lef* International Mining Congress and Exhibition of Turkey-IMCET 2003, ® 2003, ISBN 975-395-605-3

Planning of Development of Mining Operations and Freight Traffics at an Open Cast by Analytic-Imitation Systems

D.Bukeikhanov. U.Dzharlkaganov & B.Bekmurzayev
RSE "Complex Processing of Mineral Raw Materials National Center of the Republic of Kazakhstan" Almaty, the Republic of Kazakhstan

M.Zhanasov
" NOVA-Trading & Commerce AG", Almaty, the Republic of Kazakhstan

ABSTRACT: In the paper principle conception is presented of perspective and current planning of mining operations at open casts on the basis of economical-mathematical and imitating models of mining production. Worked out models provide interactive procedures when making technical and technological decisions. Offered methodology was evaluated when planning of mining operations at open casts of the Republic of Kazakhstan.

I INTRODUCTION

Industrial and financial-economical activities of mining and mining-and-proce.ssing enterprises in many respects depend on quality of planning and control of mining operations. When planning of mining operations volumes of useful minerals mining are determined with due account of their qualitative characteristics and volumes of overburden on within-year, years and stages of open cast existing. And extraction-and-loading operations must be ensured reliable freight-transport connection of working levels with points of receipt and dispatching of mineral raw material and overburden rock dumps.

Experience of perspective and current planning of development of mining operations at open casts of ferrous and poly-metallic ores and non-ferrous metals showed, that using of known methods of linear programming causes to considerable widening of domain and search, substantial increasing of computer time for their solving, increasing of errors in estimation of quality of mining ores and so on (Bukeikhanovetal. 2002).

Informational basis for mining-and-geological analysis and planning of mining operations is mathematical model of a deposit and an open cast, representing formalized description of form, structure and qualitative characteristics of a deposit and enclosing rocks, and also parameters of an open cast and its mining workings.

When .simulating open-pit field is divided into vertical sectors, which are limited of planes by different directions of studying development of mining operations. Within every sector at every open cast bench variants of technological blocks are separated. Ore blocks form as that qualitative characteristics of useful minerals, including in them, will be statistically indistinguishable. When planning, it is necessary to separate at a set of alternative variants of technological blocks for a period of planning such set of blocks in particular contours of mining operations, which will ensure receiving of production of given quality, which was taken for realization in every planned period of mining enterprise.

When simulating numbers of contours increase as advance of front of mining operations in a block. Here (' - number of a level (bench), at which block is located; *j* - number of a zone, in which block is located; *k* - number of contour of extraction in this block.

Scheme of separating section and blocks at one level and contours of variants of mining operations are presented in Figure l.

Here 1- position of /'" bench of open cast, where contour *of* mining operations is fixed; 2 - position of above located (/+//'' bench in studying k^{th} contour of mining operations; 3 - ore body within the limits of block; 4 - a part of ore body, falls within k'^{1}' contour of mining operations; 5 - boundaries of working bank of above located bench; 6 - opened-up part of ore body as of the moment of studying ot k'^{1}' contour of mining operations.

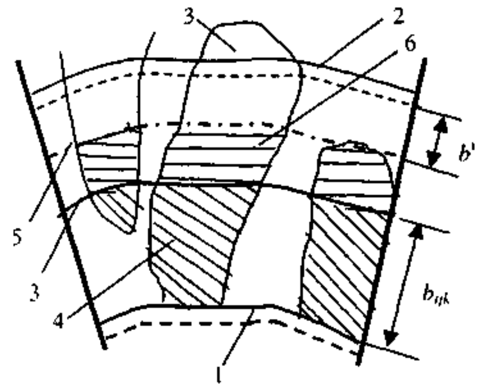

Figure 1 Scheme of separating of block into contours

For solving of this problem linear-integer-valued programming is used. As a controlling parameter Boolean variable of contour of mining operations x_{ijk} is taken. And A„A=1, if contour has included into plan, in other case ,»„<=().

