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SIMULATION ANALYSIS OF RELATIONSHIP BETWEEN PRODUCTION COST AND NATURAL ENVIRONMENT OF IRON ORE EXTRACTION AND PROCESSING

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МОДЕЛЮВАННЯ ЗВ'ЯЗКІВ МІЖ СОБІВАРТІСТЮ ТА ПРИРОДНИМИ УМОВАМИ ДОБУВАННЯ Й ПЕРЕРОБКИ ЗАЛІЗНИХ РУД

Purpose. Establishing the substantial relationship between production cost and natural environment of iron ore extraction and processing from the perspective of cost management at an ore mining and processing enterprise.

Methodology. The results are obtained by applying general scientific and specialized research methods (comparison, generalization, typology, abstraction, correlation analysis, mathematical modelling in economics) as well as systematic and logical approaches related to implementation of the theory of cost management.

Findings. With regard to industry characteristics of ore mining and processing enterprise activities in iron ore extraction and processing, a complex of natural factors of influence on product cost based on technological process stages has been developed. Within the complex, mining and geological conditions of field development, mineral resources properties, and ecological factors are distinguished. Nature of the effect of natural factors on product cost based on technological process stages is determined and a theoretical model as a three-level interaction system is developed according to costing items and technological process stages. Formalized models of relation of the level of current expenditures under costing items to certain natural factors are constructed using correlation analysis techniques. Strength of relationship in the developed models is determined and the essence and importance of certain natural factors in changing production cost of mining and concentrating production have been substantiated. Current expenditures of an ore mining and processing enterprise were readjusted under influence of certain natural factors. Based on practical check it was proved that natural factors are to be working objects in the process of cost management at an ore mining and processing enterprise while extracting and processing iron ore.

Originality. Originality of the research lies in the definition of the characteristics and influence of natural environment on cost behaviour in the process chain of iron ore extraction, processing, concentration and agglomerating taking into account the difference between actual levels of business environment performance evaluation and those specified in the enterprise's plans.

Practical value. Practical value of the obtained results lies in their update to the level of methodological materials and applied tools which can be used by ore mining and processing enterprises for the effective cost management.

Keywords: *production cost, natural environment, mining and concentrating production, technological process stages, relationship, simulation analysis*

Introduction. Production of iron ore raw material at ore mining and processing enterprises is cost-intensive due to a wide range of factors among which natural environment being specific for the industry draws particular attention. Its negative impact results in increasing expenses at every technological process stage of mining and concentrating production. This particularly regards iron ore extraction where the negative effect of mining and geological conditions of field development is the most significant. Following considerable increase in

production cost for iron ore products, ore mining and processing enterprises (OMPE) often neglect recognizing the natural environment as that which is to be a working object in the process of cost management [1, 2]. This range of problems is of strategic importance since ore mining and processing enterprises of Ukraine are powerful integral parts of its export potential.

Analysis of the recent research and publications. The process of paradigm development regarding costing and cost management has been longstanding. However, cost behaviour in mining and concentrating production continues attracting attention of even a greater number of analysts and experts. Various aspects of OMPE cost behaviour have been studied in works by contemporary scientists, in particular, by Ye. V. Afanasiev, I. A. Belkina, O. H. Vagonova, M. I. Ishchenko, O. M. Kondratiuk, Ye. V. Kochura, M. M. Kurylo, I. I. Maksymova, S. V. Maksymov, N. M. Maliuha, I. V. Mamchuk, A. A. Mutieva, V. Ya. Nusinov, O. V. Plotnikov, A. M. Turylo, I. V. Khimko, M. S. Chetveryk and others. They have considered issues regarding deficiency detection in strategic cost management of a mining enterprise [3], planning, forecasting and modelling of current expenditures of an iron ore mining and processing enterprise [4], cost production formation for iron-ore concentrate dressing [5], role of iron ore production cost in developing economic strategies and investment projects for mining plants [6, 7], development of co-ordinate method of calculating mining costs [8].

However, a large number of research studies have hardly considered or partially considered the influence of the natural environment on the level of production cost of iron ore extraction and processing at ore mining and processing enterprises.

Unsolved aspects of the problem. Current research in cost management by ore mining and processing enterprises is primarily based on studying the differentiated subsystem which involves scientific and technical, financial, organisational, social and economic as well as legal factors [3–8]. This is a major drawback since neglecting the stationary subsystem, which includes such factors as mining and geological conditions, physical and mechanical and chemical properties of mineral resources and ecological factors, results in decreasing efficiency of cost management by OMPE due to failure to take into account particular operational conditions in the process and, therefore, is one of the causes of increasing production cost at every stage of mining and concentrating production. Thus, failure to maintain consistency in strategies for cost management because of lack of estimating the influence of natural environment on current expenditures relating to extracting and processing iron ore is the scientific problem which requires urgent solution.

