Application of simulation models for optimization of coal blends

***Alois Burý*[1]**

Aplikácia simulačných modelov pre optimalizáciu zložení uholných zmesí

V prostrediu trhovej ekonomiky sú kladené zvlášť vysoké požiadavky na riadenie výrobných technológií v oblasti uholných hlbinných baní (ťažba, odťaženie, apod.) z hľadiska dosiahnutia čo najlepších ekonomických parametrov (produktivita práce, zisk, rentabilita).

Jednou z možností ich zlepšení je aj užitie metód selektívnej ťažby a homogenizácie. Toto je však veľmi zložitý technický problém a jeho riadenie patrí k problémom, ktoré doposiaľ neboli uspokojivo vyriešené.

Metódy riadenia týchto procesov sú založené na modelovom riešení štandartných i neštandartných situácií a na využitiu simulačného systému.

Článok je zameraný na možnosti využívania simulačných modelov aplikovateľných na problematiku riadenia selektívnej ťažby a homogenizácie. Na podklade výsledkov riešenia projektov GAČR: 105/ 94/1119 a 105/97/1320, sme na našom pracovisku (Inštitútu ekonomiky a systémov riadenia, na HGF, VŠB – TU Ostrava) vyvinuli simulačný program, ktorý sme nazvali SIMDUL. Tento program umožňuje vytvorenie simulačného počítačového modelu konkrétnej hlbinnej bani, bez potreby programovania, formou interakčného dialógu užívatelia so systémom s možnosťou simulovať dynamicky kontinuálne vývoj kvalitatívnych parametrov uholných zmesí v zásobníkoch a na linkách pásových dopravníkov v bani s možnosťou optimalizácie ich zložení.

***Kľúčové slová**: selektívna ťažba, simulačné modely, optimalizácia, riadenie kvality*

***Key words**: selective mining, simulation models, optimization, quality control*

Introduction

The problems of the selective haulage and homogenisation are still up-to-date, also with the respect of the complicated conditions in the underground coal mining sector, especially from the viewpoint of the competition on the market there is necessary that the coal mines would adopt customers requirements in maximum extent, since the prices and qualitative indicators of coal blends are concerned. The methods of selective mining and homogenisation of raw coal blend, already in mine storage bunkers, enable a dynamic adjustment of underground coal production system to changing conditions and requirements of market. Criterion of optimisation is to gain a maximum profit from sale of coal blend at given seam parameters of working fields or of other working areas as well.

The application of selective haulage methods and homogenisation, however, is conditioned by the control of whole process of the more effective evaluation of the mined coal. It is generally known that the quality of control of any technological process depends on the knowledge of this process, on information concerning this process and on the possibility of its prediction. These requirements are met by computer simulation models.

In cooperation with ViPk.ú.o. Praha, branch-office Ostrava, (GACR 105/94/1119, GACR 105/97/1320) we have taken share in necessary analysis for creation of the mathematical model and later simulation models realized on computer as well. The analysis were based on the documents obtained in underground coal mines (Darkov, Paskov, Staříč, Lazy, etc.)

Problem statement

At present, the quality of hard coal is mined in the Ostrava-Karviná coal basin and the Příbor-Těšín coal basin in the Czech Republic. The mines in the Ostrava's part of the basin have already finished the mining but some mines in the Karviná's part have the seams both from the Karviná's layers and from the Ostrava's layers as well of different qualitative parameters. It is evident it that the possible relatively wide variety of qualitative parameters of coal seams mined in the framework of one enterprise that would enable the selective haulage or also the homogenisation already in mine storage bins. The selection of the optimum variant of the coal blend composition can be set on the basis of the structure of the output from given seams. These coal blends can be prepared by suitable mixing of outputs from the single mining places, resp. by their selective haulage.

For example, if the mine mines the coal of three trade groups V, VI, a VII, then it is not economically advantageous to sell the coal in the trade group VII. Then one of the variants can be the selective haulage of seams with significantly different qualitative parameters, and then to homogenize the rest of the coal mined. To

[1] *Doc. Ing. Alois Burý,CSc.*VŠB – Technická univerzita Ostrava, tř. 17. listopadu, Ostrava – Poruba, 708 33, Hornicko – geologická fakulta, institut ekonomiky a systémů řízení
(Recenzovaná a revidovaná verzia dodaná 18.4.2004‘

haul the coal of higher trade group selectively and to concentrate for the possibility of its evaluation in more expensive trade group. (Bury, 2000).

