Optimizing Transport in Surface Mines, Taking into Account the Quality of Extracted Raw Ore

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This articles concerns problemacy of appropriate separation of transporting mechanisms for mining minerals from individual teritories. In the following sections of the article a model solution is presented with the use of newly created program for optimization of transport, taking into account the required quality of extracted raw ore. This process is being done through computing analysis and programming language Borland C++ Builder

***Key words**: optimizing transport, open pit, quarry,*

Introduction

The current difficult economic situation is reflected in all industries, not excluding mining. It brings necessary economic analysis of production and puts particular emphasis mainly on optimal use of various productive resources. From the perspective of efficiency assessment of surface mining, the transport of extracted raw ore from the mines to the refraction plants represents an important component. Although in many cases the transport system in surface mines is organizationally simpler than in underground mines, especially in the optimization of large surface mines significant savings cost can be achieved. On the other hand, one should consider and respect the requirement of the refraction plant on quality of burden, which in some cases significantly makes the whole optimization process difficult and makes projections for the introduction of new computer resources for solving these problems.

There were several authors who led the studies concerning truck allocation. Sgurev et al. (2003) concentrated on studying the automated system that would represent a real-time control in open-pit mines for industrial truck haulage. The next study was done by Alarie and Gamache (2002) and concerned the description of solution strategies, which are further used in systems for truck dispatching in open pit mines. Different approach was taken by Nenonen et al. (1981) who was able to present a truck/shovel operations in an interactive computer model for open pit mine. Ramani (1990) developed a study about a simulation of the haulage system that served as an analysis for surface mining. Barnes et. Al. (1972) performed his studies based on probability techniques in order to be able to analyze open pit productions systems. Camichael (1986) was trying to determine the level of open-cut mining operations and their production by cyclic queuing theory. Shangyao et al. (2008) was able to combine truck dispatching with production scheduling of ready mixed concrete (RMC) by creating integrated model that allowed this comparison in the same framework. Sabah et al. (2003) introduced a queuing theory as a basis for methodology, which is interpreted in a computerized module demonstrating the uncertainties that can arise during the selection process of the equipment

Initial conditions, criterial conditions and objectives of optimization

Above mentioned transport optimizing is done by the method of linear programming, which is represented by an exact mathematical formulation of the task and by the method of solving it. In this way it can come into practice very well. [1]

Initial conditions can be divided into two basic groups, namely:
Constant: they are entered to the program application of a specific extracting operations,
Variables: are entered each time you start the program.

Constants define the fundamental characteristics of mining operations, used technology and mechanization.

As variable we define the expected current goals and conditions in mining operations.

Certain input conditions are given in the tab. 1 below.

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Tab. 1. Selected input conditions as a solution for transport optimization.

<table>
<tr><th colspan="4">Input conditions</th></tr>
<tr><th colspan="2">Constants</th><th colspan="2">Variables</th></tr>
<tr><td colspan="2">total daily extraction</td><td>combination of departments, from which unload should be provided</td><td></td></tr>
<tr><td colspan="2">duration of a shift (working time within 1 day)</td><td rowspan="4">proportion of mixture of the individual components of burden in refraction plant (in our case e. g. white respectively. dark limestone)</td><td>amount of white limestone in mining</td></tr>
<tr><td rowspan="3">average capacity performance of containers while transporting from individual workstations</td><td>types and load capacity of used containers</td><td>amount of dark limestone in mining</td></tr>
<tr><td>average distance of workstations from refraction plant</td><td>percentage of white limestone in mining</td></tr>
<tr><td>average cycle's time duration for each container on workstations</td><td>percentage of dark limestone in mining</td></tr>
</table>

Limestone mining operation was chosen as the base model for the solution, where during refraction of raw materials process of mixing of the dark and white limestone is performed in designated proportions. The organization of the ongoing mining exploration takes place in several workplaces for mining white limestone and in other workplaces for mining dark limestone. The distances of these two workplaces from the refraction plant are different.