Objectives of the article. The work aims at the following:

- to determine the nature of the natural environment influence on expenditure levels of iron ore extraction and processing at OMPE according to relevant stages of mining and concentrating production;

- to define the level of cost production dependence on partial natural environment behaviour at every stage using correlation analysis;

- to substantiate recognition of natural factors as belonging to working objects at every stage of mining and concentrating production.

Presentation of the main research. Iron ore extraction and processing is a technologically complicated, multi-stage and expensive process. Moreover, considering the fact that Kryvorizkyi Iron Ore Basin (Kryvbas) has been worked for over 130 years, the number of topical issues which require urgent solution is constantly increasing. It is obvious that their solution is possible provided available financial resources. However, owners of Kryvbas ore mining and processing enterprises are reluctant to invest their funds into social and economic and technological development, which they explain by a number of unfavourable external factors which constantly accompany political and economic spheres of the country. They mostly prefer to decrease production expenditures on account of such "popular measures" as staff rightsizing, saving regarding certain complex expenditures, etc. That is why formation of the cost management system which would provide expenditure optimisation at every stage of the technological chain of iron ore raw material production and consider the influence of both differentiated and stationary factor subsystems is to be a primary task for OMPE of the iron ore basin under study.

Since the 21st century the development of Kryvbas mining and processing enterprises have been characterised by increasing intensity of field development; therefore, the influence of the natural environment on their cost production formation is increasing to a greater extent and is complicating the cost management process [2].

Under such conditions estimation of natural environment effect is to be the major stage while developing cost management strategy; natural factors are to become direct working objects.

In our opinion, specifics of the cost management system at mining and processing enterprises lies in existence of steady essential relations between production cost and natural environment of iron ore extraction and processing which reveal themselves differently at certain stages of iron ore production (Table 1).

Methods for determining natural environment influence on production cost at certain stages and on financial results of OMPE's operations have been considered by us earlier [1].

To estimate relations between production cost and natural environment of iron ore extraction and processing at certain technological process stages, a theoretical research model was developed which presents a three-level interaction system; at the first level the relationship between the natural environment and expenditures according to set tasks will be determined; level two defines the relationship between expenditures according to set tasks and costing items while level three – between individual costing items and production cost of a technological process stage.

Table 1

Occurrence of natural environment at certain stages of iron ore mining and concentrating production of [1]

Production process stage at OMPE	Natural environment groups
1. Iron ore extraction	Mining and geological conditions of field development, mineral resources properties and ecological factors
2. Iron ore breaking	Mineral resources properties and ecological factors
3. Iron ore concentration	Mineral resources properties and ecological factors
4. Iron ore agglomeration	Chemical properties of mineral resources and ecological factors

Table 2 shows essential relations between production cost and natural factors which occur in mining and concentrating production [1], as well as symbol legends of properties for the following development of formalised models.

Table 2 presents the natural factors influencing current expenditures at certain stages which were selected according to reconciliation of their potential mining with services of the engineering director and economic department of "Pivdennyi Ore Dressing Integrated Plant" PubJSC as well as with Professor A. I. Katalents, Doctor of Geological and Mineralogical Sciences, and according to the following rules of correlation analysis: evaluation of factors based on paired correlation coefficient eliminating one of the interrelated factors; elimination of factors which are related to production cost (level 2 factors); evaluation of factor significance according to Student criterion [9].

Considering the fact that it is difficult to apply techniques of deterministic analysis for most factors while determining relation, it is proposed to use correlation analysis techniques.

Thus, regarding the methods of the analysis of defining the natural environment influence on production cost at certain stages [1] and taking into account the information in Table 2, the following will be the basic models in further research

$$y = f(x_1, ..., x_n);$$
$$z = f(y_1, ..., y_m);$$
$$c = f(z_1, ..., z_k).$$

With the help of the correlation analysis and "Statgraphicsplus 5.1" software, formalised models of relation of production cost and natural environment of iron ore extraction and processing were obtained, which were developed based on the costing items at "Pivdennyi Ore Dressing Integrated Plant" PubJSC over the period of 2000–2015.

