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Cutoff grade optimization in open pit mines using genetic algorithm

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ABSTRACT

The fundamental objective of production planning is to create a mechanism for the implementation of the mining cutoff grades and short-term production planning. One of the most important parameters in open pit design is a determination of the optimal cutoff grade. Optimum cutoff grade results in maximizing profits or maximizing the net present value. Given that in determining the cutoff grade with the goal of maximizing profits, a constant value is obtained for the entire life of the mine. The annual income of the mine will be the same throughout its lifetime, and the time value of the money has not been neglected; which is the main disadvantage of this optimization process. While in optimization with the goal of maximizing net present value, the optimal value will be a function of the time and will be greater in the early years of the mine and will gradually decrease. Optimization of cutoff grades with the aim of maximizing the net present value over the life of the mine is important due to its dependence on the economic parameters, the design of the open pit mining and fundamental issues. Maximizing the net present value is a nonlinear programming problem. To determine the optimal cutoff grade Lane method is commonly used. Lane provided his method to determine the optimal cutoff grade by considering factors such as the capacity of the mine, concentrator and load capacity of the treatment plant, the time value of money and distributing grade. The procedure of the Lane method for cutoff grade calculation is complicated and time-consuming. Considering the widespread use of heuristic methods in optimizing parameters, In the present study genetic algorithm, which is a smart algorithm, is used to determine the optimal cutoff grade. In this paper, we compare the efficiency of the genetic algorithm and Lane's theory in optimizing the degree of limit based on maximizing the net present value. Using separate programming based on the genetic algorithm and considering the capacity limitations and the proportion between the parameters of mining to smelter and refining in the mine is done. For this purpose, consider precision of 0.001%, optimum cutoff grades, the amount of output per unit and the net present value are calculated. The optimum cutoff grade at the beginning of the life of the mine is equal to 0.506% and at the end of the life of the mine to 0.222% using the genetic algorithm. Using the Lane model at the beginning of the life of the mine the optimum cut-off grade from 0/503% to 0/220% reaches at the end of the mine's life. The net present value of earnings over a lifespan of 7 years mine in the genetic algorithm and Lane model is \$ 93,467,914 and \$ 94,408,000 respectively. Also, the amount of mining, the amount of processing and the amount of refinery obtained by the genetic algorithm method are compared to the Lane model. The results of the research indicate high speed and very low error of genetic algorithm and also a convergence of results with the Lane method.

1. Introduction

A grade of the ore and waste defines the boundary between simple means; it is a technical and economic scale which is determined by various parameters such as geological features (such as grade distribution), technical limitations of operations and financial parameters. The cutoff grade strategy for an open pit mine has an impact on annual liquidity flows and the net present value of the project. Therefore, in each given period, the allocation of materials sent to the processing unit and the production of the product in the refinery unit for sale to the cutoff grade depends (Cetin and Dowd, 2016). Due to the dependence

of technical and economic parameters on the cutoff grade; determining this value is the fundamental issue at different periods over the life of mine planning, and it is the most difficult problems facing engineers (Rahimi and Ghasemzadeh, 2015; Azimi et al., 2013). Take into account that in calculating the break-even cutoff grade based on the break-even analysis; Time Value of Money, grade distribution and operational capacity of the various units are not considered. So, mining operation according to this grade will not lead to the optimization of the process. For this reason, since 1954 cutoff grade optimization has been gained more attention (Ataei, 2003; Osanloo et al., 2008). In determining the optimum cutoff grade, the issues should be pointed out