Goal function of solving of the problem of annual planning of mining operations is specified by the following expressions:

$$\sum_{i=1}^{N_k}\sum_{j=1}^{s_i}\sum_{k=1}^{n_{ij}} S_{ijk}\, x_{ijk} \to \min, \qquad (1)$$

where S„i - annual costs on mining and processing of ore from a variant of contour of mining operations, tenge; tt,,, s,,, N_x - correspondingly a number of variants of contours of mining operations in a sector, zones (sectors) at a level and working benches in open cast.

$$S_{ijk} = [\,S_i^{or} + S_i^{op} + S_i^{ora} l_{ij}^{ora} + (S^{oa} l_{ij}^{oa} + S_{sor}^{or}) \cdot d_i^{ora} +$$
$$+ (S^{ok} l^{cl} + S^{cl}) \cdot n_i^{cl} d_i^{ok}\,] \cdot A_{ijk}^{or} \cdot \gamma_p +$$
$$+ [\,S_i^{v} + S_i^{vra} l_i^{vra} + (S^{va} l_i^{va} + S_{sor}^{va}) \cdot d_i^{va} +$$
$$+ (S^{vk} l^{cl} + S^{cl})\; n_i^{cl} d_i^{vk}\,] \cdot (Q_{ijk} - A_{ijk}^{or}), \qquad (2)$$

where i," - variable part of operating cost of ore mining without costs on transportation, tenge/f, .\"'" - variable part of operating cost of ore processing into concentrate, tenge/t; *y''''*- variable part of operating cost of transportation 1 t of ore by rail from /'' level, tenge/tkm; /„ ' - distance of ore transportation by rail, km; ^ - variable part of operating cost of transportation of 1 t of ore by road, tenge/tkm; *S'Z* - costs per I ton of ore for construction of storehouse for ore re-loading from road transport to rail transport, tenge/t; /,; distance of ore transportation by road from contour of ore extraction up to nearest point of re-loading to rail transport or conveyor, km; *d''''* - Boolean variable, indicating ore transportation by road from faces to re-loading storehouses (1 - road transportation uses, 2 - road transportation does not use); *S'''*- variable part of operating cost of transportation of I ton of ore by conveyors, tengc/tkm; *S''*- costs per 1 ton of ore on 1 conveyor line, tcngc/t; /'' - length of one conveyor line, km; *n''* - a number of conveyor lines for haulage of rock mass from lower levels up to re-loading on rail transport; *d'~* - Boolean variable, indicating using of conveyor transport for ore transportation from lower levels (1- uses; 0 - no); $A_{,lt}$ - reserves of commercial ore within limits of contours of ore extraction, m ; v„, - ore density, t/m ; ö,;n - reserves of rock mass in *k'^1'* contour of extraction, m\

In the second part of the expression symbols *y''*, A,'''', l_{ij} and the others indicate costs, distances of transportation and other parameters for overburden from /'' sector of *i'^1'* level. Conveyor lines service both ore flows and rock flows.

The following equations and inequalities present limits of economical-mathematical model of the problem:

$$(1 - f_{pl}^{l}) \cdot A_{pl}^{or} / \gamma_{or} \le \sum_{i=1}^{N_k}\sum_{j=1}^{s_i}\sum_{k=1}^{n_{ij}} A_{ijk}^{or} x_{ijk}$$
$$\le (1 + f_{pl}^{h}) \cdot A_{pl}^{or} / \gamma_{or}; \qquad (3)$$

$$\alpha_{min} \le \frac{\sum_{i=1}^{N_k}\sum_{j=1}^{s_i}\sum_{k=1}^{n_{ij}} A_{ijk}^{or} \alpha_{ijk} x_{ijk}}{\sum_{i=1}^{N_k}\sum_{j=1}^{s_i}\sum_{k=1}^{n_{ij}} A_{ijk}^{or} x_{ijk}} \le \alpha_{max}; \qquad (4)$$

$$b_{ij}^{wh} \le d_{ij} + \sum_{k=1}^{n_{ij}} b_{(i+1)jk} x_{(i+1)jk} - \sum_{k=1}^{n_{ij}} b_{ijk} x_{ijk};$$
$$i = 1, 2, \ldots, N_k - 1; \;\; j = 1, 2, \ldots, s_i; \qquad (5)$$

$$\left| \sum_{k=1}^{n_{ij}} b_{ijk} x_{ijk} - \sum_{k=1}^{n_{ij}} b_{i(j+1)k} x_{i(j+1)k} \right| \le b_{ij}^{wd};$$
$$i = 1, 2, \ldots, N_k; \;\; j = 1, 2, \ldots, s_i - 1; \qquad (6)$$

