Journal of Engineering and Applied Sciences 13 (7): 1624-1631, 2018
ISSN: 1816-949X

Methods for the Reduction of Loss and Optimization Processes Open Pit Mining Operations When Mining Man-Made Deposits Formed by Sections

Argimbaev Kaerbek Rafkatovich and Kristina Vladimirovna Mironova
Saint-Petersburg Mining University, 21 Line V.O., 2, 199106 St. Petersburg, Russia Federation

Abstract: Exploitation of a man-made deposit formed by sections should be conducted with a minimum number of technological operations in order to improve the technical and economic performance of the enterprise involved in its development. This study describes methods for reducing the losses that arise during maintenance of a man-made deposit formed by sections, using a pull shovel or a walking dredge, the dependence of linear approximations of the faces of the walking dredge, dumpers installation diagram for loading while processing man-made raw materials within the sections. A mathematical model is provided that describes open-pit mining process flow during the development of a man-made deposit obtained by the method of linear programming. The research results allow involving man-made deposits with valuable minerals and at minimal cost.

Key words: Man-made deposit formed by sections, pull shovel, walking dredge, loss, mathematical mode, installation

INTRODUCTION

Currently, at least 95% of all mined ores undergo a milling process. Integrated use of mineral raw materials in concentrating mills should be increased by introduction of process charts, new reagents, tailings re-treatment for metals recovery and the use of non-metallic parts as well as by application of the most advanced technology (Kholodnyakov and Argimbayev, 2014).

Development of milling refuse is of great environmental and economic importance. In cost effectiveness analysis, it is necessary to take into account not only the obtainment of additional products but cost reduction for creation and operation of tailing dumps, refuse storage, prevention or reduction of damage from environmental contamination by concentrating mills refuse as well (Arriagada *et al.*, 2009; Argimbaev and Kholodjakov, 2016; Kholodjakov and Argimbaev, 2014).

When the assay of tailings decreases, even by the hundredths percent, a significant effect can be achieved because of huge production volumes and cost reduction due to crushing and grinding operation cost reduction which accounts for 40-50% of all costs for conventional ore processing. When tailings are processed, these expenditures will disappear, since, the tailings have been already crushed and opened for almost any type of processing (Arvas *et al.*, 2013; Borgegard and Rydin, 1989).

In a number of cases when developing a man-made deposit, losses are unavoidable, for example when replacing amortized extraction and loading equipment, using various types of extraction and loading equipment, using one type of extraction and loading equipment but with different specifications, etc.

The need to eliminate losses and completeness of extraction can be caused by various factors: development of man-made deposits containing valuable and rare commercial components, changes in the requirements for quality and quantity of extracted man-made raw materials when off-balance reserves become profitable, changes in the country's economy or in international commodity markets (Borgegard and Rydin, 1989).

Therefore, the elimination of losses is of top priority in the development of the man-made deposit formed by sections. It should be noted that additional measures require involvement of additional equipment or changes in the parameters of the man-made deposit being formed which may lead to an increase in the cost of man-made raw materials extraction.

MATERIALS AND METHODS

During the research, a modern approach to solving the set tasks was used, namely advanced laboratory equipment and methods of domestic and international level.

An integrated research method was used to solve the said tasks: an analytical method which includes: an assessment of the prerequisites of resource-saving, low-cost, efficient and high-performance technologies for man-made raw materials extraction *in situ* method

Corresponding Author: Argimbaev Kaerbek Rafkatovich, Saint-Petersburg Mining University, 21 Line V.O., 2, 199106 St. Petersburg, Russia Federation

which includes: collection, analysis and generalization of the results of mining practice in given and similar conditions, carrying out mine survey of the faces of the walking dredge, mathematical analysis: probability theory and mathematical statistics, the approximation analysis was carried out using the Mathematica 11 program by Wolfram, synthesis of the results of private research in various fields of science (Pivovarova and Makhovikov, 2016; Argimbaev, 2016).

RESULTS AND DISCUSSION

In the course of the research, loss reduction methods were developed which are carried out in the following way. Flatting out slope angles of the bench of a section under development to the bench face angles of the walking dredges (Fig. 1).

Having carried out the mine survey of the faces of the walking dredge under research and processed its results, we obtained graphs of empirical linear equations (East-horizontal distance (l) which characterizes the O_x axis and height-the depth of the excavation (h_k) which is the O_y) (Fig. 2).