It is evident from the above mentioned example that it is possible to apply the simulation models realized with the help of simulation program, which we developed at our Institute of Economics and Control Systems, for quality control of coal blends, not only from the viewpoint of the quantity mined, but also from the viewpoint of presentation of the qualitative parameters development in mine storage bunkers.

The optimization task, with the criterion of optimisation:

$$P \longrightarrow max$$

can lead to more efficient enhancement of mined bitumous coal. However maximum profit P from the sale of coal blend, must respect the following limitations: ensuring of a sufficient space for mining and ensuring the sufficient coal stock in mine storage bins in such a way so that the continuous run of the haulage from a mine would not be disturbed, and, due to it, also the run of the coal preparation plant. (Qout = Qdes) and also desirable qualitative parameters of the coal blend (ash content Aout = A des , and others qualitative parameters, where :Ades, Qdes, … are desired values and Aout, Qout are the total values.

The complex research tending to the working out of this type model required the solution of the following single problem spheres:

- the analysis of the coal transport structure including storage tanks and transfer points of selected coal mines in the Czech Republic,
- the analysis of research of coal blends mixing in storage tanks with the respect of their different quality and quantity mined, with the aim to determine the resulting coal blend composition discharging into the given storage bin,
- the research of coal flows from the working faces up to the expedition from the mine, with the respect of the possibility of selective haulage and homogenization,
- the realization of computer models of single objects of the haulage system and their mutual interconnection,
- the research of variants of possible operation situations (simulation on real data),
- the research of control systems (organization, information flows, technical equipment of mines, with the aim to work out the type incorporation of the selective haulage system into the control system of the underground coal mine,
- the development and realization of the simulation program for the possibility of modeling and simulation of variants of selective haulage and homogenization,
- the simulation of variants with the aim to determine the optimum blend or required composition of qualitative parameters of coal blends.

In the course of simulation the models of variants had to present the following data:

- from which mining place, in what qualitative composition and quantity in given time sequence the coal flow enters the storage bins, res. connects with other flow on the overflow point.
- what is the dynamic change of levels conditions in the storage bins and what is the actual composition of qualitative parameters of the coal blend.
- which conveyers are in operation in given moment, whether they convey coal and at what quantity.
- what is the activity of vertical haulage.
- what is the composition of resulting coal blend on the surface and in what total quantity for given time period.
- whether the capacity of transport lines of horizontal haulage is sufficient.
- what is the suitable capacity of mine storage bins of coal blends etc.
- how will the change in haulage come to light (in quantity as well as quantity of coal blend) in case of simulation of conveyers, mining complexes defects
- how will the changes in the blends composition as well as their quantity in case of storage bins overfilling come to light.

The conceptual model of optimal enhancement of coal blends produced in an underground mine is presented on Fig.1. This principal block scheme illustrates the fundamental components that participate in the whole process.

Creating a simulation model for the purpose mentioned above uses the analytical way of identification, based on the knowledge of elements structures and their all parameters both construction, quantitative and also qualitative. There are three main analysis, among others, which can share on creating the simulation model:

- analysis of the underground mine transport network (TNA) with database D1 of parameters
- analysis of the seams qualitative data (A 2)
- analysis of the coal faces working schedules (WS).