$$\left| \sum_{k=1}^{n_{ij}} b_{ijk} x_{ijk} - \sum_{k=1}^{n_{ij}} b_{i(j-1)k} x_{i(j-1)k} \right| \le b_{ij}^{wd};$$
$$i = 1, 2, \ldots, N_k; \;\; j = 1, 2, \ldots, s_i; \qquad (7)$$

$$\sum_{k=1}^{n_{ij}} b_{ijk} x_{ijk} \le B_{ij}^{wh} - b_{ij}^{wh};$$

$$i = 2, 3, \ldots, N_g; \ j = 1, 2, \ldots, s_i, \tag{8}$$

$$Q_{ij}^{min} \le \sum_{k=1}^{n_{ij}} Q_{ijk} \ x_{ijk} ;$$

$$i = 1, 2, \ldots, N_g; \ j = 1, 2, \ldots, s_i; \tag{9}$$

$$k_t^{min} \le \frac{\sum_{i=1}^{N} \sum_{j=1}^{s} \sum_{k=1}^{n_{ij}} (Q_{ijk} - A_{ijk}^{or}) \cdot x_{ijk}}{\sum_{i=1}^{N} \sum_{j=1}^{s} \sum_{k=1}^{n} A_{ijk}^{or} \cdot x_{ijk} / \gamma_{or}} \le k_t^{max} ; \tag{10}$$

$$\sum_{i=1}^{N} \sum_{j=1}^{s} \sum_{k=1}^{n_i} A_{ijk}^{op} \ x_{ijk} \ge \frac{N_{or}}{12 \cdot \gamma_{or}} \ A_{pl}^{or} . \tag{11}$$

$$\sum_{k=1}^{n} x_{ijk} = 1; \ i = 1, 2, \ldots, N_g; \ j = 1, 2, \ldots, s_i; \tag{12}$$

$$x_{ijk} = 1 \text{ or } 0; \ i = 1, 2, \ldots, N_g; \ j = 1, 2, \ldots, s_i;$$

$$k = 1, 2, \ldots, n_{ij}, \tag{13}$$

where A_t - planned annual productivity of an open cast by ore, t: $;_{/tl}$, J_{pl}- permissible standards of deviations of annual planned productivity by ore to less and bigger side, share of a unit; a_{ijk} - metal content in ore in k^{th} contour of mining operations *ij* block, %; a_{mm}, a_{mn} - lower and top limits of deviations of metal content in annual output from planned ore quality, ^{c}/<; $o_{:i}$ - minimum width of working bank of (/+//" bench at the top of // block, in: d_n - distance between i^{th} and /+/ benches up to the beginning of planning, m; o_{ijk} - advance ot mining operations at /'"bench in k^{th} contour, in; "o + Dk - advance of (/'+/)"' bench from initial position when studying of k" contour of extraction *ij* block, m; ö$_{::}$' - permissible mutual advance of lines of benches in adjacent zones (blocks); tf„ - determined distance from initial point of/'" bench up to temporary spoil bank in advance of *ij* block, m; ti_n - width of transport (safety) beim at a bottom of temporary spoil bank slope, m; u_{ij} - minimum necessary volume of mining operations in *ij* block, in : *ki*....., *k*'''''' - permissible boundaries of variations ot current stripping ratio to less and bigger side; A_{n}/ - volume of opened-up reserves between *k*" contour in // sector and working bank of above bench, m; $/N_{w}$, - standard ot opened-up ore reserves at open cast, months.

Balance limits of economical-mathematical model express the following. Deviations of plan by ore from required indexes are admitted in fixed limits (restriction (3)). Restriction (4) regulates metal content in market ore.

Technological restrictions lake into account characteristic property of carrying out of mining operations at an open cast. For upkeep of normal width of working banks at benches of an open cast rate of front of mining operations advance at above level must be not less than rate of front of mining operations advance at lower level (restriction (5)). At extracting bench in adjacent sectors (blocks) it is required to save smoothness of lines of front of mining operations. This requirement of technology of mining operations is taken into account by restrictions (6) and (7). Advance of a bench may be limited by temporary spoil bank in zone of *ij* block. This condition is taken into account by inequality (8). Possible volume of rock mass extraction in contour must be not more than minimum necessary volume of rock mass extraction in block (inequality (9)).Variations of current stripping ratio plans of mining operations are admitted in given limits (inequality (10)). Volume of opened-up reserves must ensure open cast operation with planned output during normative time (inequality (II)). Restriction (12) is caused by condition of contours forming. In every block only one contour is worked out or no one.