Analyzing the results of the correlation and variance analyzes, the likelihood estimation criteria (AIK, BIK, adjusted R^2) and the graphs constructed, it is fair to say that the nature of linear equations fully describes the part of mine under research and it can be taken for further calculations. Therefore, the part under research is represented by a linear equation which has the following form Eq. 1:

$$y = -k.x + b \qquad (1)$$

Where:

k = The empirical coefficient characterizing the angle of slope of the face of the walking dredge and depending on its model
b = The equation constant

Having formulated and solved the system of linear equations of faces of the walking dredge and the slope angles of rocky walls, we have got the volume of the required fill in i-th section as follows Eq. 2:

$$V_i = \left(\frac{f.(f+2b)}{2k_1} + \frac{2f.(-y_2-b-k_2.x_2)+f^2}{2k_2} + \frac{(-f).(-y_0^2-k_0^1.x_2)-f^2}{k_0^1} \right).L, m^3 \qquad (2)$$

Where:

b	=	The means equation constant
(x, y^1_0) and (x_2, y^2_0)	=	The mean coordinates of slope angles of walls from rocky overburden in the i-th section
$f = H^S$|; k_1, k_2	=	The mean empirical coefficients describing the angle of slope of the face of the walking dredge (of 1st and 2nd respectively), depending on its model
L	=	The means length of i-th section at the bottom (m)
k	=	The means coordinate of the location of the 2nd walking dredge along the O_y axis
k^1_0	=	The empirical coefficient that characterizes the angle of slope of the face of the rocky overburden in the section treated

If the same type of the extraction-and-loading equipment is used, the area and volume of fill in the i-th section will be Eq. 3 and 4:

$$S_i = f.\left(\frac{f-y_2}{k_1} - x_2 \right) + \frac{(-f).(-y_0^2-k_0^1.x_2)-f^2}{k_0^1}, m^2 \qquad (3)$$

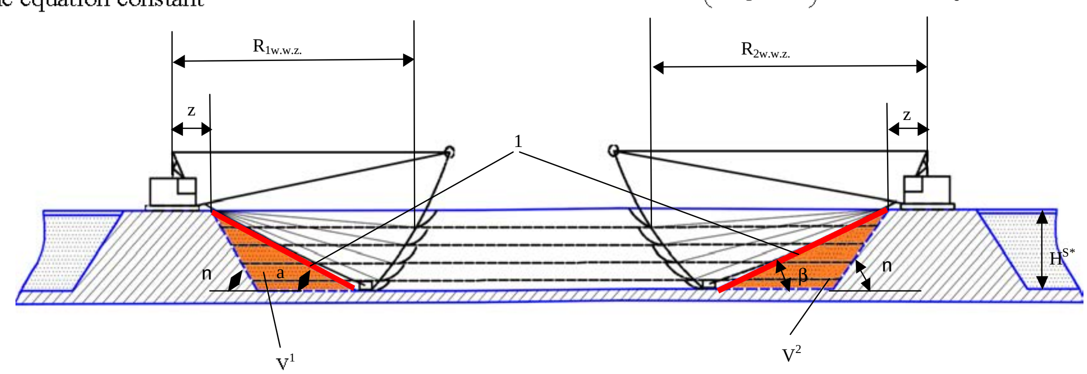

Fig. 1: Section development when flatting out slope angles of walls from rocky overburden in i-th section to the bench face angles of the walking dredges: H^S: Section Height (m); $R_{1w.w.z.}$: Radius of the working zone of the 1st dredge (m); $R_{2w.w.z.}$: Radius of the working zone of the 2nd dredge (m); z: safe distance to the bench crest (m); V^1, V^2, the volume of the required fill (m^3); 1: part of the faces of the walking dredge under research; φ: slope angles of walls from rocky overburden (degrees); α, β: the angles of the part of the faces under research (degrees)