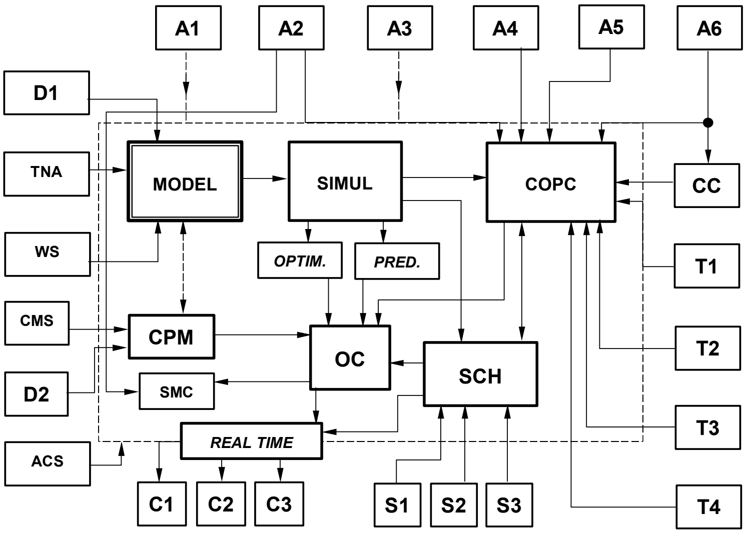

Fig. 1. General block scheme of modelling, simulation and control

Another denotations, which have been used in Fig.1: SIMUL- simulation, COPC- co-operation control centre, OC- operating control, SCH- synoptic chart, S1,S2,S3- sensors, C1,C2,C3- automatic control of skip hoist system, automatic control of conveyer underground lines, etc., SMC – system of selective mining control, ACS- automated control systems in underground coal mines, CPM- critical path method, CMS- control and management structure for controlling process of selective mining and homogenisation with database D2 of numeric time characteristic, OPTIM- optimisation, PRED- prediction,A1-analysis of technical means for automation, A3- analysis of the mining technology used, A4- customer requirements analysis, A5- coal prices analysis, A6- analysis of selective mining possibilities, CC- coal classification, T1- test of skip hoist system capacity, T2- test of equalising capacities of coal bunkers, T3- test of conveyer lines capacity, T4- test of the right control strategy.

Mathematical model of coal blend development dynamics

By analysing in detail of the production systems of underground coal mine, we are able to arrive at the conclusion that there is the transport system, which is the main conceptual approach to the so- called reduction of the production process to a system (Burý, Strakoš 1996). Then it is possible to generally formulate the system of transport for mining formations by the help of relation.

Mathematical model of the transport network created by pre-condition of two central underground bunkers for filling the skip hoist system provides the total output:

$$Qy(t) = \int y(t) \cdot dt\,, \qquad y(t) = \left[D_{Z1} D_{Z2} \right] \times \begin{bmatrix} q_1(t) \\ q_2(t) \end{bmatrix}$$

D_{Z1} and D_{Z2} represent dead zones, $q_1(t)$ and $q_2(t)$ correspond with the quantity of coal blends in the central bunkers.

The evolution of coal blends in these bunkers is given by the equations:

$$\frac{dq_1(t)}{dt} + p_1 \cdot q_1(t) = \left[D_{zi} ... D_{zk} \right] \times \begin{bmatrix} q_j(t) \\ . \\ . \\ . \\ q_k(t) \end{bmatrix}, \qquad \frac{dq_2(t)}{dt} + p_2 \cdot q_2(t) = \left[D_{zs} ... D_{zu} \right] \times \begin{bmatrix} q_s(t) \\ . \\ . \\ . \\ q_u(t) \end{bmatrix},$$

D_{zi} is a dead time of the **i-** th belt conveyer line and **q** is a vector of coal blend evolution flows in coal bunkers at underground mining area.

Modelling of the coal evolution flows in underground bunkers has to include except quantitative parameters (output), also quantitative parameters of coal blends as: percentage of ash, moisture, sulphur, plasticity, etc. By analogyiz is given the evolution of coal blends in the other bunkers in underground mine:

$$\frac{dq_j(t)}{dt} + p_j \cdot q_j(t) = [D_{z1} \ldots\ldots D_{zm}] \times \begin{bmatrix} \vec{Q}_1(t) \\ \vec{Q}_2(t) \\ . \\ . \\ \vec{Q}_m(t) \end{bmatrix}, \qquad \frac{dq_k(t)}{dt} + p_k \cdot q_k(t) = [D_{zm+1} .. D_{zn}] \times \begin{bmatrix} \vec{Q}_{m+1}(t) \\ \vec{Q}_{m+2}(t) \\ . \\ . \\ \vec{Q}_n(t) \end{bmatrix}$$

where: j = 1,2,3,….,m and k = 1,2,3,….,n

$\vec{Q}i(t)$ represent a vector created by elements of tonnage per hour (i = 1,2,3,…..,n+k) from each working face. Letters marked as **p** illustrates parameters of bunkers. Selective mining describe these equation:

$$\frac{dq_{s(t)}}{dt} + p_s \cdot q_{s(t)} = D_{zs} \cdot \vec{Q}_{n+1}(t), \qquad \frac{dq_{u(t)}}{dt} + p_u \cdot q_{u(t)} = D_{zu} \cdot \vec{Q}_{n+k}(t) \quad .$$

The work cycles of working faces with the regime of selective mining are presented by:

$$\vec{Q}_i(t) = \{Q_{i1}, Q_{i2}, \ldots\ldots Q_{i8}, \ldots\ldots Q_{i16}, \ldots\ldots. Q_{i24}\}, \mathrm{i} = 1,2,3,\ldots\ldots \mathrm{m}, \mathrm{m}+1, \mathrm{m}+2, \ldots\ldots., \mathrm{n}, \mathrm{n}+1, \mathrm{n}+2, \ldots\ldots.\mathrm{n}+\mathrm{k}$$

Q_{i1} - output from the **i**-th working face in the first hour, etc.