While developing the models, exogenous factors were checked regarding preciseness, uniformity and relevance of information to the normal probability law. Based on evaluation of every factor by standard deviation value and variation coefficient, non-typical values were eliminated from the primary statistical array.

Determination of types of stochastic analysis model is done according to the results of evaluating diagrams which show the correlation field regarding the dispersion of factor values in relation to production cost values. It has been established that the theoretical regression line can be a straight line which indicates the linear nature of relations between the characteristics under analysis. At the same time, correspondence of the selected model type to the actual data was checked based on the comparative evaluation of different models according to Fisher's ratio, test factors of average error of approximation and value of multiple determination coefficients.

The models for levels 1 and 2 of the factor analysis substantiated under these conditions are presented as regression equations and their modifications in Table 3.

The data in Table 3 show that the samples of natural factors, which are included in the research of the stationary subsystem of "Pivdennyi Ore Dressing Integrated Plant" PubJSC, consist of 20 factors taken from different groups. The analysis results show that natural environment and expenditures according to set tasks as well as expenditures according to set tasks and costing items are closely related. This is proved by obtained values of coefficients of multiple correlations within Level 2 of the analysis.

The models obtained for Level 2 of the factor analysis are presented as regression equations and their modifications in Table 4.

The data of Table 4 are integrated and show the results of the factor analysis of Level 3 which were obtained using the results of the first two stages and give evidence of essential influence of the natural environment on both certain costing items and expenditures according to a certain technological process stage and full production cost of corresponding iron ore products. The evaluation of correlation relationship showed that its value exceed 96 % at every stage of mining and concentrating production, which proves rather close relationship between the factors which represent the natural environment influence on the production cost of iron ore extraction and processing.

The natural environment influence is the highest at the first and last stages, which are extraction of iron ore and its agglomeration.

The estimation of the quality of the obtained models according to the coefficient of multiple determination showed that the change of the production cost by over 92 % at every technological process stage is explained by the influence of the natural factors which were included in these models. Thus, all the models contain only the most essential factors influencing the production cost of the process.

Substantiation of relation factor validity in the obtained models and appropriateness of their practical application allowed evaluating the natural environment influence on the production cost at every stage of mining and concentrating production with sufficient probability. The results of the evaluation are summarized in Table 5.

Table 2

Relationship between iron ore production cost and natural environment and symbol legends of properties

Results		Level 3 factors		Level 2 factors		Level 1 factors	
Production cost at a stage	c'	Costing items	z	Expenditures according to set tasks	y	Partial natural factors	x
1. Production cost of extracting 1 tn of iron ore	c'_1	1.1. Accessory material	z_1	1.1.1. Expenses on drilling bits	y_1	Abrasiveness	x_1
				1.1.2. Explosive consumption	y_2	Strength of rocks (according to M. M. Protodiakonov)	x_2
		1.2. Electrical power and engineering targets	z_2	1.2.1. Power consumption for crushing of oversize	y_3	Breakability	x_3
						Hardness of rocks	x_2
						Porosity	x_4
						Density	x_5
				1.2.2. Power consumption for thrusting of oversize	y_4	Poisson's ratio	x_6
						Young's modulus	x_7
		1.3. Interplant movement of raw stock, materials and products	z_3	–	–	Depth of ore body formation	x_8
				–	–	Unit specific gravity of iron ore	x_9
						Unit specific gravity of draw rock	x_{10}
		1.4. Indirect wages	z_4	–	–	Content of harmful impurities and toxic agents in ore	x_{11}
				–	–	Gas wastes	x_{12}
				–	–	Dust formation capacity	x_{13}
		1.5. Reclamation of mining and development	z_5	–	–	Release ratio	x_{14}
		1.6. Others	z_6	1.6.1. Expenses on water pumping	y_5	Field water–cut	x_{15}
				1.6.2. Impost for land use	y_6	Volume of overburden removal	x_{16}
2. Production cost of breaking 1 tn of iron ore	c'_2	2.1. Electrical power and engineering targets	z_7	–	–	Breakability	x_3
						Hardness of rocks	x_2
						Porosity	x_4
						Density	x_5
						Magnetic and electromagnetic properties	x_{17}
		2.2. Indirect wages	z_8	–	–	Content of harmful impurities and toxic agents in ore	x_{11}
				–	–	Gas wastes	x_{12}
				–	–	Dust formation capacity	x_{13}
3. Production cost of 1 tn of concentrated product	c'_3	3.1. Electrical power and engineering targets	z_9	–	–	Magnetic and electromagnetic properties	x_{17}
				–	–	Hardness of rocks	x_2
				–	–	Breakability	x_3
				–	–	Porosity	x_4
				–	–	Density	x_5
		3.2. Indirect wages	z_{10}	–	–	Content of harmful impurities and toxic agents in ore	x_{11}
				–	–	Gas wastes	x_{12}
				–	–	Dust formation capacity	x_{13}
4. Production cost of 1 tn of agglomerate	c'_4	4.1. Material expenses	z_{11}	–	–	Concentrated product moisture	x_{18}
						Iron content of concentrated product	x_{19}
						Content of harmful substances	x_{20}
		4.2. Indirect wages	z_{12}	–	–	Content of harmful impurities and toxic agents in ore	x_{11}
				–	–	Gas wastes	x_{12}
				–	–	Dust formation capacity	x_{13}

