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Professional paper

OPTIMISATION OF UNDERGROUND MINE DECLINE DEVELOPMENT SYSTEM USING GENETIC ALGORITHM

UPOTREBA GENETSKOG ALGORITMA U OPTIMIZACIJI OTVARANJA PODZEMNOG RUDNIKA SISTEMOM NISKOPA

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Abstract: When deposit is composed of few ore bodies it is necessary to interconnect them into one integrated system. Suppose the deposit characteristics indicate that decline development system is preferred one. In such environment we treat development of an underground mine as access infrastructure composed of different decline sections. Access infrastructure designing can be treated as spanning the spatial network which will connect all main terminals (points). In our model we defined spatial network by adequate nonlinear constrained objective function representing the cost of mine development and ore haulage. To find the minimum value of the objective function we use Genetic algorithm.

Key words: underground mine, decline development, optimisation, genetic algorithm

Apstrakt: Kada je ležište sastavljeno od više rudnih tela, neophodno je sva rudna tela međusobno povezati u jedan integralni sistem. Pretpostavimo da karakteristike ležišta ukazuju da je otvaranje ležišta niskopima najbolje projektno rešenje. U takvom okruženju, tretiramo otvaranje podzemnog rudnika u svojstvu pristupne infrastrukture, koja je sastavljena od različitih deonica niskopa. Projektovanje ove infrastrukture se može tretirati kao razapinjanje prostorne mreže koja će povezati sve glavne terminale (tačke). U našem modelu definisali smo prostornu mrežu pomoću adekvatne nelinearne uslovljene funkcije cilja, koja predstavlja trošak otvaranja rudnika i transporta rude. Za pronalaženja minimalne vrednosti funkcije cilja primenjujemo Genetski algoritam.

Ključne reči: podzemni rudnik, otvaranje niskopom, optimizacija, genetski algoritam

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1. INTRODUCTION

When deposit is composed of few ore bodies it is necessary to interconnect them into one integrated system. There are different development systems (shaft, decline, adit) which can be used to create such system. Suppose the deposit characteristics indicate that decline development system is preferred one. In such environment we treat development of an underground mine as access infrastructure composed of different decline sections. Access infrastructure design can be treated as spanning the spatial network which will connect all main terminals (points). Main terminals are: mineral processing facility, surface breakout point and ore body access points.

Brazil et al. created a software tool called Decline Optimization Toll (DOT). The heuristic methods used in DOT1 are replaced in the new version of the software tool, DOT2, by a method based on an understanding of exact solutions to a constrained 3-dimensional path problem. Their approach is based on the minimization of the cost of the decline, where the cost is a combination of both development and haulage costs, subject to design constraints (Brazil et al. 2003; 2008).

In our model we defined spatial network by nonlinear constrained objective function representing the cost of mine development and ore haulage. To find the minimum value of the objective function we use Genetic algorithm.

2. THE MODEL OF A DECLINE DEVELOPMENT SYSTEM

In many cases, the ore deposit is composed of a few ore bodies that must be interconnected into one integrated system. The main idea that we used to create such system is based on the fact that somewhere in $\mathfrak{R}^{3u}$ (3–dimensional underground space) there is a point through which we can connect all ore bodies with surface portal (or surface breakout point, SBP) and afterward with mineral processing facility (MPF), with minimum costs. This point is called underground mass concentration point (UMCP). Basic hypothesis used in the optimisation model are as follows:

- Location of MPF is fixed;
- Location of SBP is allowed to vary;
- Location of UMCP is allowed to vary;
- Locations of the access points are fixed;
- The tonnage of ore to be hauled from each orebody to the surface portal is fixed.

A decline development system is modeled as a 3–dimensional or space network interconnecting all main points. Such network must incorporate the navigability constraints caused by the mine trucks and other equipment characteristics. The absolute value of the decline slope must be less or equal to the maximum value of the slope that can be handled by loaded mine truck in a safe way.