A mathematical model of transport network in underground coal mine that was presented above in a generally form, has to include also qualitative data of the seams. To obtain them, it is necessary to work out analysis of the coal seams in the mining area.

It can be done by coal sampling method, when a small portion of material is collected for testing, believed to be a representative sample of the entire volume. The sample value is generally different from the true. This difference (sampling error) has a frequency distribution with a mean value and a variance. It is necessary to estimate the magnitude of the sampling error before results can be reported. Every sampling operation consists essentially of either extracting one sample from a given quantity of material or extracting from different parts of the lot a series of small portions that are combined into one “ gross sample “ without prior analysis (sampling by increments).

Coal is a complex mixture of mineralogical and chemically compounds, and the application of its physical properties gives an average structure of the whole substance in terms of certain parameters.

A desired qualitative parameter, for example- ash contents, of coal blend for two, three and more components is given by the equation:

$$A_{des} = Q^{-1} \sum A_i \cdot Q_i \qquad \textit{for : i = 1,2,3,.....,n}$$

The following denotations have been used : A_1 , A_2 , A_3 ,..A_n – ash contents in components, Q_1,..Q_n – tonnage of components, A_{des}, - desired value, Q- total tonnage ($Q = Q_1 + Q_2 + Q_3 + \ldots + Q_n$)

Similarly another qualitative parameters of coal seams and coal blends can be obtained (e.g. density of coal, contraction, moisture, plasticity, sulphur content, caloric value, etc.).

Simulation program

For the purpose mentioned above, we decided to develop the special simulation program, which we called SIMDUL, that has been worked out on base of object oriented design techniques with the possibility of using an interactive approach during the creating the simulation model. (Bury, Hettner 1996)

The simulation program has been specifically based on a possibility to carry out a capacity analysis of belt conveyers and bunkers with the possibility for using selective mining and homogenisation. SIMDUL uses the objects programming, based on the transportation and mining equipment, using in a mine. From the working faces or from road heads is coal conveyed by the network of belt conveyors with transfer points and bunkers to the shaft. Coal is then hoisted through the skip to the surface storage. (Fig.2)

The structure of program is composed with:

- system of communication between the program and an user (user interface)
- simulation mechanism

The user interface and the display device of objects form the system of communication between the program and a user. The user interface ensures communication between the user and the simulation program. It is formed by a menu system.

The particular work regimes are sorted to begin with setting up the initial states (F1), saving the created model in disk memory (F2), loading the model which we want to test (F3), that had been created in regime F4 and at last using regime F5 for simulation.

The display device of objects is a subroutine for a displaying of graphic symbols (belt conveyor, working face, bunker, etc.) in the co-ordinate system in the branches of the haulage system in an underground coal mine.

The mechanism of simulation ensures to perform the simulation with the model, which had been worked out.

The mechanism incorporates:

- the calculation of states of face outputs
- the calculation of states on the objects.

From the Fig. 2 there is evident the distribution of haulage network structure in single branches so as they have been created gradually in editing mode (F4) in the form of interactive dialogue. The situation from the Lazy Mine in Ostrava-Karviná District (OKR) was modelled, and namely for two central coal bunkers in a scheme marked as E and K and four sectional coal bunkers, indicated as: DU, SEL, 46, and 900. It is evident from the illustration that the long wall faces indicated as P1 and P2 mine into the coal bunker 46, the long wall faces P3 and P4 into the coal bunker 900. The long wall faces P6 and P7 mine into the coal bunker SEL. The output from the long wall face P5 is led into the coal bunker DU, what enables the possible selective mining. The total output from the mine is presented in the scheme indicated as OUT.

From the animation scheme also the motion of coal flows on belt conveyor lines and change of levels in coal bunkers in given actual simulation time is evident (in left upper corner of the display). From the illustration also the required detailed information, presenting by table, concerning the level state and qualitative parameters composition in given coal bunker (900) is evident for given actual time period.