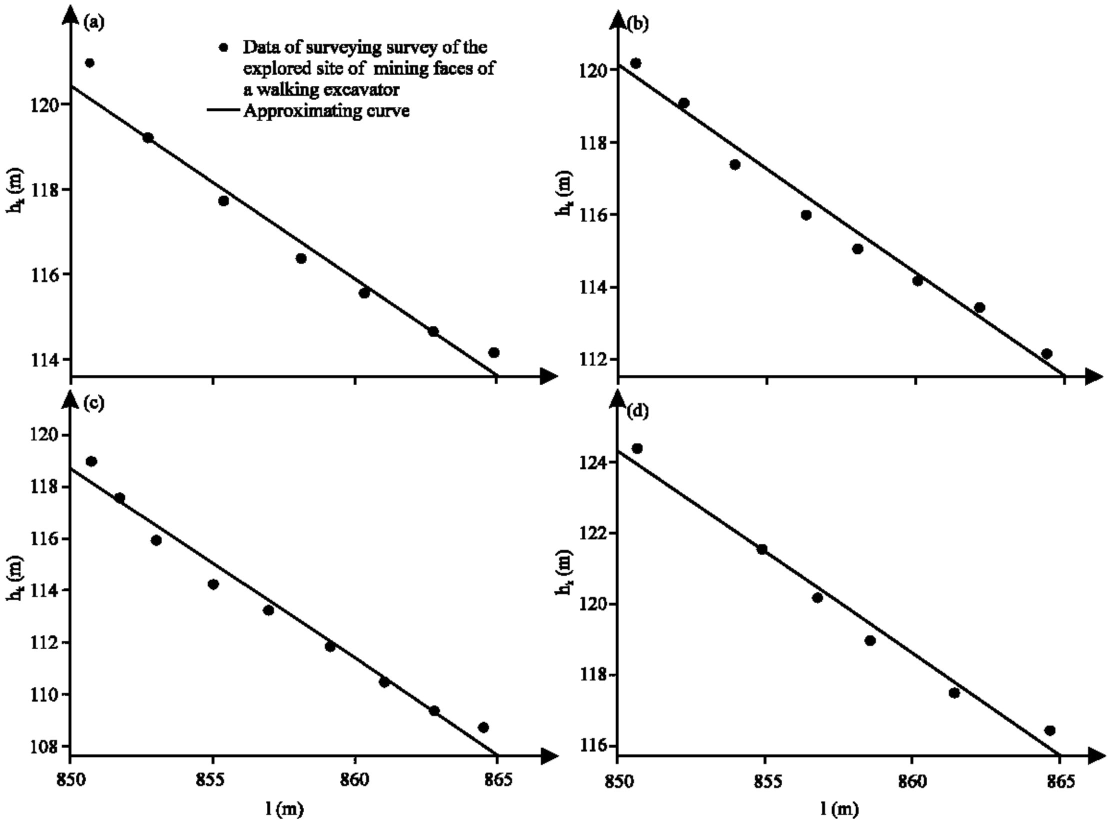

Fig. 2: Graphs of linear approximations of the faces of the walking dredge. a) Face No. 1; b) Face No. 2; c) Face No. 3; d) Face No. 4; h_k: the depth of the excavation; l: horizontal distance

$$V_i = S_i.L, m^3 \tag{4}$$

Due to the fact that the integral limits depend on the height of a section, the data of the area and volume formulas can be used to determine the required fill within the section for dredges being at the same level and at different degrees of the dredges (above or below each other).

Creation of crossovers in sections and placement of bulldozers therein for advancing the remai ning man-made raw materials to the working zone of the extraction and loading equipment (Fig. 3 and 4)

In order to use this method, the bases of sections should have sufficient bearing capacity to ensure the movement of bulldozers and operations security.

Advancing of losses arising due to the crossing of working areas of the dredge should be carried out for a distance equal to the length of the base of the loss triangle that would allow to get the remainder of man-made materials (Fig. 5).

Length of the base of the loss triangle, arising due to crossing of working areas, should be determined according to Eq. 5-8. For walking dredge when $j_1 \neq j_2$:

$$L^w_{base.} = ctg\ j_1.H^s\text{-}ctg\ j_1.y_2 + ctg\ j_2.H^s\text{-}ctg\ j_2.y_2,\ m \tag{5}$$

when $j_1 = j_2 = j$ (angel of natural slope of man-made raw materials):

$$L^w_{base.} = 2.ctg\ j.H^s\text{-}2.ctg\ j.y_2,\ m \tag{6}$$

For pull shovel when $j_1 \neq j_2$:

$$L^p_{base.} = ctg\ j_1.(H^s + a)\text{-}ctg\ j_1.y_2 + ctg\ j_2.(H^s + a)\text{-}ctg\ j_2.y_2,\ m \tag{7}$$

When $j_1 = j_2 = j$ (angel of natural slope of man-made raw materials):

$$L^p_{base} = 2.ctg\ j.(H^s + a)\text{-}2.ctg\ j.y_2,\ m \tag{8}$$

Then, the distance of advancing of losses will be Eq. 9 and 10. For walking dredge:

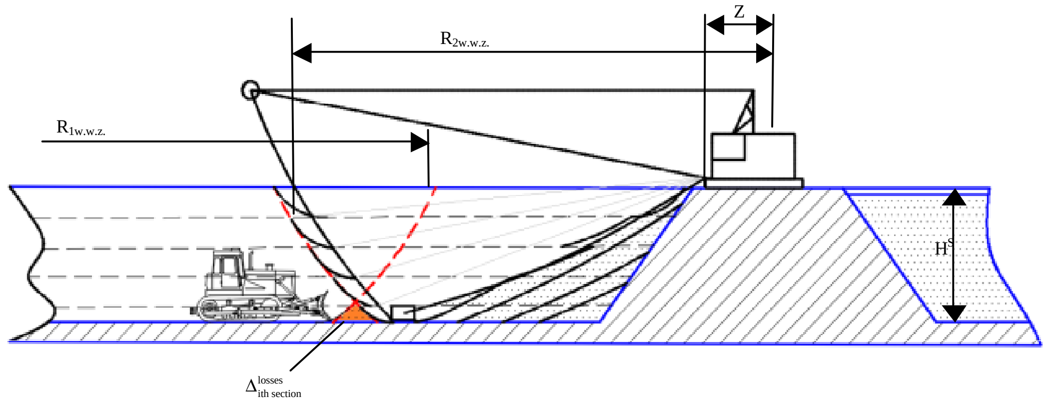

Fig. 3: Advancing of the remaining material by a bulldozer to the working zone of the walking dredge: H^S: Section Height (m); $R_{1w.\ w.\ z}$: Radius of the working zone of the 1st dredge (m); $R_{2w.\ w.\ z}$: Radius of the working zone of the 2nd dredge (m); $\Delta^{losses}_{ith\ section}$: rate of losses when crossing the working zones of the dredges in the ith section; z: safe distance to the bench edge (m)

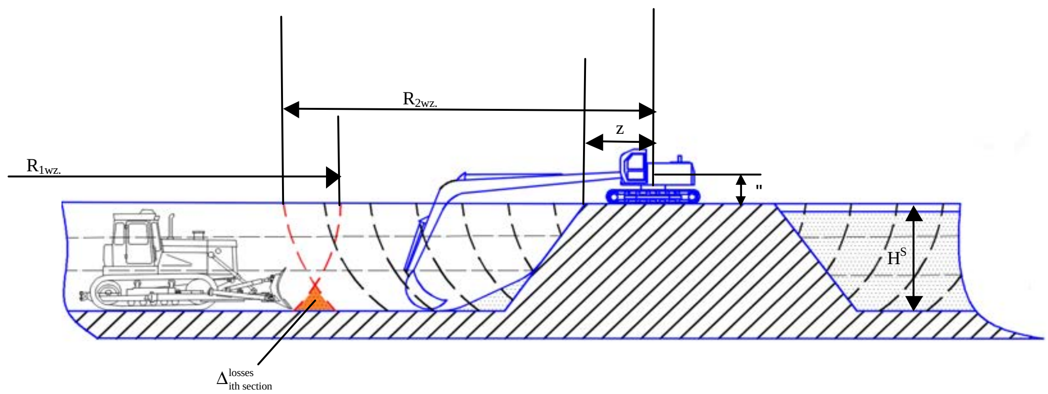

Fig. 4: Advancing of the remaining man-made materials by a bulldozer to the working zone of the pull shovel: $R_{1wz.}$: working zone radius of the 1st pull shovel (m); $R_{2wz.}$: working zone radius of the 2nd pull shovel (m); $\Delta^{losses}_{ith\ section}$: rate of losses when crossing the working zones of the pull shovels in the i-th section; H^c: Section Height (m); z: safe distance to the bench edge (m)

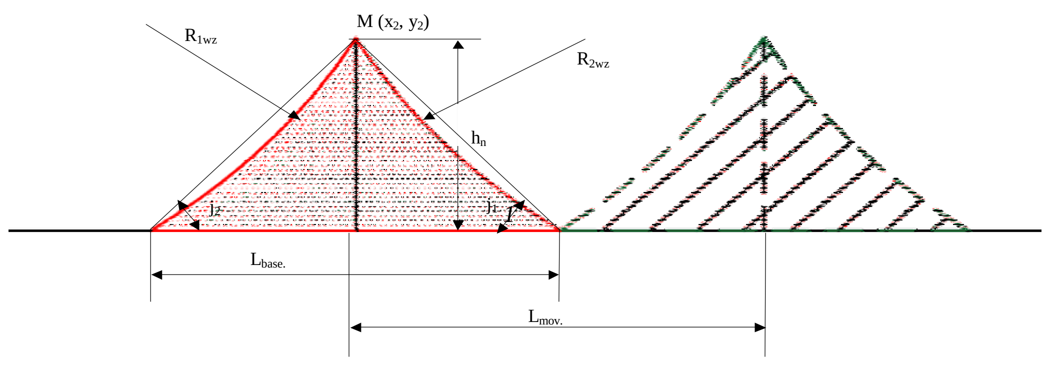

Fig. 5: Diagram of the losses, arising as a result of the crossing of working areas of the dredges: h_l: Loss Height (m); $R_{1wz.}$: Radius of the working zone of 1st dredge (m); $R_{1wz.}$: radius of the working zone of 2nd dredge (m); M (x_2, y_2): coordinate of crossing of working zones of dredges (m); $L_{base.}$: length of the base of the loss triangle (m); $L_{mov.}$: distance of moving of loss of man-made materials (m); j_1, j_2: angles of surface slope, forming the loss triangle (m)