When suggesting the optimal traffic management in the mine one should consider the planned daily production in the mine, the quality requirements of the refraction plant on the raw ore and the average transport capacity of individual mechanisms for each specific workplace.

In an opencast mine, the mining cycle is influenced by the excavator working cycle, truck-changing time, loading time,tipping time, travelling time for empty and laden trucks, travelling distance, amongst other factors. These parameters have direct and indirect relationships, which can be expressed mathematically by the use of formulae, as shown below [4]

Transport capacity of the individual transport mechanisms are set from their basic parameters, the average transport distances and from the average time working in the transport cycle from particular workplaces.

An important parameter is also an effective duration of a shift (working day), which will vary in proportion to the total time of the shift, which is often dependent on the calendar period, but also may be constant. In our case a time of constant shift was considered.

In the mines and on other workplaces it is an ongoing cycle of operations (drilling, charging, shooting), which aim is to prepare raw ore and in certain time phases it does not allow the transport of the raw ore. Therefore it is necessary to take into account what operations are carried out at certain workplaces and what is the amount of raw ore stocks in them. Therefore while optimizing the transport it is very necessary to leave a possibility to define current situation on workplaces and also the possibility of choosing accessible one.

Although in stone quarries there is no big emphasis given on the need for quality control of the raw material as it is in the mines where e.g. iron ore is mined, where in some cases the refraction plant might require continuous supplies of specific quality of raw materials. This case may be, e.g. mixing white and dark limestone in various proportions depending on the desired properties of the resulting product. This implies the need to introduce new criteria conditions and widening requirements for solutions of how to optimize transport in mining operation. For an optimization it is necessary to allow these requirements to be entered within input conditions.

Sample definition of input parameters in the generated program in the figure 1.

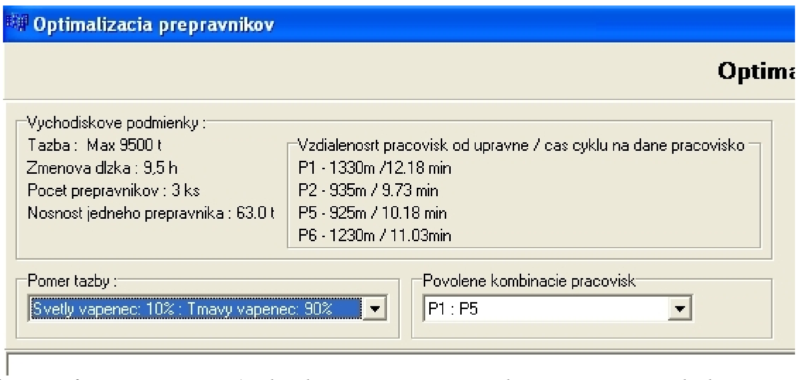

Fig. 1. Sample definition of input parameters (in the above part constant conditions are given, in the bottom part variable input conditions are given).

An important part of optimization is the proper setting of criteria conditions, which are an instrument for fulfilling the objectives of optimization. When defining criteria conditions it is necessary to classify their sequence according to their importance and thereby achieve a smooth processing of input data into the required outputs. Before defining criteria conditions it is necessary to define the main objectives of optimization.

The main objectives of transport optimization are mainly; achieving the planned production capacity at minimal cost and optimal work cycle of containers with minimal downtime and delays, allowing a good organization of work of transport mechanisms. If we are talking about mines with increased requirements of the refraction plant goal of achieving a required quality of raw ore plays a significant role.

Following the above objectives are criteria conditions can be traced, which must ensure achieving the above-mentioned objectives. In our model for were such criteria conditions:

- the minimum divergence from the planned mining,
- the minimum hourly divergence from the desired ratio of white and dark limestone,
- minimum downtime of used containers.

Introducing these criteria conditions the objectives of optimization will be achieved.

