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STUDY ON FACTORS HAVING INFLUENCE UPON THE PRODUCTIVITY OF CYCLIC-FLOW-LINE TECHNOLOGY APPLIED IN OPEN PIT "ASAREL"

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ABSTRACT
The cyclic-flow-line-technology (CFLT) for mining of overburden has been introduced since 2000 in "Asarel-Medet". It's working is characterized by often interrupts with different continuance.
The stays of technological line has been studied. A review of factors having an influence upon the productivity has been made. A statistic working of data is used for a determination of the degree of significance of each of the investigated characteristics.
A comparative analysis has been used for the determination of the indexes having the most important influence upon the work of CFLT. A mathematical model has been developed with describing the connection between the studied indexes and the CFLT' s productivity.

INTRODUCTION

The cyclic–flow-line technology (CFLT) is most extensively applied at Asarel Medet Open Pit. The mine is the primary producer of copper and pyrite concentrates in Bulgaria, and one of the main producers in Europe. The processing complex is located on an area of 20 000 da close to the city of Panagyurishte (Bulgaira).

CFLT was introduced in the production process in 2000. This technology involves great variety of mining and transportation equipment and it was introduced for the first time in our country. The following machines are used: excavators "ЕКG"-8И, "ЕКG"-5А, "RH"-120C, "R"-994, front loader "CAT"- 992D, drills "SBS" – 250, trucks "BelAZ"-7519, "BelAZ"-75125, "BelAZ"-7522, "BelAZ"-7523, "CAT"-777C, "CAT"-777D, "O&K"-K95, "TR"-100, a stationary re-loading point equipped with screen and cone crusher "KRUPP", belt conveyors and spreader "VOEST-ALPINE".

The cyclic-flow-line is used for overburden haulage from "Asarel" Open Pit to the Western Dumpsite (fig. 1).

Factors influencing upon productivity of the CFLT

The mechanization in open pit "Asarel-Medet" works in various and variables conditions. For that reason the work of the mining machinery is characterized with often interrupts. Because of that there is a special interest in analyzing the work time structure, the kind of stays and their influence upon the machinery productivity using the CFLT for output of overburden.

The following are the main reasons for the interruption of the production process in an open pit area: the planned running repairs (PRR), the moving of mining machines, the different kinds of damages, blasting, weather conditions, physical-mechanical properties, rock compositions, the interruption of the work in next section and etc. All that allows that it could be accepted that the productivity of mining mechanization is influenced by numerous accidental factors. Therefore it has a probable character. The planned repairs have not been taken into account in this paper, because of the fact that they are known in advance, and they don't influence upon the productivity of CFLT.

Figure 1.

The main factors influencing upon the productivity of CFLT are given in a table 1. The values for 24 hours stays of mechanization in "Asarel-Medet" in 2001 have been used.

Statistical working of data

Some formulas of (Toncov, 1984) have been used for solving the concrete task of statistical working of data. The calculations have been done by "Statgraphics Plus" program. The used symbols are as follows:

- $\overline{X}$ - average;
- σ^2 - variance;
- σ - standard deviation;
- X_{min} – minimum value;

- X_{max} – maximum value;
- X_l – lower limit (95% confidence intervals);
- X_{up} - upper limit (95% confidence intervals);
- A_s – standard skewness;
- E_x – standard kurtosis;
- r - correlation;
- R – rank correlation;

The final results of data statistic working are given in tables 1 and 2. The analysis shows that average overburden 24 h productivity of CFLT is 33079 t.

The mining quantities of overburden for 24 hours are in interval from 31507,7 t to 34651,7 t in 95 % of the cases.

The correlation analysis is used to study connection between a productivity of CFLT and the factors given above. The calculations have been done by "Statgraphics Plus" program using the entrance data. The results are given in tables 1 and 2. The found correlations and rank correlations are given in table 3.

It can be seen from the made correlation analysis that every studied index has a weak influence upon a productivity of CFLT. On the other side it can be seen the accumulation of influence by the different factors upon the system's work. That is why the further efforts are directed to the investigation of the joint influence between given indexes and productivity of CFLT.

Determination of the degree of importance of the studied indexes

The correlation analysis has been used for determination of the multiple correlation between indexes given in table 3. The calculations are made by "Statgraphics Plus" program using the entrance data. The receiving multiple correlation is 0,665.

Table 1 Found statistical indexes of data.