Table 3

Formalised models of relationship between production cost and natural environment of iron ore extraction and processing developed according to stages of mining and concentrating production for levels 1 and 2 of the factor analysis

Level 1 of the factor analysis		Level 2 of the factor analysis			
Basic model $y = f(x_1, ..., x_n)$	Correlation coefficient, %	Basic model $z = f(y_1, ..., y_m)$	Modifications	Modified model	Correlation coefficient, %
Production cost of extracting 1 tn of iron ore					
$y_1 = -2.44 + 2.48x_1$	73.17	$z_1 = -138.133 + 5.34y_1 + 11.15y_2$	$z_1 = -138.133 + 5.34 \cdot (-2.44 + 2.48x_1) + 11.15 \cdot (-257.78 + 16.13x_2)$	$z_1 = -3025.4 + 13.24x_1 + 179.85x_2$	84.01
$y_2 = -257.78 + 16.13x_2$	50.04				
$y_3 = -9.6 + 0.83x_3 + 0.15x_2 - 12.23x_4 + 1.44x_5$	85.50	$z_2 = -0.63 + 1.6y_3 + 17.48y_4$	$z_2 = -0.63 + 1.6(-9.6 + 0.83x_3 + 0.15x_2 - 1.23x_4 + 1.44x_5) + 17.48(-0.57 + 1.08x_6 + 0.054x_7)$	$z_2 = -25.95 + 1.33x_3 + 0.24x_2 - 1.97x_4 + 2.3x_5 + 18.88x_6 + 0.94x_7$	97.52
$y_4 = -0.57 + 1.08x_6 + 0.054x_7$	52.93				
–		–	–	$z_3 = 204.21 + 0.44x_8 + 8.71x_9 + 16.76x_{10}$	86.78
–		–	–	$z_4 = 29.16 + 3.6x_{11} + 2.25x_{12} + 6.52x_{13}$	91.07
–		–	–	$z_5 = 29.16 - 37.86x_{14}$	77.00
$x_5 = -32.38 + 9.75x_{15}$	67.95	$z_6 = 0.117 + 3.68y_5 + 0.98x_6$	$z_6 = 0.117 + 3.68 (-32.38 + 9.74x_{15}) + 0.98(-59.03 + 6.67x_{16})$	$z_6 = -176.9 + 35.84x_{15} + 6.54x_{16}$	99.42
$x_6 = -59.03 + 6.67x_{16}$	69.06				
Production cost of breaking 1 tn of iron ore					
–		–	–	$z_7 = 5.23 + 1.02x_3 + 0.45x_2 - 1.64x_4 + 1.95x_5 - 13.2x_{17}$	99.42
–		–	–	$z_8 = 11.2 + 0.62x_{11} + 1.04x_{12} + 0.95x_{13}$	81.07
Production cost of 1 tn of concentrated product					
–		–	–	$z_9 = 3.06 + 0.9x_3 + 0.38x_2 - 1.61x_4 + 1.83x_5 - 11.4x_{17}$	88.22
–		–	–	$z_{10} = 8.85 + 0.51x_{11} + 0.8x_{12} + 0.27x_{13}$	97.52
Production cost of 1 tn of agglomerate					
–		–	–	$z_{11} = 112 + 5.23x_{18} - 8.45x_{19} + 3.64x_{20}$	88.22
–		–	–	$z_{12} = 12.96 + 0.26x_{11} + 0.58x_{12} + 0.31x_{13}$	97.52

Table 4

Formalised models of relationship between production cost and natural environment of iron ore extraction and processing developed according to costing items and stages of mining and concentrating production for level 3 of the factor analysis