Optimizing transport in a mine using a program "Optimizing containers / Optimalizácia prepravníkov"

The program "Optimizing container" has been implemented in a development environment of Borland C + + Builder. Optimization in this program is solved by serial algorithmic calculations. The program looks for optimal solutions based on the set of input conditions and doing this by conversion of all combinations of solutions.

To optimize the transport through this program, when using the large-scale container, the following tasks were given and program had to solve them:

- to optimize the use of containers for individual workplaces according to their time capacity,
- calculate the number of cycles of containers for individual workplaces,
- find the optimal container solution as to eliminate in as much divergence from the hourly planned mining,
- finding solutions resulting from such actions, which suit the most to the continuous quality requirements on the raw ore (in our case, the minimum hourly divergences from the specified ratio of mixing white and dark limestone).

The initial step in our optimization model was the verification of the possibility of achieving planned production parameters after entering the input conditions. The program in this case determines objectivity of achieving the planned mining in the required ratio of mixing white and dark limestone, and the selection of workplace based on relations (1), (2). [2],[3]

$$\sum T_{p_i} \leq T_S.n \qquad (1)$$

$$T_{p_i} = t_{c_{p_i}}.p_{c_i} \qquad (2)$$

T_{pi} – time needed for unload from the workplace to meet the required volume of extraction,
T_{ci} – average time of one cycle at the workplace,
p_{ci} – number of cycles needed to meet the required volume of extraction,
T_S – effective time one shift,
n – number containers.

Demonstration of a positive assessment of basic conditions is shown in fig. 2 and a negative evaluation in fig. 3.

When failing fullfiling the basic conditions it is then necessary to look for a different combination of workstations or contiue working in this mode with the result that daily minig production plan won't be fullfilled.

In case of fullfiling the condition, program continues calculating and optimizing the distribution of containers into individual departments based on the following relations.

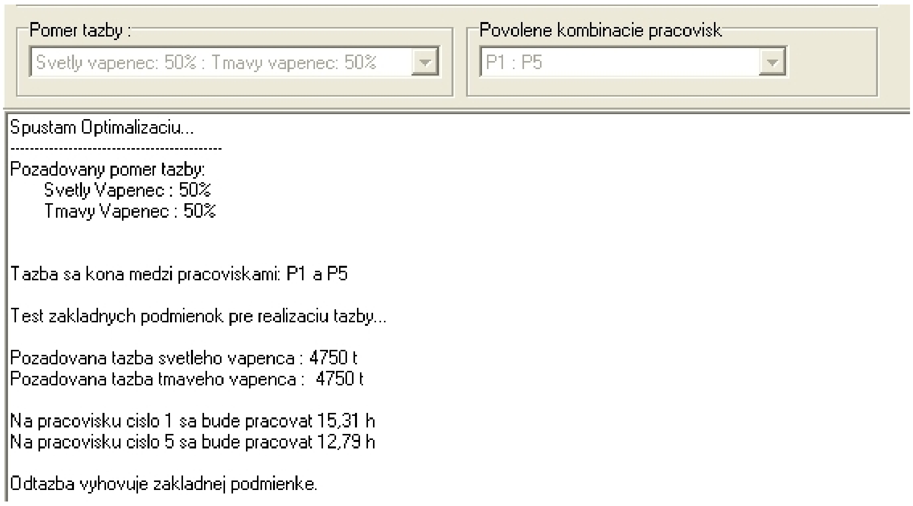

Fig. 2. Demonstration of a positive assessment of basic conditions, where the input data meet the specified conditions in achieving the planned mining production.