Studied indexes	Characteristic				
	Number of data	X_{min}	X_{max}	$\overline{X}$	σ
Productivity of CFLT, t per 24 h	290	2800	65500	33079,7	13601,6
Stays for material, h	290	0	12,45	1,328	1,916
Stays for rocks with bigger size than crusher size in hopper, h	290	0	2,43	0,19	0,4
Stays for metal detector switched off, h	290	0	4,38	0,261	0,539
Stays for voltage falls, h	290	0	3,98	0,153	0,522
Stays for weather, h	290	0	8,97	0,214	0,99
Stays for blasting, h	290	0	2,47	0,247	0,605
Stays for personnel change, h	290	0	5,54	0,552	1,172
Stays for crusher damage, h	290	0	11,6	0,991	2,135
Stays for screen choked and overfilled conveyer belt, h	290	0	3,35	0,146	0,459
Stays for overfilled delivery chute, h	290	0	13,79	0,457	1,774
Stays for conveyer belt vulcanization, h	290	0	21,9	0,514	2,619
Stays for conveyer belts 1, 2 and 3 removal and conveyer belt's disconector switched off, h	290	0	21,1	1,191	2,717
Stays for spreader damage, h	290	0	17,87	0,475	2,043

Table 2 Found statistical indexes of data.

Studied indexes	Characteristic				
	σ^2	$X_{ляв}$	$X_{десен}$	A_s	E_x
Productivity of CFLT, t per 24 h	185003522,6	31507,7	34651,7	- 1,069	- 2,223
Stays for material, h	3,672	1,107	1,55	22,507	40,405
Stays for rocks with bigger size than crusher size in hopper, h	0,16	0,144	0,236	23,747	45,898
Stays for metal detector switched off, h	0,291	0,199	0,323	32,724	92,61
Stays for voltage falls, h	0,273	0,093	0,214	29,505	68,46
Stays for weather, h	0,98	0,099	0,328	42,75	148,387
Stays for blasting, h	0,366	0,177	0,317	15,121	10,668
Stays for personnel change, h	1,374	0,417	0,688	16,956	17,57
Stays for crusher damage, h	4,577	0,774	1,238	22,713	38,771
Stays for screen choked and overfilled conveyer belt, h	0,211	0,093	0,199	29,375	68,986
Stays for overfilled delivery chute, h	3,147	0,252	0,662	39,204	122,311
Stays for conveyer belt vulcanization, h	6,859	0,211	0,817	40,08	120,21
Stays for conveyer belts 1, 2 and 3 removal and conveyer belt's disconector switched off, h	7,384	0,877	1,506	33,672	90,334
Stays for spreader damage, h	4,172	0,239	0,712	43,999	148,601

Table 3 Correlation, rank correlation and β coefficient of the studied indexes.

Studied indexes	Symbol	Productivity of CFLT, t per 24 h		
		r	R	β
Stays for material, h	X_1	-0,192	0,149	-0,348
Stays for rocks with bigger size than crusher size in hopper, h	X_2	0,097	0,27	0,009
Stays for metal detector switched off, h	X_3	0,053	0,185	0,012
Stays for voltage falls, h	X_4	-0,032	0,058	-0,132
Stays for weather, h	X_5	--0,104	-0,135	-0,173
Stays for blasting, h	X_6	-0,11	-0,123	-0,148
Stays for personnel change, h	X_7	-0,008	-0,173	-0,121
Stays for crusher damage, h	X_8	-0,173	0,012	0,257
Stays for screen choked and overfilled conveyer belt, h	X_9	0,048	0,093	0,021
Stays for overfilled delivery chute, h	X_{10}	-0,18	-0,114	0,227
Stays for conveyer belt vulcanization, h	X_{11}	-0,277	-0,213	0,362
Stays for conveyer belts 1, 2 and 3 removal and conveyer belt's disconector switched off, h	X_{12}	-0,264	-0,058	0,35
Stays for spreader damage, h	X_{13}	-0,2	0,058	0,284

This shows that there is an expressive linear dependence between studied indexes. It is express by multiple regression equation.

$$Y = 45325{,}6 - 2473{,}82X_1 + 309{,}737X_2 + 295{,}25X_3 - 3433{,}61X_4 - 2381{,}64X_5 - 3321{,}52X_6 - 1411{,}16X_7 - 1638{,}37X_8 - 611{,}662X_9 - 1739{,}39X_{10} - 1881{,}38X_{11} - 1749{,}95X_{12} - 1892{,}58X_{13} \quad (1)$$

where:
Y – productivity of CFLT, t per 24 h;
X_i – indexes noticed in table 3;

Multiple regression allows influence of different factors upon productivity of CFLT to be measured. For this purpose it is used so called β coefficients (Четыркин, 1982).