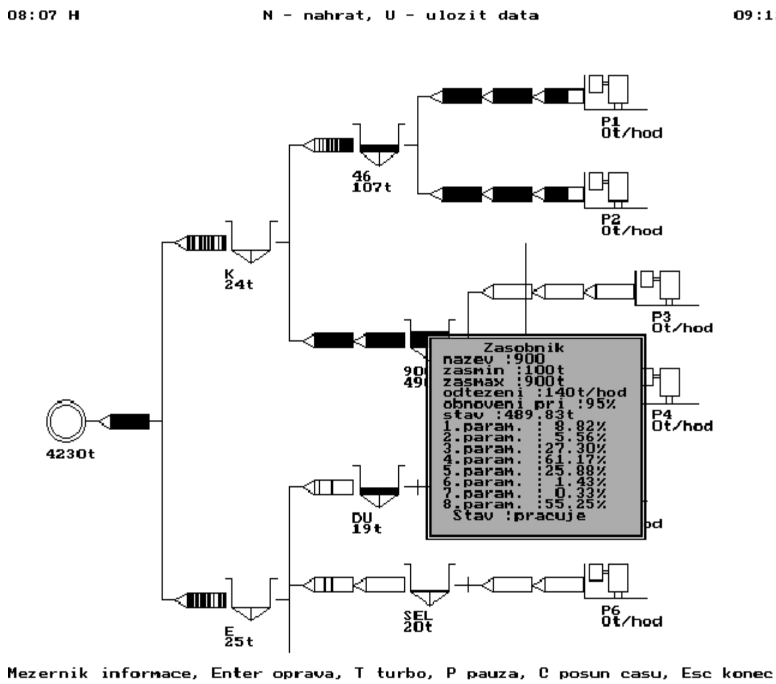

Fig.2 Underground transport network with detailed information

The models of working faces create, in a substance, the generators of input values respecting both the viewpoints of quantitative level as well as the qualitative evaluation the coal seams mined. From the viewpoint of quantity the single mining outputs are entered in the relation with the applied mining complex, and so in the relation with mining works processes. The modeled flow of the product exploited must contain, in addition to information concerning the quantity, also the required qualitative parameters. The conveyer lines create the single branches of haulage network which are characterized by corresponding transport delay.

The flows of the rock transported are connected in the places of overflows and also in the mine storage bins. If the given branch is ended by the overflow, then at the calculation (simulation) of the output entering into the following branch the qualitative parameters will be calculated according to the blending equation. In the storage bins the coal is mixed in such a ratio how the single batches come from mining places and how they are gradually hauled by the control system.

The time schedules of mining works can be entered in hour, half an hour or also in ten minutes time intervals. In this way the wide variety of modeling of the corresponding mining technology and also the possibility of modeling of haulage from the preparatory working places is made possible. The time interval of 10 minutes is also suitable for using in modeling and simulation with respecting and compensating the transport delays due to various length of belt conveyers lines. In the new version of SIMDUL, among others, it is possible to enter the time schedule of mining works, including the qualitative parameters of coal seams, separately from the model creation editing mode). In the course of the new simulation model creation on the basis of the analyses mentioned, necessary for given problems, there is being based on the mode F4.

The mode of editing of the model (F4) is controlled by an interactive dialog which is secured against the possibility of error arise. The number of edited branches of the haulage network makes 20 and in each branch it is possible to edit also 20 objects. The single branches of transport network are entered gradually according to the system instructions.

Methodology of determination of the output volume and structure.

For the possibility to affect the analytical indicators of coal blends the knowledge of the output volume both in mining places and on conveyer lines and in the storage bins in the coal field is necessary.

If we want to determine, in any time as well as spatial section the output volume and structure, we have to base on the calculation of transport delay and to determine from which place and what time interval the given coal comes. If we are to determine the coal quantity from single seams which can be found in given time moment - *t* in certain storage bins, then it is necessary to set [26, 8] as follows :

- the time interval when the coal started to enter the single storage bins and when this entering was completed
- the time interval of coal blends passage through the mine storage bins
- the time interval of the coal passage through the transport lines from single sectional storage bins
- the time of rock mined passage from the working faces to single sectional storage bins
- time interval of mining in single working faces.

For calculation of minimum time delay between single objects of transport network of haulage the following is valid:

- the time delay between working faces and sectional storage bins is given by transport speeds of belt conveyer lines and speed of haulage, whereas the transport distances are changed due to the working faces process.
- the time delay between the sectional storage bins and central storage bins is given by constant distances and haulage speed.
- The time delay between the central mine storage bins and surface storage bins is given by the constant length of vertical haulage which is proportional with the depth of the haulage level and constant speed of haulage and variable delay given by the frequency of the skip lift number.

In case of the idle time arise the given time delay is prolonged by the time of given idle time duration. With the exception of the haulage calculation model the idea of the grant project is based on the obtaining the documents concerning the distribution and development of qualitative parameters of coal blends in given transport network of haulage, in coal flows starting from the working faces through the sectional storage bins and central storage bins, in mine part of an underground mine up to the skip haulage.