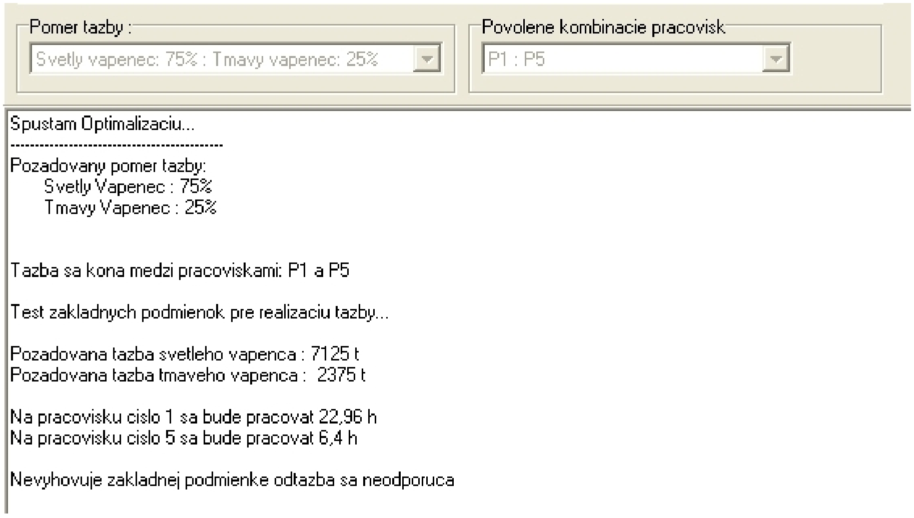

Fig. 3. Sample assessment for which the input data do not meet the specified conditions in achieving the planned mining production.

Calculation of hourly unload of container and transfer of raw ore

1. hour:

$$Q_v = n_1 . M_u \tag{3}$$

$$P_1 = Q_p - Q_v \tag{4}$$

Other hours:

$$Q_{v_i} = n_i . M_u \tag{5}$$

$$P_i = Q_{p_i} \pm P_{i-1} - (n_i . M_u) \tag{6}$$

Q_p – planed unload in a given hour [t]
Qv – performed unload of the container in an hour [t]

Qp_p – required hourly unload = $Q_p + P$ [t]
P – transport of the unload into the next hour [t]
P_1 – transport of the raw ore from the first hour [t]
i – an hour, for which is the parameter converted

Condition: n – number of cycles allowed in a given hour

When distributing cycles of the containers into individual workplaces a preferred workplace Px is preffered to the workplace Py, where the first cycle of container takes place. Further distribution of cycles the program enters in order to achieve the smallest divergence ratio of raw ore.

The containers carry out obligatory cycles and if there is still time to make the next cycle in a given hour again, a support cycle is used. If we do not have enough time to implement the next cycle in a given hour, container carries out a cycle, but it will end in the following hour.

Calculation of time used for optimization:

1. hour:

$$T_{v_1} = (n_{x_1}.T_{cp_x}) + (n_{y_1}.T_{cp_y}) \tag{7}$$

$$P_{r_1} = 60 - T_{v_1} - (T_{c_{bp}} - 0{,}1) \tag{8}$$

$$T_{z_1} = 60 - T_{v_1} - P_r \tag{9}$$

Other hours:

$$T_{v_i} = (n_{x_i}.T_{cp_x}) + (n_{y_i}.T_{cp_y}) + T_{z_{i-1}} \tag{10}$$

$$P_{r_i} = 60 + T_{z_{i-1}} - T_{v_i} - (T_{c_{bp}} - 0{,}1) \tag{11}$$

$$T_{z_i} = 60 + T_{z_{i-1}} - T_{v_i} - P_r \tag{12}$$

Tv – used time of the container in a given hour [min]
Tz – extra time of the container in a given hour [min]
Pr – downtime of the containers [min]
Nx – number of cycles of the containers to a workplace Px
Ny – number of cycles of the containers to a workplace Py
Tcp_x – duration of one cycle to the workplace Px [min]
Tcp_y – duration of one cycle to the workplace Py [min]
Tc_{bp} – cycle time for the closer workplace [min]
i – hour, for which the parameter is converted

<u>Calculation of hourly divergence from the planned hour production:</u>
Calculation of hourly divergence in (t).

$$X = (Q_{p_{px}} + Q_{p_{py}}) - (Q_{v_{px}} + Q_{p_{py}}) \tag{13}$$

Calculation of hourly divergence in (%).