They are found by the following equation:

$$\beta_I = a_i.\left(\frac{\sigma_{X_i}}{\sigma_Y}\right) \quad (2)$$

where:
a_i – coefficient in correlation equation;
β_I – correlation received after calculation;
σ_{X_i} - standard deviation of variable X_i;
σ_Y - standard deviation of Y for each factor;

The calculated coefficients β_I for each of the factors are given in table 3. Using them the following arrangement of the indexes according to their degree of influence upon the productivity of CFLT has been used:

1. Stays for conveyer belt vulcanization – 100%;
2. Stays for conveyer belts 1, 2 and 3 removal and conveyer belt's disconector switched off – 97%;
3. Stays for material – 96 %;
4. Stays for spreader damage – 78 %;
5. Stays for crusher damage – 71 %;
6. Stays for overfilled delivery chute – 63 %;
7. Stays for weather – 48 %;
8. Stays for blasting – 41 %;
9. Stays for voltage falls – 36 %;
10. Stays for personnel change – 33 %;
11. Stays for screen choked and overfilled conveyer belt – 6 %;
12. Stays for metal detector switched off – 3 %;
13. Stays for rocks with bigger size than crusher size in hopper – 2 %;

It is accepted that index having the heist value of coefficient β has the relative weight 100 %. The relative weight of the other factors is expressed through it.

A mathematical model describing connection between study indexes and productivity of CFLT

Figure 2 describes change of multiple regression in depending on number of factors having influence upon productivity. For example the influence of the first six indexes arranged by a degree of significance is determined (table 3).

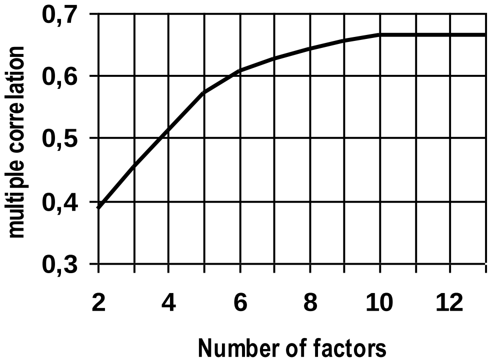

Figure 2. The change of multiple correlation depending on number of factors

The follow conclusions are done by chart from fig. 2:
- The first six factors have the most important influence upon the multiple correlation;
- The influence of the other four indexes is less;
- The last three factors almost don't influence upon multiple correlation;

The received model by determining the above – mention 13 factors according to their grouping from 1 to 13 will be difficult to use. That is why the most important factors from 1 to 6 will be used.

The correlation analysis is used for describing a connection between productivity and chosen factors. The calculations are done by a "STATGRAPHICS PLUS" program using the entrance data. The received model is:

$$Y = 41879,7 - 2118,63X_1 - 1750X_{11} - 1570,29X_{12} - 1679,35X_{13} - 1722,19X_8 - 1552,45X_{10} \quad (3)$$

Multiple correlation is 0,606. This shows that there is an obviously expressed linear dependence between the productivity of technological line for output of overburden and the studied indexes.

Forecasting the change of productivity by the received model

The studied model is used for forecasting of productivity of CFLT by indexes influencing upon it.

The forecasted results, received by the model and the results, observed for the period January – March 2001 are given in figure 3.

The evaluation of the developed model can be done by absolute percentage mistake ($e_{pr.m.}$) (Shim.J. 2000). It is calculated by a formula:

$$E_{pr.m.} = \frac{100}{n}\sum_{i=1}^{n}\frac{|Y_i - f(x_i)|}{Y_i}, \% \quad (4)$$

where:

Y_i – observe value;
$f(X_i)$ – forecasted value;
n – number of data;

The model including the all 13 factors is used for comparison. The forecasted results received by equation (1) and the observed values for the period January – March are shown on figure 4.

The percentage mistake for each of the models is calculated for the whole studied period. It is 34 % for equation (1) and 36 % for equation (2).

The analysis shows that a model (2) forecasts productivity of CFLT has almost the same accuracy as a model (1), in spite of the less number of used factors in model (2). Therefore the equation (2) is better for practical calculation.