Result (production cost)	Level 3 of the factor analysis			
	Basic model $c = f(z_1, \ldots, z_k)$	Modifications	Modified model	Correlation coefficient, %/ determination coefficient, %
Production cost of extracting 1 tn of iron ore	$c'_1 = 3.25 + 1.22z_1 + 1.13z_2 + 6.98z_3 + 0.45z_4 + 0.13z_5 + 0.164z_6$	$c'_1 = 3.25 + 1.22(-2926.15 - 158.3x_1 - 179.85x_2) + 1.13(-25.95 + 1.33x_3 + 0.24x_2 - 1.97x_4 + 2.3x_5 + 18.88x_6 + 0.94x_7) + 6.98(-204.21 + 0.44x_8 + 8.71x_9 + 16.76x_{10}) + 0.45(2916 + 3.6x_{11} + 2.25x_{12} + 6.52x_{13}) + 0.13(29.16 - 37.87x_{14}) + 1.64(-176.9 + 35.84x_{15} + 6.54x_{16})$	$c'_1 = -5288.44 - 193.13x_1 - 219.15x_2 + 1.5x_3 + 2.23x_4 + 2.60x_5 + 20.54x_6 + 1.06x_7 + 3.07x_8 + 60.8x_9 + 116.98x_{10} + 1.62x_{11} + 1.01x_{12} + 2.93x_{13} - 4.92x_{14} + 58.78x_{15} + 10.72x_{16}$	99.82/99.64
According to technological process stage				
According to full introduction cost				
Production cost of breaking 1 tn of iron ore	$c'_2 = 0.95 + 0.42z_7 + 0.05z_8$	$c'_2 = 0.95 + 0.42(5.23 + 1.02x_3 + 0.45x_2 - 1.64x_4 + 1.95x_5 - 13.2x_{17}) + 0.05(11.2 + 0.62x_{11} + 1.04x_{12} + 0.92x_{13})$	$c'_2 = 3.71 + 0.43x_3 + 0.19x_2 - 0.69x_4 + 0.82x_5 - 5.54x_{17} + 0.03x_{11} + 0.05x_{12} + 0.05x_{13}$	96.42/92.97
According to technological process stage				
According to full introduction cost	$c_2 = 4.2 + 1.22z_1 + 1.13z_2 + 6.98z_3 + 0.45z_4 + 0.13z_5 + 1.64z_6 + 0.42z_7 + 0.05z_8$	–	$c_2 = -5284.73 - 19.13x_1 - 219.5x_2 + 1.93x_3 - 2.92x_4 + 3.42x_5 + 20.54x_6 + 1.06x_7 + 3.07x_8 + 60.8x_9 + 116.98x_{10} + 1.65x_{11} + 1.06x_{12} + 2.98x_{13} - 4.92x_{14} + 58.78x_{15} + 10.72x_{16} - 5.54x_{17}$	
Production cost of 1 tn of concentrated product	$c'_3 = 4.96 + 1.89z_9 + 0.23z_{10}$	$c'_3 = 4.96 + 1.89(3.06 + 0.9x_3 + 0.38x_2 - 1.61x_4 + 1.83x_5 - 11.4x_{17}) + 0.23(8.85 + 0.51x_{11} + 0.8x_{12} + 0.27x_{13})$	$c'_3 = 2.78 + 0.9x_3 + 0.38x_2 - 1.61x_4 + 1.83x_5 - 11.4x_{17} + 0.51x_{11} + 0.8x_{12} + 0.27x_{13}$	96,53/93,18
According to technological process stage				
According to full introduction cost	$c_3 = 916 + 1.22z_1 + 1.13z_2 + 6.98z_3 + 0.45z_4 + 0.13z_5 + 1.64z_6 + 0.42z_7 + 0.05z_8 + 1.89z_9 + 0.23z_{10}$	–	$c_3 = -4271.95 - 193.13x_1 - 218.52x_2 + 2.83x_3 - 4.53x_4 + 5.25x_5 + 20.54x_6 + 1.06x_7 + 3.07x_8 + 60.8x_9 + 116.98x_{10} + 2.16x_{11} + 1.86x_{12} + 3.25x_{13} - 4.92x_{14} + 58.78x_{15} + 10.72x_{16} - 16.94x_{17}$	
Production cost of 1 tn of agglomerate	$c'_4 = 109.56 + 21.6z_{11} + 9.4z_{12}$	$c'_4 = 109.56 + 21.6(112 + 5.23x_{18} - 8.45x_{19} + 3.64x_{20}) + 9.4(12.96 + 0.26x_{11} + 0.59x_{12} + 0.31x_{13})$	$c'_4 = 2650.58 + 112.97x_{18} - 182.52x_{19} + 78.62x_{20} + 2.44x_{11} + 5.45x_{12} + 2.91x_{13}$	96.7/93.51
According to technological process stage				
According to full introduction cost	$c_3 = 118.72 + 1.22z_1 + 1.13z_2 + 6.98z_3 + 0.45z_4 + 1.13z_5 + 1.64z_6 + 0.42z_7 + 0.05z_8 + 1.89z_9 + 0.23z_{10} + 21.6z_{11} + 9.4z_{12}$	–	$c_4 = -1621.37 - 193.13x_1 - 218.52x_2 + 2.83x_3 - 4.53x_4 + 5.25x_5 + 20.54x_6 + 1.06x_7 + 3.07x_8 + 60.8x_9 + 116.98x_{10} + 4.6x_{11} + 7.31x_{12} + 6.16x_{13} - 4.92x_{14} + 58.78x_{15} + 10.72x_{16} - 16.94x_{17} + 12.97x_{18} - 182.52x_{19} + 78.62x_{20}$	