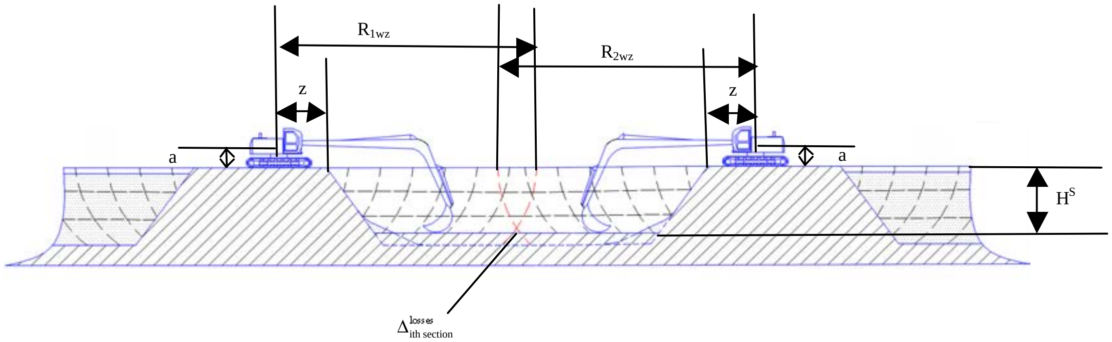

Fig. 6: Development of the section of shallower depth by pull shovels: R_{1wz}: radius of the working zone of the 1st pull shovel (m); R_{2wz}: radius of the working zone of the 2nd pull shovel (m); $\Delta^{losses}_{ith\ section}$: rate of losses when crossing the working zones of the pull shovels in the ith section; H^c: Section Height changed (m); z: safe distance to the bench edge (m)

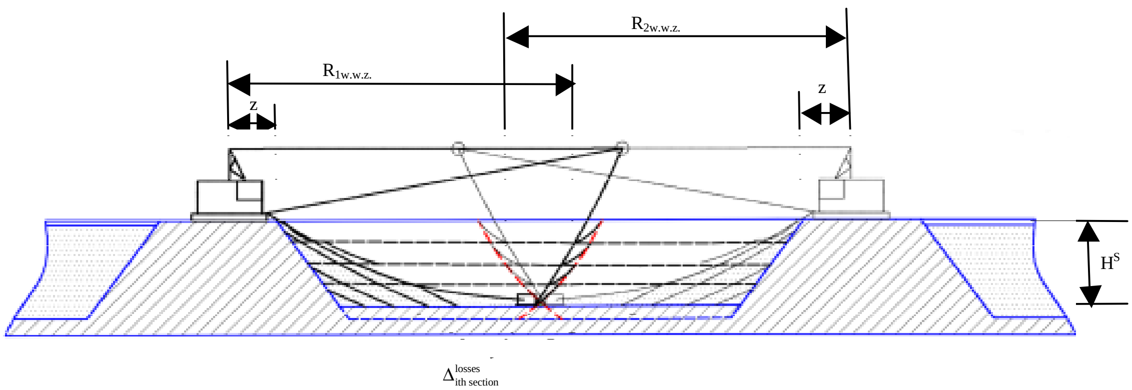

Fig. 7: Development of the section of shallower depth by walking dredges: $R_{1w.w.z.}$: radius of the working zone of the 1st dredge (m); $R_{2w.w.z.}$: radius of the working zone of the 2nd dredge (m); $\Delta^{losses}_{ith\ section}$: rate of losses when crossing working zones of dredges in the ith section as well as material, non-mined due to limited technical parameters of extraction and loading equipment; H^c: Changed section Height (m); z: safe distance to the bench edge (m)

$$L^{w}_{mov.} = L^{w}_{base.}, \text{ m} \quad (9)$$

For pull shovel:

$$L^{p}_{mov.} = L^{p}_{base.}, \text{ m} \quad (10)$$

Reduction of the depth of the i-th section (Fig. 6 and 7). Under this method of loss liquidation, the height of the I-th section is changed by the value h^S that equals to Eq. 11:

$$h^s = y_2, \text{m} \quad (11)$$

where, y_2: coordinate of the crossing of working zones of dredges along the O_y, m axis. Reduction of the width of the i-th section (Fig. 8 and 9).

The value, by which the width of the i-th section is reduced, ΔB^S: equals to the length of the loss triangle $L_{base.}$, then we will obtain Eq. 12 and 13. When using the walking dredge:

$$\Delta B^{s.} = L^{w}_{base.}, \text{ m} \quad (12)$$

For use by pull shovel:

$$\Delta B^{s.} = L^{p}_{base.}, \text{ m} \quad (13)$$

Man-made deposit development process chart significantly differs from traditional charts, adopted at mining enterprises and includes stages, from extraction and loading works to delivery of the finished product to the consumer (Fig. 10).

Low quantity of stages of the process chart (Fig. 10) shows clearly the ease of development of such deposits and mining processes are less energy intensive compared with the processes represented at natural deposits which makes man-made deposits attractive for their development. Special attention at mining works should be paid to losses and dilution.

