optimization.

Keywords: *functional block, coal mining, model, simulation.*

JEL: *C15, C51, L71, M11, P42.*

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ІМІТАЦІЙНА МОДЕЛЬ УПРАВЛІННЯ ВИРОБНИЦТВОМ У ВУГЛЕВИДОБУВНІЙ ГАЛУЗІ

У статті проаналізовано проблеми інтенсифікації виробництва у вуглевидобувній галузі, розроблено імітаційну модель системи управління, яка відповідає сучасним вимогам. У цій моделі враховано динамічні зміни, особливості виробничої системи та її управління, описано функціональні характеристики, зв'язок і вплив елементів структури, тобто особливості, що визначають динаміку процесу вуглевидобування. Імітаційна модель є структурою з функціональних блоків і зв'язків між ними з урахуванням їх організаційної і тимчасової ієрархії. Створення такої імітаційної моделі засноване на теоретичних знаннях регулювання, ієрархічних систем і оптимізації.

Ключові слова: *функціональний блок, вуглевидобування, модель, симуляція.*

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ИМИТАЦИОННАЯ МОДЕЛЬ УПРАВЛЕНИЯ ПРОИЗВОДСТВОМ В УГЛЕДОБЫВАЮЩЕЙ ОТРАСЛИ

В статье проанализированы проблемы интенсификации производства в угледобывающей отрасли, разработана имитационная модель системы управления, которая соответствует современным требованиям. В этой модели учтены динамические изменения, особенности производственной системы и ее управления, описаны функциональные характеристики, связь и влияние элементов структуры, то есть особенности, определяющие динамику процесса угледобычи. Имитационная модель представляет собой структуру из функциональных блоков и связей между ними с учетом их организационной и временной иерархии. Создание такой имитационной модели основано на теоретических знаниях регулирования, иерархических систем и оптимизации.

Ключевые слова: *функциональный блок, угледобыча, модель, симуляция.*

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1. Introduction. One of the problem issues of production activity in mining organizations is intensification of the coal extraction process in the coalface by creating and application a flexible management system, which would be adequate to new requirements. This issue is often associated with environmental issues and environmental responsibilities (Hartman, Mutmansky, 2002). In an effort to achieve sustainability new underground mining are applied methods reflecting different natural and economic environment (Hustrulid, Bullock, 2001).

Generally, it is pertaining mainly to the accomplishment of higher level of concentration parameters by increasing the level of work productivity, time and production utilization of equipment, staff economy, relative savings of physical work, determination of optimum parameters of mining workplaces in the connection to economic decisions' criteria (cost optimization, expenses, profit etc.). The achieved level of these parameters indicates the competitiveness of a company (Horvathova, 2010; Mikusova, 2011). They are also the basis for forecasts, in the wider context for the classification of resources (Rudenno, 2009). The economic and mathematical methods have irreplaceable position in these considerations (Bank, Nelson, 2010; Starr, 2008).

To create such a management system it is necessary to have knowledge of a dynamic behavior and characteristics of production system and its management (Snapka, Konkolski, 2007). Under the term of dynamic behavior we consider reactions, i.e. with what changes of output levels in time does the production system react to changes of the values of its inputs, while the dynamic behavior of the system is dependent on its dynamic characteristics. One of the possibilities how to solve the problems in the analysis and creation of the systems with required dynamic behavior is its exploration with the use of simulation models (Snapka, 1995; Snapka, Copikova, 2011).

This approach was used for the analysis and projection of dynamic behavior system of mining production in the process of coal extraction in coalface. It could not overlook the principles of logistics (Goncarov, Kostyuk, 2011) and the principles of feedback control (Dorf, Bishop, 2001). Formed simulation model was elaborated on theoretical findings of regulation, hierarchical systems, optimization and was systematically elaborated on the computer.

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

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

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

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

Criteria condition of assessing 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 certain time to the end of a given period. This requires apart from securing the mining of remaining amount of required extraction by the period end, also balancing already existing undesirable deviation in the mining tasks fulfillment. The time duration of unproductive state at a workplace influences productive time in shift (the time, in which coal is produced). If the projected time t_m is fulfilled, the shift is considered, from the viewpoint of possibility to fulfill extraction tasks as normal, if the projection time t_m is not fulfilled, the shift is considered as pessimistic, and if it comes to extension of time t_m, the shift is considered as optimistic.