Table 5

Integration of data on the natural environment influence on production cost at certain stages of mining and concentrating production

Environmental factors	Measuring unit	Legend	Factor change tendency	Changing production cost of 1 tn of iron ore, %
Iron ore extraction (producte – crude ore)				
Abrasiveness	mg	x_1	increase	+12.31
Strength of rocks (according to M.M. Protodiakonov)	MPa	x_2	increase	+14.00
Breakability	cm^3	x_3	increase	+0.96
Porosity	%	x_4	increase	–1.42
Density	g/cm^3	x_5	increase	+1.69
Poisson's ratio	H	x_6	increase	+13.1
Young's modulus	$Eg*10^{-5}kg/cm^2$	x_7	increase	+0.68
Depth of ore body formation	m	x_8	increase	+1.95
Unit specific gravity of iron ore	tn/m^3	x_9	decrease	+3.89
Unit specific gravity of draw rock	tn/m^3	x_{10}	decrease	+7.46
Content of harmful impurities and toxic agents in ore	%	x_{11}	increase	+1.03
Gas wastes	tn	x_{12}	increase	+1.35
Dust formation capacity	g/cm^3	x_{13}	increase	+1.87
Release ratio	m^3/t	x_{14}	increase	–3.14
Field water-cut	m^3	x_{15}	increase	+37.49
Volume of overburden removal	m^3	x_{16}	increase	+6.83
Total influence of factors				**+100.05**
Iron ore breaking (product – crushed ore)				
Strength of rocks (according to M. M. Protodiakonov)	MPa	x_2	increase	+0.11
Breakability	cm^3	x_3	increase	+0.25
Porosity	%	x_4	increase	–0.36
Density	g/cm^3	x_5	increase	+0.03
Content of harmful impurities and toxic agents in ore	%	x_{11}	increase	+0.02
Gas wastes	tn	x_{12}	increase	+0.06
Dust formation capacity	g/cm^3	x_{13}	increase	+0.03
Magnetic and electromagnetic properties	%	x_{17}	increase	–3.24
Total influence of factors				**–3.16**
Iron ore concentration (concentrated product)				
Content of harmful impurities and toxic agents in ore	%	x_{11}	increase	+0.08
Gas wastes	tn	x_{12}	increase	+0.11
Dust formation capacity	g/cm^3	x_{13}	increase	+0.06
Magnetic and electromagnetic properties	%	x_{17}	increase	–10.11
Total influence of factors				**–9.86**
Iron ore agglomeration (product – agglomerate)				
Content of harmful impurities and toxic agents in ore	%	x_{11}	increase	+5.45
Gas wastes	tn	x_{12}	increase	+10.6
Dust formation capacity	g/cm^3	x_{13}	increase	+5.62
Concentrated product moisture	%	x_{18}	increase	+4.10
Iron content of concentrated product	%	x_{19}	increase	–38.42
Content of harmful substances	%	x_{20}	increase	+3.16
Total influence of factors				**–9.49**

According to the information in Table 5, the influence of the natural factors which occur at different technological process stages of iron ore extraction and processing at "Pivdennyi Ore Dressing Integrated Plant" PubJSC can be described in the following way:

1) the stage of iron ore extraction:

- the influence on production cost of crude ore of almost every factor included into sampling, which makes 16 factors taken from different groups, is negative except for the influence of release and porosity factors;