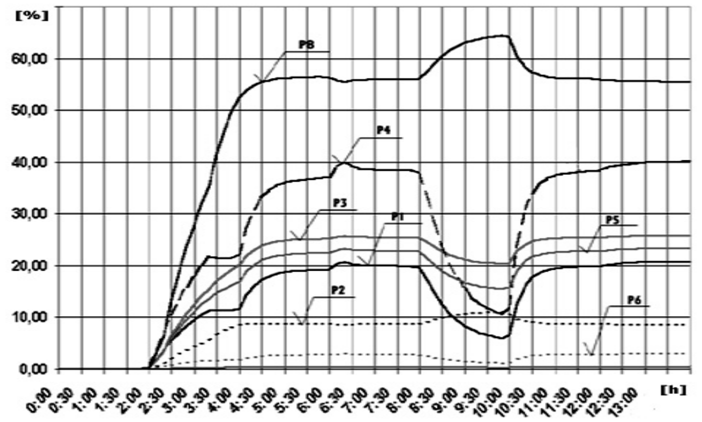

Fig.3 Dynamic development of qualitative parameters in the coal bunker E.

Simulation graphic outputs

For the possibility of the development research of the qualitative parameters in coal blends in single network objects, and then especially for analysis of blends development up to the expedition from a mine, the program is supplemented by the subprogram which summarizes single data for selected time period in such a way that they can be processed further in the product MS Excel, version 7, see Fig.3.

For increase of the operative character of the graphs processing we have realized also further programs as follows: KONVERZE enabling the conversion of tables created by the program SIMDUL on the form suitable for processing by MS Excel, program GRAFY which creates directly the 2D graphs in the environment of MS Excel. The program 3D-GRAF simplifies the graphs creation with the spatial display, see Fig.4.

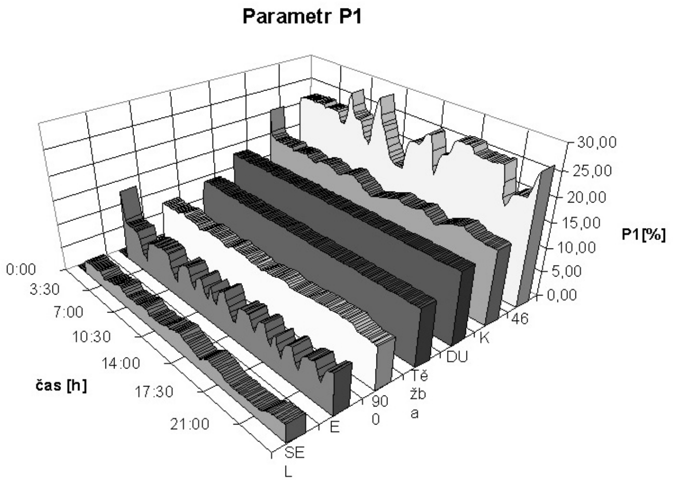

Fig.4 D presentation of ash evolution in all underground coal bunkers

Conclusion

The methods of selective mining and homogenization enable to optimize coal production according to the criterion- maximum profit from the coal sale. The simulation models of coal blends development in the transport network of haulage for the purpose of quality control of resulting product and simulation of single variant realized in the simulation program have verified the possibility of contribution of selective mining and homogenization as set in goals of grant project for solution of which we have taken part just in the sphere of analysis, modelling and simulation.

References

Burý,A.: Control of Modelling and Simulation of Automated Selective Mining Coal Flow., *Conference Process Control´95*, *Tatranské Matliare ,1995.*

Burý, A., HETTNER, M.: SIMDUL–Mining Process Simulator, *2nd Scientic-Conference: Process Control*, Horní Bečva, 1996,p.26-27

Burý, A., STRAKOŠ,V.: CA–Simulation of automated control system for selective mining and homogenisation., *5th International Symposium on Mine Planning and Equipment Selection MPES´96*, Sao Paulo, Brazil, 1996, A.,A. Balkema, Rotterdam, Brookfield.

Burý, A., Vajs, S.: Modelling simulation and control of effective utilization process mining., *13th International Conference on Automation in Mining-ICAMC 1998,High Tatras,Slovak Republic.*

Burý, A.: Modelling and simulation of transport in deep mines., *14th International Conference on Automation in Mining-ICAMC 2001, Tampere, Finland*.