Losses arise along the outline of each section developed. Because of extraction and loading works, the

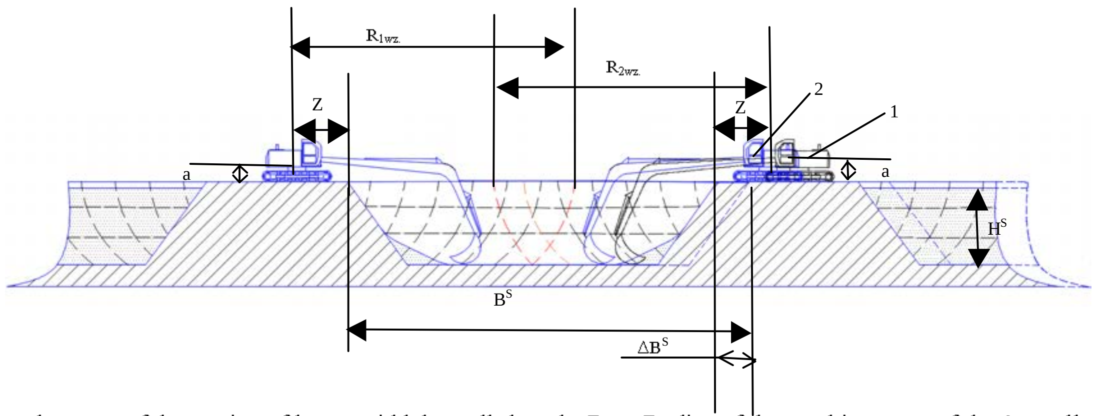

Fig. 8: Development of the section of lower width by pull shovels: R_{1wz}: Radius of the working zone of the 1st pull shovel (m); R_{2wz}: Radius of the working zone of the 2nd pull shovel (m); B^S: width of the Section at the Bottom; ΔB^S: Section Height changed (m); Z: safe distance to the bench edge (m); H^S: Section Height (m); 1: previous position of the pull shovel; 2: new position of the pull shovel

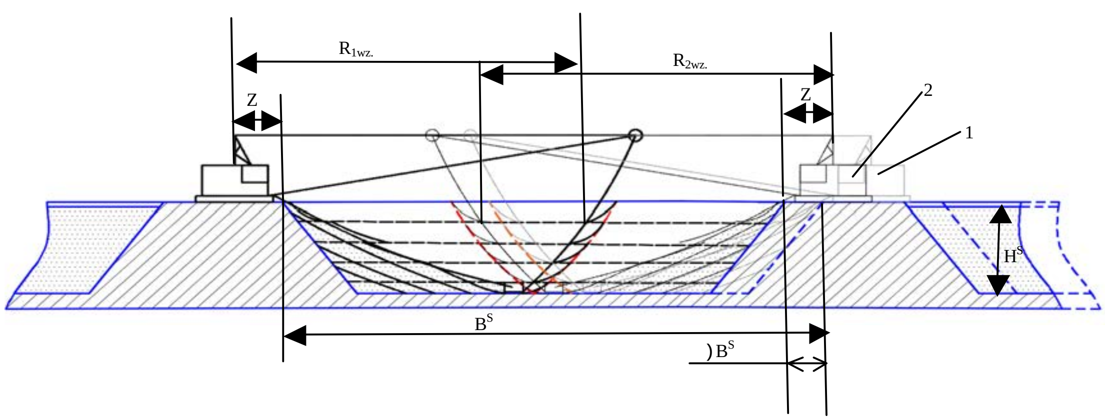

Fig. 9: Development of the section of lower width by walking dredges: $R_{1w.w.z}$: radius of the working zone of the 1st dredge (m); $R_{2w.w.z}$: radius of the working zone of the 2nd dredge (m); z: safe distance to the bench edge; H^S: width of the section at the bottom; B^S: section height changed (m); ΔB^S: safe distance to the bench edge (m); 1: previous position of the walking dredge; 2: new position of the dredge

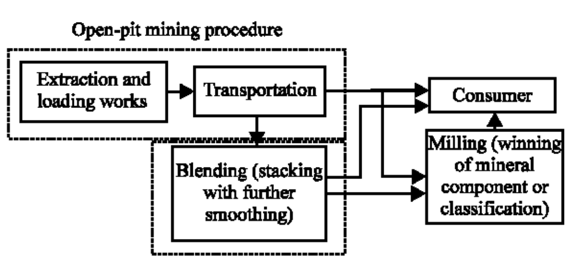

Fig. 10: Man-made deposit development process chart

mined man-made raw materials are lost which are left by the mining and conveyor equipment due to various technical reasons.

This process can be carried out both by pull shovels and walking dredges. The mining procedure when using pull shovels may exceed the walking dredges by its workload; in this case, the maximum extraction value is reached.

The workload of processes performed is the number of cycles carried out as well as an increase of their duration. Development in this case begins with a maximum radius of the working area and gradually approaches the upper edge of rock overburden fill. Upon selection of the distant points of the working zone, man-made materials are extracted, remaining at the slope of rock fill.