Criteria condition for evaluation of the required level of dynamic process' characteristics of coal extraction in coalface can be expressed by the formula:

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

where:

$Q_{pT}^{\max}(T-\tau)$ — 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, productivity of conveying equipment (including extraction out of coal face, capacity of container etc.), level of requirements for ventilation, safety and climatic conditions at a workplace, admissible level of cost effectiveness of workplace operation, level of influence of factors with mining-geological character influencing performance of 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 $t = \tau$.

$(T - \tau)$ — time when it should come to balancing of arised 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 of the production progress and deviation in production.

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

2. Simulation model structure. The base of simulation model structure is formed on the basis of regulation circumference, since by the regulation process application it is possible to simulate fulfilling the criteria condition of the coal extraction in a coal face management process' objective.

Individual functional blocks of the model labeled "PR", "MAX", "RS", "PSI", "PSII", and "NS" and its functional linkage and behavior in given hierarchical structure (functional, time and organizational decomposition) are set in the analogy of process management with a feedback, on which base we are able to test the level of required dynamic characteristics of coal extraction process in coal face.

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

Time decomposition is based on the fact that partial subsystems of a given system are activated at different time levels. In the case of 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 market (based on demand).

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

Organizational decomposition of a complex system, which production system is, is realized considering organization structure of its creation purpose (Snapka, 1995). In the case of the model it is a structure of 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 4 levels (layers), namely into the following:

— stabilizing — regulation with balancing undesirable deviation — activity of block "RS";

— optimizing — optimization of controlling quantity (quantities) — activity of block "PR";

— adaptation — adaptation of regulation process, including optimization of controlling quantity considering newly arised condition of system's activity — activity of block "PR";

— self-organizing — system's structure change, if it is not able to fulfill target behavior with given limitations (it is not applied in the model).

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

Functional block "MAX". This block is modeling the outcome of criteria condition (1) required dynamic characteristics of mining process, i.e. such situation in evaluating the possibility to fulfill mining tasks at the workplace, when the given time for the whole period is fully used for extraction together with maximal possible extraction dynamics in the shift.

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

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

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

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

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

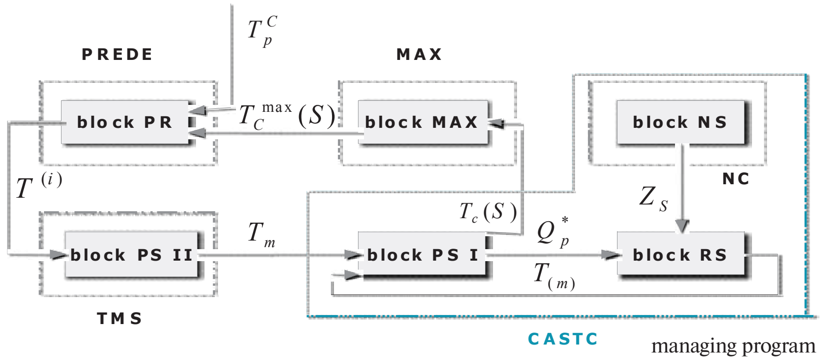

Figure 1. **Simulation model structure**

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

T^{c}_{p} — market required mining amount (demand) from coalface for given period (t. period $^{-1}$);

$T^{(i)}$ — by calculation determined optimal amount of required mining for i-th coalface for given period (t. period $^{-1}$);

T_m — required mining amount from coalface per shift (shift expectation) (t. sm^{-1});

$T_c^{max}(S)$ — maximum amount of mining from coalface given by simulation for given period (t period^{-1});

$T_{(m)}$ — shift expectation of coalface mining after having done the correction as the consequence of undesirable deviation inception in mining (t. sm^{-1});

$T_{(c)}S$ — determined mining amount from workplaces, given by simulation, after finishing s-th shift from the period beginning (for given time) (t. time^{-1});

ZS — unproductive state with maximum amount of its influence in coalface towards lowering possible extraction from coalface (t. min^{-1}).

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

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

Linkage structure of the functional blocks including its sub-blocks is shown in Fig. 2. According to this figure within the functional block:

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

Simulation process in terms of 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 period towards to functional blocks impacting in lower time levels.