$$X = \frac{100.((Q_{p_{px}} + Q_{p_{py}}) - (Q_{v_{px}} + Q_{v_{py}})}{(Q_{p_{px}} + Q_{p_{py}})} \tag{14}$$

X – hourly divergence [%]

Qp_p – required hourly unload = planned hourly unload ± transport of the raw ore from the previous hour [t]
Qp_{px} – required hourly mining from the workplace Px [t]
Qp_{py} – required hourly mining from the workplace Py [t]

<u>Calculation of the total divergence from the mining planned:</u>

1. hour:

$$X_{c_1} = (Q_p - Q_{v_1}).100 \tag{15}$$

Other hours:

$$X_{c_i} = (i.Q_p - \sum_{j=1}^{i} Q_{v_j}).100 \qquad (16)$$

Qp – planned unload in a given hour [t]
Qv – performed unload in a given hour [t]
Xc – total divergence [%]
i – hour, for which is the given parameter calculated

The program allows conversion of ideal parameters that are accurate, but in practical operation inapplicable because it counts also the incomplete cycles and so on. It is rather an example of the ideal parameters for comparison with real parameters, which are the main output for optimization and which are applicable for concrete solutions.

The results are given in the form a chart for an ideal conversion and also for a real conversion, in which there is also a possibility of displaying in a graphical form the individual cycles of the containers. (Fig. 4 - 6).

Tabulka Idealnych vysledkov experimentu

	Hodina 0 - 1	Hodina 1 - 2	Hodina 2 - 3	Hodina 3 - 4	Hodina 4 - 5	Hodina 5 - 6	Hodina 6 - 7	Hodina 7 - 8	Hodina 8 - 9	Hodina 9 - 9.5
Idealna tazba Px [t]	520	520	520	520	520	520	520	520	520	260
Idealna tazba Py [t]	480	480	480	480	480	480	480	480	480	240
Idealny pocet cyklov Px	8,25	8,25	8,25	8,25	8,25	8,25	8,25	8,25	8,25	4,12
Idealny pocet cyklov Py	7,61	7,61	7,61	7,61	7,61	7,61	7,61	7,61	7,61	3,8
cas k dispozicii Pa [min]	60	60	60	60	60	60	60	60	60	30
cas k dispozicii Pb [min]	60	60	60	60	60	60	60	60	60	30
cas k dispozicii Pc [min]	60	60	60	60	60	60	60	60	60	30
Idealny prenos materialu Px [t]	0	0	0	0	0	0	0	0	0	0
Idealny prenos materialu Py [t]	0	0	0	0	0	0	0	0	0	0
Idealny zvysny cas Pa	0	0	0	0	0	0	0	0	0	0
Idealny zvysny cas Pb	0	0	0	0	0	0	0	0	0	0
Idealny zvysny cas Pc	0	0	0	0	0	0	0	0	0	0
Idealne prestoje Pa	0	0	0	0	0	0	0	0	0	0
Idealne prestoje Pb	0	0	0	0	0	0	0	0	0	0
Idealne prestoje Pc	0	0	0	0	0	0	0	0	0	0
Povolena Odchylka (70 [t]) odtazby	0	0	0	0	0	0	0	0	0	0

Fig. 4. Example of a chart with the ideal conversion results.