Calculating process of construction of boundaries of working bank includes the following operations. Having coordinates of limiting points/' zone on line (/+/)" bench from sequence of points U$_r$, y$_r$) (r = 1, 2 . . . .TJ by lower edge of bench point r(A$_r$, y$_r$) is separated by coordinate grid. Than some set of points is formed, abscissas of which on the main grid of coordinates lie between A$_r$ and A„, and ordinates - between v$_r$ and y„. In other words a number of points is produced, which lie in an area of the direct product of set *A x B, $A_{r>l}$* = [\$_r$, A„], *But* = fvr. v,,]. And values A„, y„ are determined by boundaries *ij* block by front of mining operations. In received set of points *A* x *B* some subset *M* of points v(Ai- , v,) is selected for which the following condition is correct:

$$b_{ij}^{wb} \le \sqrt{(x_v - x_r)^2 + (y_v - y_r)^2} \le b_{ij}^{wb} + d_0 , \tag{14}$$

where *du* - permissible value of variation from given value o$_{ij}$ distances from point, which must be found, r(.v$_r$, y$_r$) up to point v(.v„ y,.) of a set *M*.

In a set *M* new subset of points *N cM* is separated, distance of which up to points (A$_r$.ı, v$_r$.ı) and (A$_{r+}$i, w+i), adjacent with r(.i$_r$, Vr), not less than width of working bench o$_{ij}$.

If any point from direct product of sets *A* x *B* will be denote by (A;;',y ;'), and the shortest of distances from it up to adjacent with ri.v$_r$, y$_r$) points by *R* (A'; ,y$_;$ "), that as a result of all above-sited operations some number of points is formed:

$$\sigma_p^{(r)}(x_\sigma, y_\sigma) \ (p = 1, 2, \ldots, r)$$

under condition

$$\sigma_{p}^{(r)} \in E\{\pi\, x_{p}^{(r)}, y_{p}^{(r)}\ \phi \in M \mid R\,(x_{p}^{(r)}, y_{p}^{(r)}) \geq b_{ij}^{nk},$$ (15)

where *O],* - points of new line, lie opposite T[1'] point; /• - number of points of this line, falling within a sector oft[11'] point.

Further above-sited cycle is repeated with other values of rù„ y_r). until all given number T of points will be exhausted. As a result sequence of points will be received, which presents a boundary of working bank at a surface of *ij* zone. This procedure is present in all operations on verification of technological inequalities in economical-mathematical models. Since parallelism of adjacent benches is not caused by methods of carrying out of mining operations, standard of advance distance is taken between these benches in a point of their most approach.

Taking account of difficulty of adequate description of mining-and-geological conditions of deposit mining and their interaction with economical indexes, a problem of annual planning of development of mining operations is solved into two stages.

First of all, on the above-sited economical-mathematical model and solid-digital model approximate contours of extraction are determined by levels and blocks of an open cast. Then narrowing an area of a search of optimal plan of mining operations takes place. On the second stage search of solving the problem of planning is continued by man-computer procedures - in dialogue regime.

The main basis of search only solid-digital model of deposit and open cast becomes and system of automatic calculation of volumes and indexes of ore quality in given contours by sectors and open cast as a whole. Variants of contours of extraction "are drawn" by computer on plane of zone and level by all depth of open cast, and economic justification is carried out. And all roughness in configurations of ore bodies intersections, curvature of front of mining operations and so on are taken into account. If the best variant of plan does not bring to light, repeal calculation is possible with software complex of economical-mathematical model using. Only here boundaries of parameters and indexes, giving by inequalities, will be the most accurate and close real conditions. Carries out of planning, any person is carried out noted search procedures not blindly, but follow specific rules. These rules resemble algorithm of adaptation and teaching in automated systems of control by complex dynamic processes and objects. That is why here description is given of rules for optimal contours of extraction search in solid-digital model of open cast in terms and notions of these systems.