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

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

Based on this information and described functional activity of block "PR" blocks 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 simulation, an activity of functional blocks "PSII" and later "PSI" is induced, which leads to 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 workplace (Q_p) considering the limitation of extracted amount caused by ventilation, transportation and technological capacity of the workplace. In case of the workplace being affected by these limitations in the full amount, the shift condition (Q_p) reaches the maximum Q_p^{max}, i.e. $Q_p = Q_p^x = Q_p^{max}$.

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

Linkage and reaction of block "RS" at the output of block "NS" (linkage of the unproductive state realization) is realized 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. Reaction of "RS" block is caused by the inception of undesirable regulation deviation as a consequence to the influence of unproductive states at the workplace which were found out based on 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^{τ}_p and by simulation derived minute speed of extraction in shift (V^{τ}_s) the regulation deviation (E). If this deviation is negative or zero, the activity of functional block "RS" settles down in the sense of transformation the 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 incepted deviation. It comes to the reaction of sub-block of controlling influence ("S6"), i.e. it comes to a change of quantity value (V_k), and subsequently to reaction of sub-blocks "S7", "S8" and "S9". The quantity V_k characterizing the minute amount of extraction in the shift with the consideration of inception of undesirable deviation when fulfilling the extraction task during the shift.

Intensity of the reaction of controlling 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).