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such as changing the cutoff grade over time for technological and economic reasons, and also the difference in the distribution of grade in different parts of the mineral deposit (Azimi and Osanloo, 2011). Considering the scope of mining activities, the price changes of minerals, the presence of valuable Secondary metals, the need to determine and optimize the cutoff grade and determining strategies mixing of minerals grade low and grade high in different scenarios to increase revenue and reducing tailing especially at high depths makes it inevitable (He et al., 2009; Bascetin and Nieto, 2007). In recent years, numerous attempts have been made to develop models and relationships that are capable of calculating cutoff grade optimization in order to maximize the net present value. In these relationships, in addition to economic factors, limitations such as mining capacity, processing capacity, smelter capacity, refinement, and the time value of money are also considered (Lane, 1988; Thompson and Barr, 2014). In order to calculate the optimum level, the minerals must be extracted so that the net present value of the operation is maximized. Thus, during the first years of the mine's life, extraction of high-grade materials will be achieved and the net present value will increase (Azimi and Osanloo, 2011; Ataei and Hosseini, 2011). In the Lane model, mining operations are divided into mining, processing and refinery units. Then, using 6-grade candidates, based on the limited capacity of each of the three stages or they mutually balance, the optimum cutoff grades are calculated each year (Lane, 1988). After Lane theory, there is no independent method or algorithm done by other researchers; they focused on the use of other optimization methods based on the Lane method or investigating the role of various factors in this case based on Lane theory. Among these studies in metal deposits, in recent years, we can mention the following: The cutoff grade Optimization of single-metal ore deposits with the goal of maximizing the net present value by using the methods of knocking out and comparing its results with the Lane model (Ataei and Osanloo, 2013; Asad and Dimitrakopoulos, 2013). In 2005, during the study of Lane's algorithm, the various adjustment factors for the product price, fixed and operational costs combine in this algorithm, and proved the effectiveness of the adjustment of economic parameters in the target function. In this case, prices are monitored dynamically. (Asad, 2005). Were able to determine and optimize the optimum cutoff grades by applying an optimization factor based on the Generalized Reduced Gradient (GRG) algorithm for a metal mine (Bascetin and Nieto, 2007). To optimize cutoff grade by considering environmental issues based on minimizing acid leakages, they construct a model (Rashidinejad et al., 2008). The model is based on Lane's theory, with the difference that it takes into account the costs of waste accumulation and reduces incomes, and based on this model, determines the optimum cutoff grades (Gholamnejad, 2008). With the introduction of artificial intelligence technology in the field of mineral activity, Using an artificial neural network and a genetic algorithm, they developed a model for nonlinear simulation of mineral activity to optimize the cutoff grade (He et al., 2009). Determined a model based on the Lane algorithm, taking into account the combined stock mineral grade low, economic parameters, and modifications to optimize the cutoff grade (Asad and Topal, 2011). A model for determining the optimal cutoff grade of open pit mines by using the strategy of combining the genetic algorithm and nonlinear programming (Azimi and Osanloo, 2011). It was able to create a number of scheduled schedules for the cutoff grades and production rates, and then use dynamic planning to optimize and determine the cutoff grades that maximize the net present value (Barr, 2012). They developed a model for optimization cutoff grade based on Lane's theory that has three stages of mining, processing and market operations. In this model, the price of the mineral for the entire life of the mine is not fixed and variable. Using this model, the effect of mineral price changes on the optimum cutoff grade (Khodayari and Jafarnejad, 2012). In order to optimize the cutoff grade based on Lane's theory, with the goal of maximizing the net present value, multi-stage random planning was used for a metal mine (Li and Yang, 2012). To modify the Lane method, a model for optimizing the cutoff grade of

a metal mine, taking into account the variable capacities of the units during the life of the mine, has improved the results (Abdolahisharif et al., 2012). The multi-criteria decision scoring method was used to optimize the cutoff grade and optimum cutoff grade under uncertain prices and to plan the production of a mine (Azimi et al., 2012). A model for optimizing the cutoff grade of minerals gold, lead, and zinc was determined using the genetic algorithm and compared the results with web search method and dynamic programming (Cetin and Dowd, 2016).

Lane (1988) modeled the process of operating a mine just sold its refined product for cutoff grade optimization, and accordingly define the objective function; as a result, his method is not usable in metal mines capable of producing and selling multiple product types (Mohammadi et al., 2015; Rafiee et al., 2016). The main aim of this study is to model the process of operating a mine, and use of the proposed model to determine the cost, revenue and profit can be achieved. Also, the objective function is defined based on the maximization of net present value. To optimize the objective function, the genetic algorithm as a meta-heuristics and intelligent method is used. The main advantage of the Intelligent methods is that they are free derivative methods. So, a solution of the problem is achieved easily and at high speed using such a method. The genetic algorithm coding is done in MATLAB R2012a software, and using this code, those values of optimum cutoff grades, mine production units, profit from operations and net present value of a hypothetical ore deposit are calculated.

2. Methodology

2.1. Objective function

According to Lane algorithm for cutoff grade optimization, mining operations including three stages of mining, concentrate production, smelter, and refining are taken into account. Each of these steps associated with costs and each one also has a limited capacity. Moreover, fixed costs are also included. Considering the expenditure and income in these operations, operating profit is calculated from the following equation (Hustrulid et al., 2013):

$$P = (s - r)Q_r - mQ_m - cQ_c - fT \quad (1)$$

Where T is the production period, Q_m is the amount of material that should be mining, Q_c denotes the amount of ore sent to the concentrator, Q_r represents the final product, f denotes the fixed costs per unit time, S is the selling price of the final product, m is the cost of mining each of material per tonne, c is the price of the condensed minerals per ton, and r is smelter costs per unit of final product. If d is the discount rate, the difference between the net present value of the remaining reserves at time $t = 0$ and $t = T$ after the mining operation is (Hustrulid et al., 2013):

$$v = (s - r)Q_r - mQ_m - cQ_c(f + Vd)T \quad (2)$$

In which, V is the net present value of the remaining units in operation (time $t = 0$), and it can be achieved using replication process. The amount of refined material (Q_r) which is sent to the mineral processing plant (Q_c) depends on the amount of minerals. Considering the amount and average grade of minerals sent to the mineral processing facility (g), and percent recovery (y); the amount of refined material (Q_r) is:

$$Q_r = \bar{g} \cdot y \cdot Q_c \quad (3)$$

$$v = [(s - r)\bar{g}y - c]Q_c - mQ_m - (f + Vd)T \quad (4)$$

To maximize the NPV, the value of v should be maximized. The capacity of each of the units, mining, concentrator, and a refining plant can be the limiting factor in the optimization process. Depending on which of the capacity restriction is in effect, the value of T in Eq. (4) changes. If mining capacity (M) is a decisive limitation, the amount of T

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