Search algorithm in recurrent form may be presented in the following form:

$$c[n] = c[n-1] - \gamma[n] \cdot \nabla J(c[n-1]).$$ (16)

where *c[n]* - realization of solving vector *c* as a result of *n"'* step of search; *c[n-\]* - value of this vector after preceding step of search; *y[n]* - some scalar, determining the next step of search; *J* - function vector *c* = *(c* . . . . CN). In given problem this vector conforms to criterion of optimum, that is to say total costs on mining and processing of ore when annual planning of development of mining operations. Gradient of function vector shows direction of changing of criterion index when searching of optimal decision on plan of mining operations. Vectors *c[n]* and *c[n-\]* conform to variants of combination of different contours of extraction on all blocks and levels of open cast. Value)L"1 defines quantity of the next step and depends on a number of a step and vectors *c[m] (in* = ii - I, n - 2, . . .). Its quantity defines a set of steps of front of mining operations advance by the same blocks and levels that is to say by open cast. Minimum step conforms to distance between prospecting holes or, when quarterly-monthly and weekly-24-hourly planning, lo width of an excavator cut by pillar. In essence here iterative method is used, which we may call regular in difference with probable methods. These generalizations will be useful when we will change-over from search of optimal contours of mining operations "by hand" at the second stage to full automation of search of optimal plans of mining operations development. One of defining indexes in goal function of the model of annual planning is cost of loading and transportation of ore and overburden. In view of complexity of internal structure of mining-transport complex, and a fact that it is susceptible to influence of many casual factors, correct economical estimation of costs for loading and transportation of rock mass is carried out with a help of imitation simulation (Dzharlkaganov U.A. & Dzharlkaganov A.U. 2000).

Description of open cast's freight traffics it is the most convenient to carry out in terms and notions of multi-phases systems of theory of mass service with irregular channels and not equal in importance requirements. Forming of cost for loading and transportation of ore and overburden from open cast per time unit is described by the following assessing function:

$$W = \sum_{v=1}^{v1} C_v \cdot \sum_{n=1}^{N} n_v \cdot P_n + \sum_{g=1}^{g1} C_g^{0} \cdot \sum_{m=1}^{M} m_g^{0} \cdot P_{m^0} +$$

$$\sum_{g=1}^{g1} C_g^m \cdot \sum_{m_g=1}^{M} (m_g - m_g^n) \cdot P_{m_g} , \quad (17)$$

where C_e - cost of being in line of application e^{th} type per unit of time; $g1$ - number of types of applications; n_e - number of applications e^{th} type in line and on service at all stages; f_a - probability of presence of n applications of e^{th} type in line and on service at all stages; C_g - cost of downtime of a channel of service g^{th} type per unit of time; g1- number of types of channels of service; C_v - cost of operating of channel of service g^{th} type per unit of time: M_v - number of channels of service g^{th} type; m, - number of channels of service in downtime g^{th} type; r_m - probability of presence of application on service in channel g^{th} type; , „- probability of downtime of channel g^{th} type.

In expression (17) under many-types application loaded and empty trains or cars, transporting ore and rock are understood. Channels of service are all elements of transport network, sources and ends of open cast's freight-flows (face excavators, ore storehouses and rock dumps, re-loading points in open cast and at day surface and so on). In the first and the second components of the expression probable characteristics of excavator operations and transport flows and possible damage of downtime of the main equipment are determined by simulation. The third component presents costs on exploitation of this equipment and technological constructions. Cost of loading and transportation of a unit of ore volume and overburden, requiring for calculation of annual costs in annual planning by expressions (1) and (2) are determined with a help of assessing function (17) and other operations.

3 CONCLUSIONS

Distributions of volumes of rock mass by zones, technological blocks, and levels in annual planning are the basis of quarterly and monthly plans of development of mining operations. But in the last case the main purpose of planning is often achievement of the most stability of quantity of commercial ore.

REFERENCES

Bukeikhanov D.G.. Dzharlkaganov U.A.. Bekmurzaiev B.Zh 2002. Dynamic planning of mining operations at an open cast by optimization processes and expert-machines procedures. Results and problems of science and education in a field of useful minerals mining by open method *Proceedings of Iiileriitilioiiul stienliflc-reseun.il conference.* Ekaterinburg Urals Stale Mimng-and-geological Academy. p.205-2IO

Dzharlkaganov U.A.. Dzhai lkaganov A.U. 2000. Simulation and optimization of loading and transport equipment at an open cast. *Mining, Geology tmil Meicillmgv*. Materials of the first International conference Mining in Kazakhstan, p 237