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

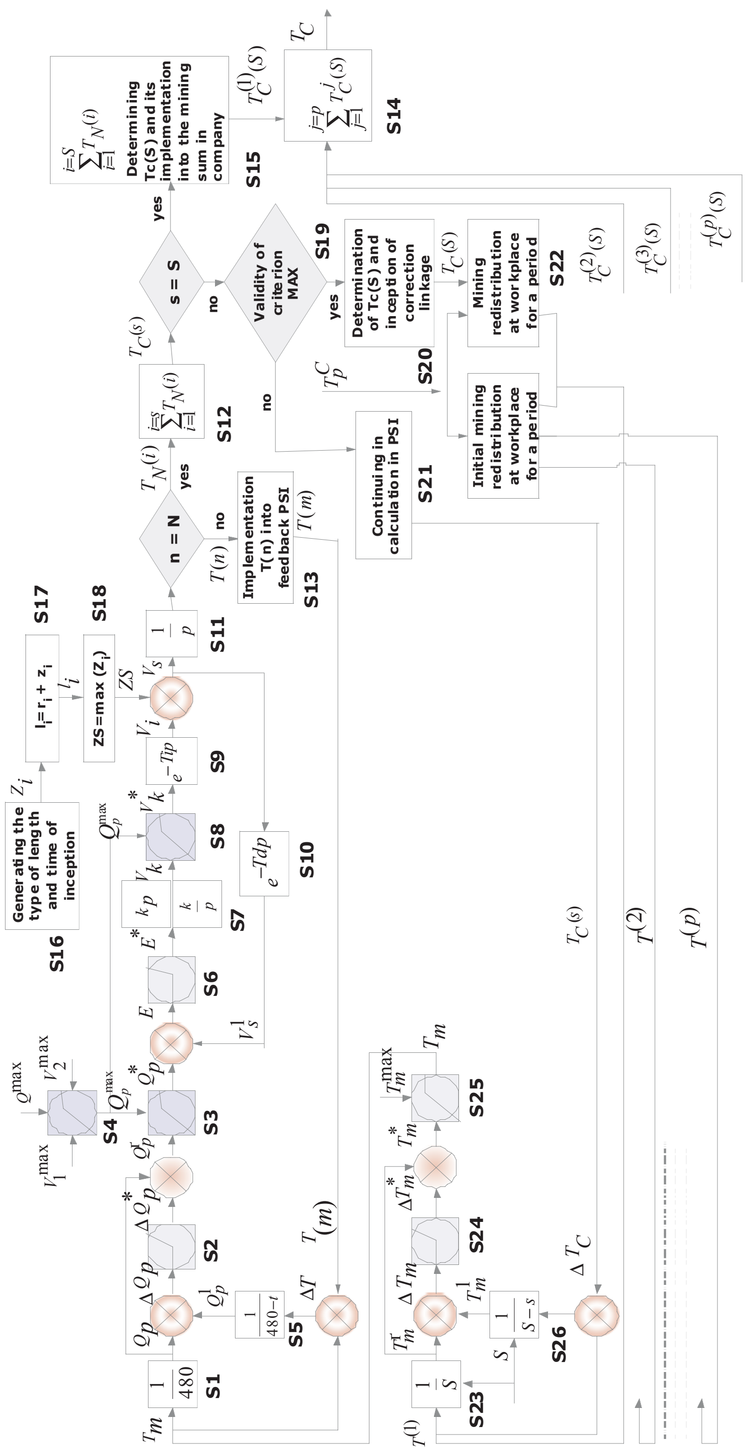

Figure 2. **Simulation model behaviour**

The amount of relative reserve in possible reaction (in behavior dynamics) of 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 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 ($V^x{}_k$). The amount of ($V^x{}_k$) is limited to 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 ($V^x{}_k$). 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 "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 less operative will be the process of regulating the undesirable deviation in mining at the workplace during the shift.

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

Invariability of 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 the case when ($Q^x{}_p$) as the maximum value of controlling quantity of regulation process reaches the value Q_p^{max}.

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

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 "PSI" block activity in simulation process is to determine derived mining from workplace per minute (V_s) and in simulation determined amount of mining ($T_{(m)}$) from the beginning of simulated shift to in simulation monitored time in shift.

The output ($T_{(m)}$) is then the entrance for activity induction of functional block ("PSI"), which enables integrating into the process of simulation the higher hierarchical controlling level due to the necessity to change controlling quantities (Q_p - required minute extraction from workplace).

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

If there are undesired deviations in fulfilling required mining amount at the workplace during the shift, based on activity of this loop, new projection of mining within the shift Q^I_p of 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 remaining productive time until the end of the shift.

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

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

In case of undesirable deviation it comes to misrepresentation and delay of possible reaction of controlling sub-block influence within block "RS" in the final realization of change of produced minute coal amount 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 behavior in hierarchical level during the shift and until the shift ending.

After the extraction process simulation in hierarchical time level during the shift, the activity feedback information loop "PSII" is induced; it influences time level of the shift in the connection to time level of period (this is given by the number of mining shifts per period). The activity of block "PSII" determines output of block "PSII", which is a required mining amount from workplace for following shift with the connection as input for functional block "PSI" - simulation of new shift during the shift.

Before the simulation of following shift process, after finishing certain shift, it comes to a workplace inspection, if it is able to ensure fulfillment of 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 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 simulation completion of the possible extracted amount at workplace, where was found a situation that endangers fulfillment of required extracted amount for a given period. Then a correction linkage is induced which helps to devide the required extraction into each workplace for 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 simulation, the situation of danger is detected (in terms of fulfillment of required task of extraction for a period), the activity of functional block "PSII" is activated basing on the influence of information feedback loop "PSII" with the determination of new required task (in mining for following shift), which is a new input for functional block "PSI".

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

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

At the same time, the workplace where fulfillment of initially required task in extraction for 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 an activity of correction linkage "PR" within the activity of block "PR", which output determins 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 desimulation 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 process of simulation model application for other workplaces, which are parts of the considered organization framework continues the same way.

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

4. Conclusion. By the application of simulation model it is possible:

— to simulate the course of mining and mining results in the process of extraction for different dynamic characteristics of workplaces (coalfaces);

— to determine in advance the situations and times when it would not come to fulfillment of workplaces' mining tasks with the necessity to adapt the whole process of mining which is lying in the redistribution of required workplace's mining tasks with the possibility to fulfill these tasks within the mining organization or 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 required extraction to individual workplaces with regards to determined objective criteria and considered limiting conditions of mining process realization;

— 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 different time, hierarchical levels with the possibility for its utilization for strategic, tactic and operative production management in mining.

Dynamics' simulation model of mining production in process of coal mining in coalfaces at the given hierarchical organizational levels can be to used in both the process of preparation of this production and also during the mining process realization, i.e. within the framework of operative mining production management and thus contributing to its rationalization.

Acknowledgement: The research work is financed by the means of Economics Faculty of Technical University Ostrava in the framework of SGS project no. SP2012/125 "Tvorba modelu strategickeho planu zamereneho na optimalizaci vyrobniho procesu v podniku".

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Стаття надійшла до редакції 01.09.2012.