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A stochastic cut-off grade optimisation algorithm

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ABSTRACT

Cut-off grade is the grade used to distinguish between ore and waste in a mining complex. The cut-off grade is a function of economic parameters, grade distribution within the deposit, metallurgical recovery, and mining, milling and refinery capacities. A cut-off grade is used to determine the quantity of material mined, quantity of ore processed and lastly, the quantity of product (e.g. metal) produced in a mine. The resultant sequence of cut-off grades generated from the cut-off grade calculations over the life of mine (LOM) defines the cut-off grade policy for that specific operation. The cut-off grade policy generated from these calculations determines the future cash flows hence the present value (NPV) of a mining project.

Optimisation of cut-off grade is paramount in most mines and aims to maximise NPV subject to economic, geological and operational parameters in a mining complex. There are different cut-off grade optimisation approaches applied in mine planning. These include break-even, Lane's and heuristic approaches. The most common approach used in the mining industry is based on Lane's cut-off grade theory. Lane developed a three-dimensional process that calculates cut-off grades that considers the economic parameters, geological parameters and production capacities. It uses mathematical derivations to generate six cut-off grades that are sorted using an algorithm to obtain an optimum cut-off grade. Lane's framework assumes that the input parameters are deterministic, yet their values are stochastic in actual operations. Therefore, Lane's approach fails to reflect the reality hence the need for its modification.

This thesis developed a stochastic approach using Lane's theory by considering the dynamic nature of the variables and constraints governing a mining operation. The stochastic cut-off grade approach which was developed in this thesis aims at maximising NPV by concurrently varying metal price and grade-tonnage distribution in the algorithm. Variation of these variables was necessary to capture the inter-temporal fluctuations experienced in these two variables for most mining operations. The metal price was varied using a random number generator developed in the code for generating values within a specified range while multiple realisations of grade-tonnage distribution were factored into the algorithm.

The algorithm for the stochastic cut-off grade approach was coded using C++ on a Microsoft Visual Studio integrated development environment (IDE) to develop a computer-aided application named *NPVMining*. Using a dataset from a gold mine, the algorithm generated a set of possible solutions with the maximum NPV against a specific time range as the optimal solution to a given block model. The resultant cut-off grade policies were compared and analysed using linear regression analysis. The analysis

indicated that metal price has a higher effect on NPV compared to the grade-tonnage distribution as these had correlation coefficients of 0.97 and 0.13 with NPV, respectively.

Using the same dataset from the gold mine, a comparison was between *NPVMining* and other cut-off grade calculation approaches. *NPVMining* produced economically superior NPV over other methods: 7% better than Cut-Off Grade Optimiser; 13% better than Maptek Evolution; 35% better than heuristic cut-off grade and 185% better than break-even cut-off grade approach. A risk analysis of the NPV generated from *NPVMining* against the input parameters using @Risk software from Palisade Corporation indicated that metal price has the highest effect on the NPV. Sensitivity analysis was undertaken on the results by factoring a range of -15% to +15% on the input variables to determine the stability of the solutions. The NPV values from the sensitivity analysis ranged from about US$460 to US$472 million, which is a relatively stable solution and can therefore be accepted with confidence when undertaking the project.

In conclusion, the study contributed to knowledge by developing a stochastic cut-off grade optimisation model. The study demonstrated the advantage of modifying Lane's cut-off grade theory to accommodate the two stochastic input parameters. For this reason, it is prudent for mining companies to apply stochastic-based techniques such as the stochastic cut-off grade optimisation algorithm developed in this thesis.