CONCLUSION

The basic factors influencing upon the mining of overburden in open pit "Asarel-Medet" are studied in this paper. The significance of each of the indexes influencing upon the productivity of CFLT is determined by a correlation analysis. Six are the most significant factors received after suitable arrange of all 13 factors. Therefore the mathematical model describing the studied connection is received by them. The absolute percentage mistake of the model is 36%.

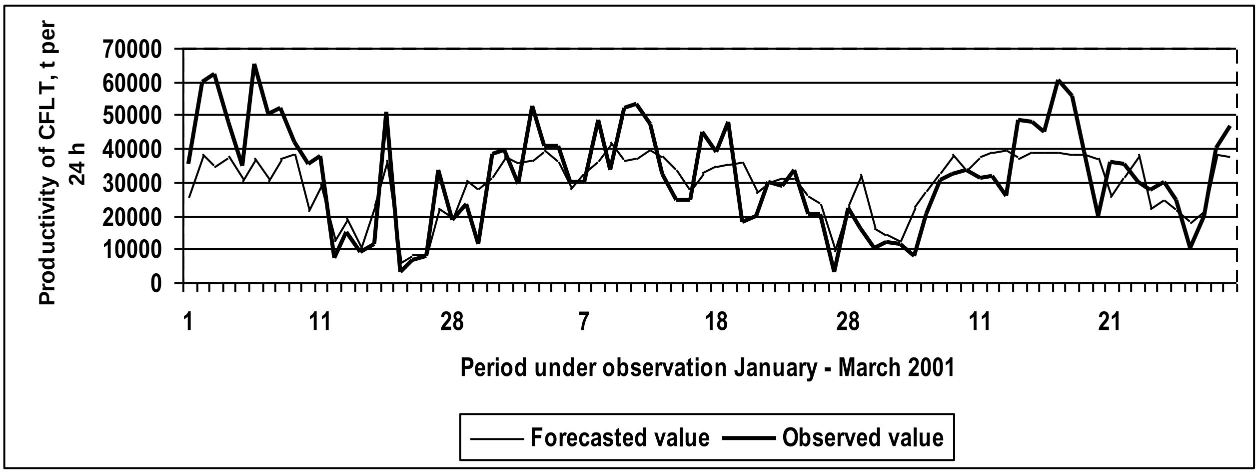

Figure 3. A change of open pit productivity during the period January – March 2001

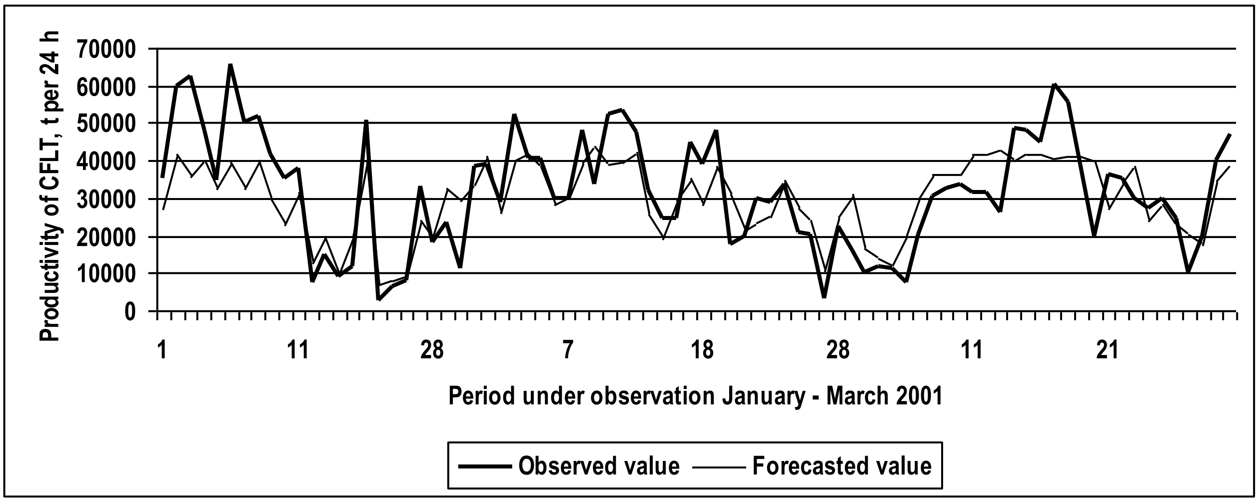

Figure 4. A change of open pit productivity during the period January – March 2001

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