- within the study period, the growth of production cost of 1 tn of extracted ore due to the defined factor sampling made 100.05 %;

2) the stage of iron ore breaking:

- the natural environment sampling which was involved in stationary subsystem research at this stage included 8 factors;

- the effect of six factors, which were studied in the sampling, is negative; as for the porosity and magnetic and electromagnetic properties, their influence on production cost of ore breaking is positive;

- in general, the influence of the model factors at the breaking stage resulted in decreasing production cost by 3.16 %;

3) the stage of iron ore concentration:

- the sampling of the natural environment involved in stationary subsystem research at the given stage included 4 factors;

- the effect of three factors of the general sampling is negative while the influence of the magnetic and electromagnetic properties factor on the production cost of concentrated product was positive;

- generally, the influence of the model factors led to decreasing production cost of the concentrated product by 9.86 %, which occurred due to one factor only whose part makes ¼ of the total sample at the concentration stage;

4) the stage of agglomeration:

- the sampling of the natural environment involved in stationary subsystem research at this stage included 6 factors;

- the influence of most factors studied in the given sampling on the production cost of iron ore agglomeration is negative;

- at the same time increasing iron content of concentrated product contributed to decreasing production cost of the agglomerate whose size exceeded negative effect of other factors;

- taking into account positive and negative influence of endogenous factors of the model at the given stage of mining and concentrating production, the general decrease in agglomerate production cost made 9.49 %.

The results of the evaluation of natural environment influence on production cost of iron ore extraction and processing according to certain technological process stages of mining and concentrating production make it possible to adjust expenses under influence of a certain natural factor with non-variable value of others. (Table 6 was developed for "Pivdennyi Ore Dressing Integrated Plant" PubJSC).

The information of Table 6 shows that most natural factors which affect formation of current expenditures have compensating or synergetic influence. That is why under independent effect elimination of negative influence of one or another natural factor will result in decreasing expenditures of certain type (costing items) at the respective stage of mining and concentrating production. In most cases this effect can be achieved due to additional capital investment to bring partial factor influence under control.

Conclusion. Summarizing the conducted research on simulating the relationship between production cost and natural environment of iron ore extraction and processing, it is necessary to consider the following:

- production cost and natural environment of iron ore extraction and processing are closely related. The relationship can be both direct and inverse depending on the effect of the factor under consideration;

- the influence of most natural factors on production cost of iron ore extraction and processing is negative, which contributes to increasing current expenditures;

- the largest influence of the natural environment is observed at the first and last stages of mining and concentrating production (extraction and agglomeration), which results in uncontrolled rise of iron ore production cost;

- the negative influence of natural factors at the extraction stage is conditioned mostly by the effect of mining and geological conditions of development of deposits of useful minerals while at the agglomeration stage – by the effect of ecological factors, mineral resources properties and concentrated product moisture.

Thus, the obtained research results show that to achieve tactical and strategic targets of OMPE it is necessary to develop a cost management system which will consider natural environment influence in the process of iron ore production cost formation at every technological process stage. Thus, the natural factors are to become working objects in the process of cost management at an ore mining and processing enterprise.

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Table 6

Adjustment of current expenditures of an ore mining and processing enterprise under influence of certain natural factors

Influence type	Cost behaviour	Influence factors at technological process stages			
		extraction	breaking	concentration	agglomeration
Compensating	Elimination of negative effect of a certain factor will result in decreasing expenditures of respective type (costing items) provided additional capital investment is applied to bring its effect under control	Unit specific gravity of iron ore, unit specific gravity of draw rock, content of harmful impurities and toxic agents in ore, gas wastes, field water-cut, dust formation capacity, volume of overburden removal	Strength of rocks, porosity, content of harmful impurities and toxic agents in ore, gas wastes, dust formation capacity	Harmful impurities and toxic agents in ore, gas wastes, dust formation capacity	Harmful impurities and toxic agents in ore, gas wastes, dust formation capacity, content of harmful substances
Synergetic	Elimination of negative effect of a certain factor will not immediately result in decreasing expenditures of respective type (costing items) and will require additional capital investment to bring its effect under control	Abrasiveness, strength, breakability, density, depth of ore body formation	Breakability, density	–	Concentrated product moisture
Independent	Elimination of negative effect of a certain factor will result in decreasing expenditures of respective type (costing items) and will not require additional capital investment to bring its effect under control	Poisson's ratio, Young's modulus	–	–	–

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Мета. Встановлення суттєвих зв'язків і характеру взаємодії між собівартістю та природними умовами добування й переробки залізних руд у контексті управління витратами гірничо-збагачувального комбінату.