Decline optimisation is concerned of determination of locations of SBP and UMCP. A general design optimisation problem is formulated as follows:

$$\min f(x)$$
$$\text{subject to}: \begin{cases} g_i(x) \le 0 & i = 1,2,...,r \\ h_j(x) = 0 & j = 1,2,...,m \\ x_L \le x \le x_U \end{cases} \tag{1}$$

In this formulation x is the n-dimensional vector of SBP and UMCP coordinates, while x_L and x_U are the n-dimensional vectors representing the lower and upper bounds of the coordinates, i.e. the design space. The optimisation goal is to minimize the objective function $f(x)$ subject to a given number of constraints: $g_i(x)$ is the r-dimensional vector of inequality constraints, while $h_j(x)$ is the m-dimensional vector of equality constraints. The objective function represents the total costs needed to develop surface route section, underground mine decline system and haul up ore reserves from each orebody to MPF via UMCP and SBP.

The optimisation problem of underground mine decline development system can be formulated as the following form. The objective function

$$f(x,y,z,x_s,y_s,z_s) = f_1(x,y,z) + f_2(x,y,z,x_s,y_s,z_s) + f_3(x_s,y_s,z_s) \tag{2}$$

where

$$f_1(x,y,z) = \sum_{i=1}^{n} (\delta_i + c_i \cdot R_i) \sqrt{(x-x_i)^2 + (y-y_i)^2 + (z-z_i)^2} \tag{3}$$

$$f_2(x,y,z,x_s,y_s,z_s) = \left(d + c_d \cdot \sum_{i=1}^{n} R_i \right) \sqrt{(x-x_s)^2 + (y-y_s)^2 + (z-z_s)^2} \tag{4}$$

$$f_3(x_s,y_s,z_s) = \left(s + c_s \cdot \sum_{i=1}^{n} R_i \right) \sqrt{(x_m-x_s)^2 + (y_m-y_s)^2 + (z_m-z_s)^2} \tag{5}$$

has to be minimized, subject to

$$\frac{|z-z_i|}{\sqrt{(x-x_i)^2 + (y-y_i)^2}} \le r_{\max} \tag{6}$$

$$\frac{|z-z_s|}{\sqrt{(x-x_s)^2 + (y-y_s)^2}} \le r_{\max} \tag{7}$$

$$\frac{|z_m-z_s|}{\sqrt{(x_m-x_s)^2 + (y_m-y_s)^2}} \le \beta_{\max} \tag{8}$$

$$x_s^{\min} \le x_s \le x_s^{\max} \tag{9}$$

$$y_s^{\min} \le y_s \le y_s^{\max} \tag{10}$$

$$z_s^{\min} \le z_s \le z_s^{\max} \tag{11}$$

where

x, y, z - location (coordinates) of the underground mass concentration point;
x_i, y_i, z_i - location (coordinates) of the i-th ore body access point;
x_s, y_s, z_s - location (coordinates) of the surface breakout point;
x_m, y_m, z_m - location (coordinates) of the mineral processing facility;

δ_i - the unit cost of decline development from the underground mass concentration point to the i-th ore body [USD/m];
c_i - the unit ore haulage cost from the i-th ore body access point to the underground mass concentration point [USD/tm];
R_i - ore reserves of the i-th ore body [t];
n - number of ore bodies;
d - the unit cost of decline development from the underground mass concentration point to the surface breakout point [USD/m];
c_d - the unit ore haulage cost from the underground mass concentration point to the surface breakout point [USD/tm];
s - the unit cost of the surface transportation route development from the surface breakout point to the mineral processing facility [USD/m];
c_s - the unit ore transportation cost from the surface breakout point to the mineral processing facility [USD/tm];
$r_{\max}$ - maximum absolute value of the decline slope [%];
$\beta_{\max}$ - maximum absolute value of the slope of the surface transportation section [%].

If we take into consideration, the underground mine truck fleet is uniform (all trucks have the same payload capacity), then the unit ore haulage cost is equal for the all underground route sections, i.e., $c_1 = c_2 = ,\ldots,= c_n = c_d$.

In our case, the optimisation problem is a non-linear constrained programming problem. In such environment, genetic algorithm is used to figure out optimal values of the design parameters.

3. BRIEF DESCRIPTION OF GENETIC ALGORITHM (GA)

Genetic algorithms are stochastic techniques whose search methods model a natural evolution. The genetic algorithms start with randomly chosen parent chromosomes from the search space to create a population. They work with chromosome genotype. The population evolves toward the better chromosomes by applying genetic operators modeling the genetic processes occurring in the nature selection, recombination and mutation.

Selection compares the chromosomes in the population aiming to choose these, which will take part in the reproduction process. The selection occurs with a given probability on the base of fitness functions. The fitness function plays a role of the environment to distinguish between good and bad solutions.