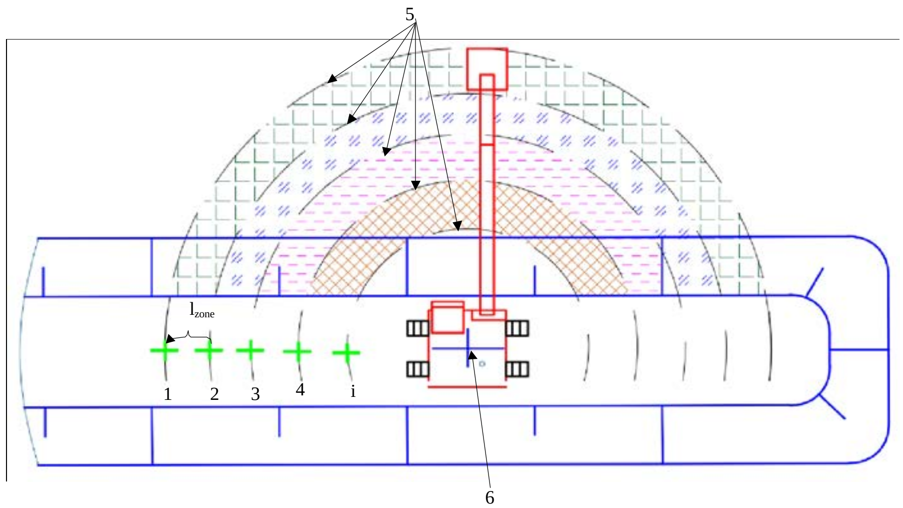

Fig. 11: The layout of dump truck placement for loading when developing the man-made raw materials within the section using the pull shovel: 1-4, i: placement of dump truck depending on the gravel face zone in which the pull shovel operates; 5: gravel face zone of the pull shovel; 6: axis of the pull shovel; l_{zone}: distance between the gravel face zones (m)

In order to reduce the operation cycle time of the pull shovel and increase its performance, it is required for the dump truck when loading to be located at the distance equal to the distance from the axis of the pull shovel to the extreme line of the gravel face zone (Fig. 11).

Recommended placement of the dump truck for loading (Fig. 11) will allow reducing mining costs by increasing t he performance of the pull shovel. Under this layout of placement, the distance transportation will be increased by the distance l^{tot}_{zone} (Eq. 14):

$$l^{tot}_{zone} = l_{zone}.n_{zone} \tag{14}$$

where, n_{zone} means the number of zones worked without the change of location of pull shovel, pcs. The loaded materials are then transported to reprocessing, storage or to the consumer.

The mining process with the use of walking dredge differs by fewer cycles but as a result of its work the losses occur due to the fact that gravel face has flatter angle compared to the angle of natural slope of rock overburden fill, on which the extraction-and-loading equipment is located. Length of the gravel face is equal to the length of the boom.

Given the technical features of the walking dredge during the development of the man-made deposit, placement of the dump truck for loading should be carried out at the distance of non-working zone without any change of the location until the area has been developed completely (Fig. 12).

In case of the specified placement of the dump truck ($l_{plmt} = l_{min}$) as shown in Fig. 11, maximum performance is achieved. During a remote placement of the dump truck for loading ($l_{plmt}>l_{min}$) transportation distance is reduced but operation cycle time of the walking dredge is increased.

When optimizing the processes of open-pit mining (if necessary), it is required to consider activities to eradicate losses arising as a result of mining operations which include additional extraction and loading works and bulldozer works and lead to an increase in production costs.

The practicability of these activities is justified based on the value of extracted materials. When optimizing the blending process, it is required to take into account the consumer's requirements for the raw materials or milling technology. Transported raw materials can be sent directly to the consumer or for the milling if the material meets the minimum requirements. Raw materials with high content of mineral components or relating to raw materials, exceeding the established requirements are sent to smoothing with defective raw materials extracted.

When considering the results and derived dependencies, we draw up the mathematical model of the man-made raw material mining process including transportation and milling with winning of two concentrates of mineral component (basic and associated component) as well as obtaining raw materials of a certain class that are demanded by various industries. Mathematical model of the mining process is as follows Eq. 15:

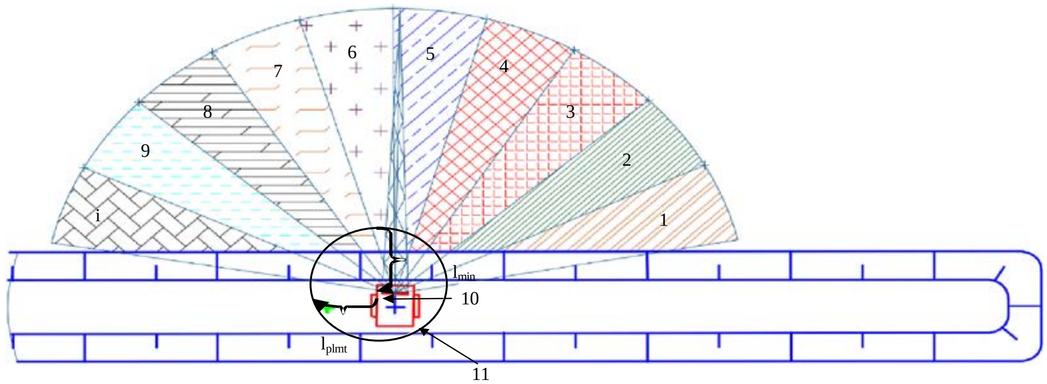

Fig. 12: Layout of dump truck placement for loading when developing the man-made raw materials within the section using the walking dredge: 1-9, i: mining area of the walking dredge; 10: walking dredge; 11: non-working zone of the dredge; l_{plmt}: distance of the placement of dump truck for loading (m); l_{min}: minimum distance from the axis of the dredge to the endpoint of gravel face (m)

$$P = K_0 + K_1x_1 + K_2x_2 + K_3x_3 + K_4x_4 + K_5x_5 + K_6y_1 + K_7y_2 - \frac{K_8}{x_3^{m_3}}\left(B - x_1 - x_2 - x_4 - x_5 + y_1 + y_2\right) + K_8x_3^{1-m_3} \quad (15)$$

Where:

$$K_0 = K_{01}B + K_{02}B_c - K_{03}B - K_{04};\ K_{01} = \frac{0.01\times\left(C_{k1}r_{01} + C_{k2}r_{02} + C_{k3}r_{03}\right)}{V}$$

$$K_{02} = \frac{0.01\times\left(C_{k1}m_{01} + C_{k2}m_{02} + C_{k3}m_{03}\right)}{V}$$

$$K_{03} = \frac{S_{\text{тр.}} + S_{\text{пер.}} + S_{\text{кпасс}}}{V}$$

$$K_{04} = \frac{A_1 + A_2 + A_3}{V}$$

$$K_i = -K_{01} - K_{02}a_i - K_{02}\beta_i + K_{03};$$

$$K_6 = K_{01} - K_{02}\times\alpha_1^{'} - K_{02}\times\beta_1 + K_{03};\ i = 1, 2, \ldots, 5$$

$$K_7 = K_{01} - K_{02}\times\alpha_2^{'} - K_{02}\times\beta_2 + K_{03};\ K_8 = \frac{N_{p.n.}.T_{M.3.}}{840.r_3.V}$$

It's natural that the best solution lies in finding values x_1-x_5 when the profit reaches the maximum. Having found the optimal man-made mwe will define the coefficients of mineral extraction out of man-made deposit and quality change during extraction.

CONCLUSION

Using the above methods, it is possible to reduce losses greatly but there expenses for performance of additional operations will occur at the same time which should be considered during technical and economic business activities.

Mathematical process model will have its own optimal parameters with the release of two types of products first one is the concentrate with same content of mineral component and the second one are raw materials of a specific class that are demanded by various industries.

REFERENCES

Argimbaev, K.R. and H.A. Kholodjakov, 2016. Tailings development and their utilization in the national economy. Int. J. Ecol. Dev., 31: 94-100.

Argimbaev, K.R., 2016. Simulation of rock mass stress-strain behavior using the method of equivalent materials during ore deposit open-pit mining. Res. J. Appl. Sci., 11: 894-899.

Arriagada, C., I. Sampedro, G.I. Romera and J. Ocampo, 2009. Improvement of growth of eucalyptus globulus and soil biological parameters by amendment with sewage sludge and inoculation with arbuscular mycorrhizal and saprobe fungi. Sci. Total Environ., 407: 4799-4806.

Arvas, O., B. Keskin and I.H. Yilmaz, 2013. Effect of sewage sludge on metal content of grassland soil and herbage in semiarid lands. Turk. J. Agric. For., 37: 179-187.

Borgegard, S.O. and H. Rydin, 1989. Utilization of waste products and inorganic fertilizer in the restoration of iron-mine tailings. J. Appl. Ecol., 26: 1083-1088.

Kholodjakov, H.A. and K.R. Argimbaev, 2014. Waste storage feasibility of concentrating mill in overburden dumps. World Appl. Sci. J., 30: 738-740.

Kholodnyakov, G.A. and K.R. Argimbayev, 2014. The choice and substantiation of the technological parameters of tailing formation in an overburden dump body. Scientific Bull. National Mining Univ., 2: 50-57.

Pivovarova, I. and A. Makhovikov, 2016. Statistical methods of zoning. Res. J. Appl. Sci., 11: 321-326.