Методика. Результати отримані шляхом застосування загальнонаукових і спеціальних методів дослідження (порівняння, узагальнення, типології, абстракції, кореляційного аналізу, економіко-математичного моделювання), а також системного й логічного підходів, пов'язаних із реалізацією теорії управління витратами.

Результати. З урахуванням галузевих особливостей діяльності гірничо-збагачувального комбінату з добування й переробки залізних руд сформовано комплекс природних факторів впливу на собівартість продукції за технологічними переділами. У складі даного комплексу виокремлено гірничо-геологічні умови розробки родовищ, властивості корисних копалин, екологічні фактори. Визначено характер впливу природних факторів на собівартість продукції за технологічними переділами й розроблена теоретична модель у вигляді трирівневої системи взаємозв'язків, побудованої за калькуляційними статтями витрат і технологічними переділами. Із використанням прийомів кореляційного аналізу побудовані формалізовані моделі залежності рівня поточних витрат за калькуляційними статтями від дії окремих природних факторів. Визначена тіснота зв'язків у розроблених моделях і доведено їх суттєвість та роль окремих природних факторів у зміні собівартості продукції гірничо-збагачу-

вального виробництва. Проведене коригування поточних витрат гірничо-збагачувального комбінату в умовах впливу окремих природних факторів. На основі практичної перевірки доведено, що природні фактори мають бути об'єктами впливу у процесі управління витратами на гірничо-збагачувальному комбінаті з добування й переробки залізних руд.

Наукова новизна. Полягає у визначенні характеру й сили впливу природних факторів на зміну витрат у технологічному ланцюжку добування залізних руд, їх подрібнення, збагачування та агломерації у зв'язку з розбіжністю фактичних рівнів показників оцінки умов діяльності з прийнятими у проекті (планах) підприємства.

Практична значимість. Практичне значення отриманих результатів полягає у їх доведенні до рівня методичних узагальнень і прикладного інструментарію, що можуть бути використані гірничо-збагачувальними комбінатами для ефективного управління витратами.

Ключові слова: *собівартість, природні фактори, гірничо-збагачувальне виробництво, переділи, взаємозв'язки, моделювання*

Цель. Установление существенных связей и характера взаимодействия между себестоимостью и природными условиями добычи и переработки железных руд в контексте управления затратами горно-обогатительного комбината.

Методика. Результаты получены путем использования общенаучных и специальных методов исследования (сравнения, обобщения, типологии, абстракции, корреляционного анализа, экономико-математического моделирования), а также системного и логического подходов, связанных с реализацией теории управления затратами.

Результаты. С учетом отраслевых особенностей деятельности горно-обогатительного комбината по добыче и переработке железных руд сформирован комплекс природных факторов влияния на себестоимость продукции по технологическим переделам горно-обогатительного производства. В составе данного комплекса выделены горно-геологические условия разработки месторождений, свойства полезных ископаемых, экологические факторы. Определен характер влияния природных факторов на себестоимость продукции по технологическим переделам и разработана теоретическая модель в виде трехуровневой системы взаимосвязей, построенной по калькуляционным статьям затрат и технологическим переделам. С использованием приемов корреляционного анализа построены формализованные модели зависимости уровня текущих затрат по калькуляционным статьям затрат от действия отдельных природных факторов. Определена теснота связей в разработанных моделях и доведена их существенность и роль отдельных природных факторов в изменении себестоимости продукции горно-обогатительного производства. Проведена корректировка текущих затрат горно-обогатительного комбината в условиях влияния отдельных природных факторов. На основе практической проверки доказано, что природные факторы должны быть объектами влияния в процессе управления затратами на горно-обогатительном комбинате по добыче и переработке железных руд.

Научная новизна. Состоит в определении характера и силы влияния природных факторов на изменение затрат в технологической цепочке добычи железных руд, их дробления, обогащения и агломерации в связи с несовпадением фактических уровней показателей оценки условий деятельности с принятыми в проекте (планах) предприятия.

Практична значимость. Практическое значение полученных результатов состоит в их доведении до уровня методических обобщений и прикладного инструментария, которые могут быть использованы горно-обогатительными комбинатами для эффективного управления затратами.

Ключевые слова: *себестоимость, природные факторы, горно-обогатительное производство, переделы, взаимосвязи, моделирование*

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