The recombination is carried out after selection process is finished. It combines, with predefined probability, the features of two selected parent chromosomes forming similar children.

After recombination offspring undergoes to mutation. Generally, the mutation refers to the creation of a new chromosome from one and only one individual with predefined probability.

After three operators are carried the offspring is inserted into the population, replacing the parent chromosomes in which they were derived from, producing a new generation. This cycle is performed until the optimization criterion is met (Shopova and Vaklieva-Banacheva, 2006).

A typical genetic algorithm has the following structure:

1. Set generation counter $t = 0$;
2. Create initial population $P(t)$;
3. Evaluate the fitness of each chromosome in $P(t)$;
4. Set $t = t + 1$;
5. Select a new population $P'(t)$ from $P(t - 1)$;
6. Apply genetic operator on $P(t)$;
   $P''(t) \leftarrow$ crossover $P'(t)$
   $P'''(t) \leftarrow$ mutation $P''(t)$
7. Generate $P(t)$;
   $P(t) \leftarrow$ replacement $(P(t - 1), P'''(t))$
8. Repeat from 3 to 8 until termination conditions are met;
9. Output the best solutions found.

In GA the equality and inequality constraints can be treated by different strategies. The penalty function technique is used to transform the constrained optimisation problem to unconstrained optimisation problem by penalizing the constraints and forming a new objective function as follows (Ali, 2014):

$$f(x) = \begin{cases} f(x) & \text{if } x \in \text{feasible region} \\ \vartheta(x) = f(x) + \text{penalty}(x) & \text{if } x \notin \text{feasible region} \end{cases} \tag{12}$$

where

$$\text{penalty}(x) = \begin{cases} 0 & \text{if no constraint is violated} \\ 1 & \text{otherwise} \end{cases} \tag{13}$$

There are two kinds of points in the search space of the constrained optimisation problems, feasible points which satisfy all constraints and unfeasible points which violate at least one of the constraints. At the feasible points, the penalty function value is equal the value of objective function, but at the infeasible points the penalty function value is equal to high value as shown in (12) (Ali, 2014).

In this paper Dynamic Penalty Function is applied to transform (1) into an unconstrained optimisation problem through Joines and Houck's method (Joines and Houck, 1994):

$$\vartheta(x) = f(x) + (C \cdot t)^{\alpha} \left\{ \sum_{i=1}^{n} \left| g_i(x) \right|^{\beta} + \sum_{j=1}^{m} \left| h_j(x) \right|^{\beta} \right\} \tag{14}$$

where
C, α, β - constants defined by the user, e.g., $C = 0.5$; $\alpha = 1$ or 2; $\beta = 1$ or 2;
t - the generation number.

4. NUMERICAL EXAMPLE

Proposed optimisation model based on GA application is tested in design task for development of ore deposit composed of four ore bodies. The Pb-Zn deposit is to be developed, the situation is hypothetical and the numbers used are in to permit calculation. The hypothetical deposit includes four ore bodies A through D with access points $i = 1, 2, 3, 4$ respectively. The relevant operational data are shown in Table 1 and Figure 1.

Table 1 - Operational data

Locations		**Cost**	
MPF (x_m,y_m,z_m)	(1,300;1,900;300)	Haulage & Transport	
SBP (x_s,y_s,z_s)	(x_s;y_s;260)		
Access point (x_i,y_i,z_i)		Decline	0.0011 USD/tm
(1)	(1,160;1,229;200)	(underground mine truck)	
(2)	(1,556;1,072;160)	Surface transport	0.0005 USD/tm
(3)	(1,474;653,130)	(surface mine truck)	
(4)	(919;733;100)		
Ore reserve		**Building**	
Orebody A	1,320,422 t	Decline (equal for all sections)	2,200 USD/m
Orebody B	223,060 t	Surface section of transportation	600 USD/m
Orebody C	560,811 t		
Orebody D	540,155 t		
Slope of decline and surface transport section		**Genetic algorithm parameters**	
Decline max 14%		Number of chromosomes in population 20	
Surface transport section max 5%		Cross-over probability 0.7	
		Cross-over type-One poin	
		Chromosome mutation probability 0.02	
		Random selection probability 0.1	
		$C = 0.5$; $\alpha = 1$; $\beta = 1$	
		Maximum number of generations 100	
		Termination condition-Maximum number of generations	