Tabulka realnych vysledkov experimentu

	Hodina 0 - 1	Hodina 1 - 2	Hodina 2 - 3	Hodina 3 - 4	Hodina 4 - 5	Hodina 5 - 6	Hodina 6 - 7	Hodina 7 - 8	Hodina 8 - 9	Hodina 9 - 9.5	Suma
Pozadovana tazba Px [t]	520	536	552	505	521	537	553	506	522	278	5030
Pozadovana tazba Py [t]	480	519	495	534	510	486	462	501	477	213	4677
Vykonana odtazba z Px [t]	504	504	567	504	504	504	567	504	504	278	4940
Vykonana odtazba z Py [t]	441	504	441	504	504	504	441	504	504	189	4536
Pozadovane cykly Px	8	8	8	8	8	8	8	8	8	4	76
Pozadovane cykly Py	7	8	7	8	8	7	7	7	7	3	69
Moznost vyuzitia dalsieho cykla Px	0	0	1	0	0	0	1	0	0	1	3
Moznost vyuzitia dalsieho cykla Py	0	0	0	0	0	1	0	1	1	0	3
vyuzity cas Pa [min]	58,9	60,9	58,9	60,9	58,9	60,9	58,9	60,9	58,9	24,36	562,46
vyuzity cas Pb [min]	58,9	56,9	58,9	56,9	58,9	67,08	58,9	56,9	58,9	34,54	572,64
vyuzity cas Pc [min]	50,9	61,08	63,08	61,08	61,08	50,9	63,08	61,08	61,08	32,54	565,9
pocet cyklov Pa na Px/Py	4/1	5/0	4/1	5/0	4/1	5/0	4/1	5/0	4/1	2/0	42/5
pocet cyklov Pb na Px/Py	4/1	3/2	4/1	3/2	4/1	3/3	4/1	3/2	4/1	2/1	34/15
pocet cyklov Pc na Px/Py	0/5	0/6	1/5	0/6	0/6	0/5	1/5	0/6	0/6	1/2	3/52
Prestoje Pa [min]	0	0	0	0	0	0	0	0	0	7,54	7,54
Prestoje Pb [min]	0	0	0	0	0	0	0	0	0	3,18	3,18
Prestoje Pc [min]	0	0	0	0	0	1,71	0	0	0	2,39	4,1
prenos materialu Px [t]	16	32	-15	1	17	33	-14	2	18	0	148
prenos materialu Py [t]	39	15	54	30	6	-18	21	-3	-27	24	237
zvysny cas Pa [min]	1,1	0,2	1,3	0,4	1,5	0,6	1,7	0,8	1,9	0	9,5
zvysny cas Pb [min]	1,1	4,2	5,3	8,4	9,5	2,42	3,52	6,62	7,72	0	48,78
zvysny cas Pc [min]	9,1	8,02	4,94	3,86	2,78	10,17	7,09	6,01	4,93	0	56,9
Odchylka odtazby[%/t]	5,5%/55t	4,45%/47t	6,59%/69t	2,98%/31t	2,23%/23t	4,98%/51t	3,44%/35t	0,49%/5t	4,5%/45t	4,88%/24t	--------
Percentualna odchylka celkova	5,5%	2,34%	2,3%	0,77%	0,46%	0,85%	0,5%	0,06%	0,5%	0,25%	--------

Graf Close

Fig. 5. Example of a chart with real conversion results.

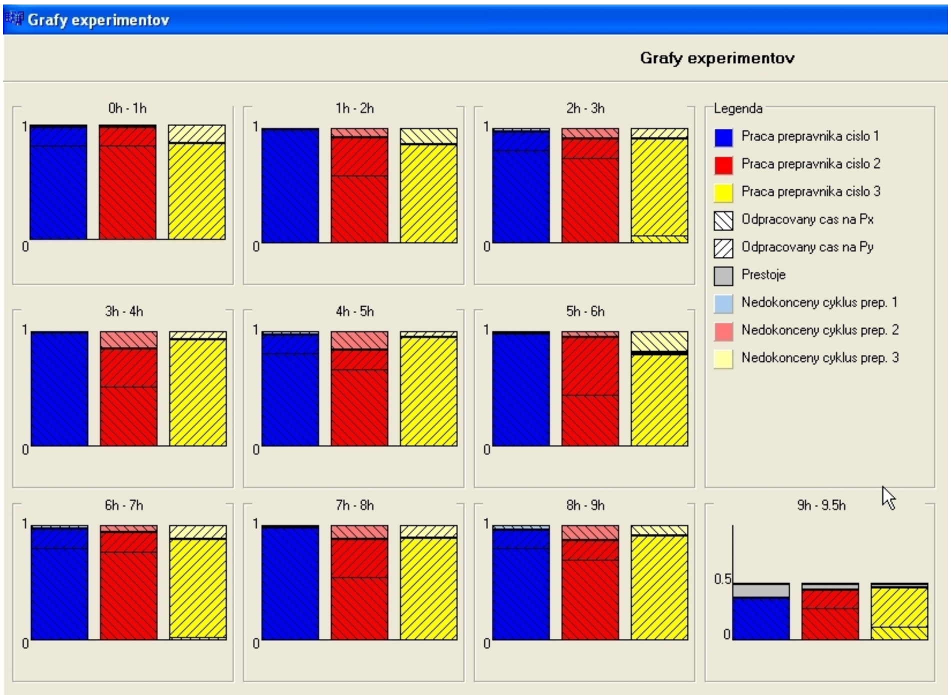

Fig. 6. Example of a graphic display of the individual work of the containers.

Conclusion

The optimization program is only an initial step towards a complex program for transport optimization in mines. It does not contain itself number of factors which are relevant in the process of optimization of the use of mechanization in the mining operation and represent further input and limited conditions for full optimization of interconnection of individual operations and processes realitzed by the extraction of raw materials, taking into account the conditions imposed by the refraction plant in the quality of raw materials.

On the other hand, program like this can be an excellent tool in managing transport in the mining operation and gives required information that are important in decision-making of the head-operator in order to maximize the usefulness of the individual transport mechanisms when required quality parameters of the output ore are clearly stated. This can then lead into financial saving, what might be in the current difficult economic situation an essential condition for the functioning of many firms operating in the field of mining industry of raw materials.

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References

[1] Čech J.: Počítačové modely na optimalizáciu dobývania ložísk, *Alfa Bratislava, 1990, ISBN 80-05-00623-3*

[2] Fabián J.: Povrchové dobývacie stroje a zariadenia, *Alfa Bratislava 1987, ISBN 63-745-87*

[3] Novák L., Puzder J.: Lomové dobývanie nerastných surovín časť II., *VŠT v Košiciach, Košice, 1988, ISBN 85-634- 88.*

[4] M.M.D.S. Vemba: Loading and transport system at SMC—optimization, *The South African Institute of Mining and Metallurgy, 2004. SA ISSN 0038–223X/3.00 +0.00.*

[5] Alarie, S., Gamache, M.: Overview of solution strategies used in truck dispatching systems for open pit mines, *International Journal of Surface Mining, Reclamation and Environment, vol. 16, no. 1, 2002. pp. 59–76.*

[6] Neonen, L.K., Graefe, P.W.U., Chan, A.W. Interactive computer model for truck/shovel operations in an open-pit mine, *Winter Simulation Conference. Proceedings of the 13th conference on Winter simulation, Atlanta, Georgia, vol. 1, 1981. pp. 133–139*.

[7] Sgurev, V., Vassilev, V., Dokev, N., Genova, K., Drangajov, S., Korsemov, C., Atanasov, A.: An automated system for real-time control of the industrial truck haulage in open-pit mines, *Institute of Industrial Cybernetics and Robotics, Sofia, Bulgaria, 2003. p. 1113*.

[8] Ramani, R.V.: Haulage system simulation analysis in surface mining, *SME publications, B.A. Kennedy, (ed.), 1990. p. 724–742*.

[9] Carmichael, D.G.: Shovel-truck queues: a reconciliation of theory and practice, *Constr. Mgmt. And Economics, vol. 4, 1986. pp. 161–177.*

[10] Shangtyao Y., Weishen, L., Maonan, C.: Production scheduling and truck dispatching of ready mixed concrete, *Transportation Research: Part E (1366-5545), vol. 44, no. 1, 2008. pp. 164-179*.