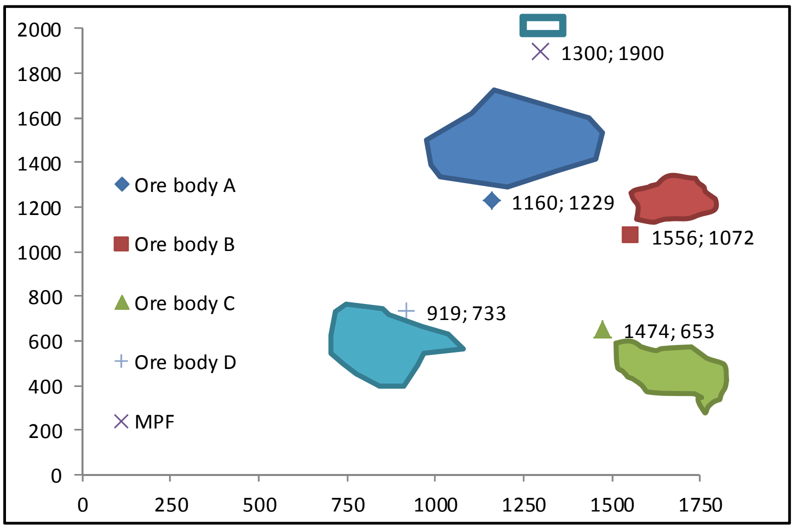

Figure 1 - Locations of the MPF and access points (plan view)

The best design solution found by GA application is shown in Figure 2. Design parameters of the underground mine decline development system are represented in Table 2.

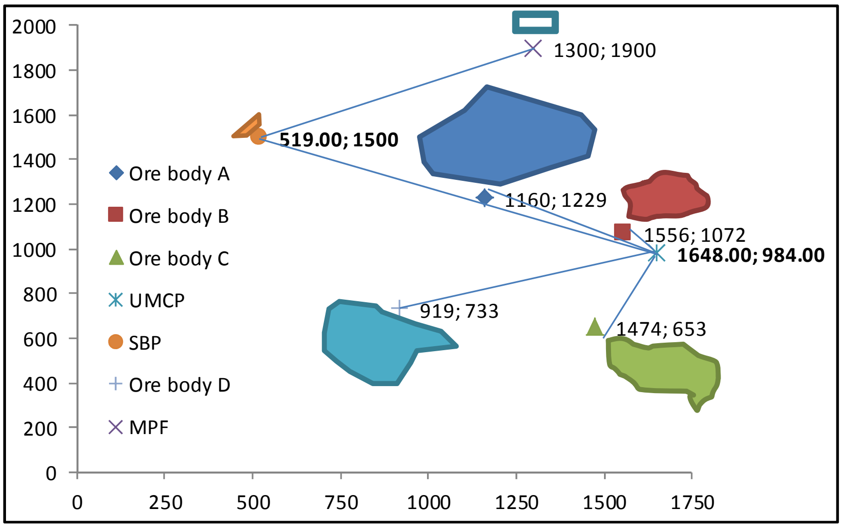

Figure 2 - Underground mine decline development system (plan view)

Table 2 - Design parameters

Section	**Start Coordinates**			**End Coordinates**			**Length**	**Slope**
	x	**y**	**z**	**x**	**y**	**z**	**[m]**	**[%]**
MPF-SBP	1,300	1,900	300	**519**	**1,500**	260	878.38	4.5 down
SBP-UMCP	519	1,500	260	**1,648**	**984**	**177**	1,244.10	6.6 down
UMCP-Ore body A	1,648	984	177	1,160	1,229	200	546.53	4.2 up
UMCP-Ore body B	1,648	984	177	1,556	1,072	160	128.44	13.3 down
UMCP-Ore body C	1,648	984	177	1,474	653	130	376.89	12.5 down
UMCP-Ore body D	1,648	984	177	919	733	100	774.84	9.9 down

Value of the total cost function is 13,581,387 USD.

5. CONCLUSION

In this paper we have presented the application of Genetic algorithm for designing underground mine decline development system in the case when the deposit is composed of few ore bodies. Underground mine development system is treated as spatial network connecting all main terminals with minimum cost. Such network is defined by adequate objective function. Optimisation model is based on the minimisation of the nonlinear constrained objective function representing the cost of mine development and ore haulage. The model is not closed and allows the underground mining engineers to incorporate additional components according to their needs.

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