SIMULTANEOUS OPTIMIZATION OF ULTIMATE PIT LIMIT AND PRODUCTION SCHEDULING FOR SURFACE MINE OPERATIONS

ABSTRACT

Economic viability of an open pit mining project largely depends upon the design of ultimate pit and production scheduling. Solving these two problems is crucial since it involves with large cash flow in the order of multi-crore investment for a big open pit project. In conventional mine planning, an ultimate pit is designed first and then an extraction scheduling for the material inside the pit is carried out. In last few decades, the upgraded computers and new techniques put the mine planner in a better position to optimize these two processes. Past studies indicate that these two problems are dealt independently and efforts are made to optimize them separately. However, independent dealing does not produce an optimal solution as they are interlinked. One cannot find the ultimate pit with the highest net present value (NPV) until one knows the block values and one does not know the block values until a mining sequence is derived. This is commonly known as a circular reasoning problem in mining literature. Therefore, efforts should be made to address the above circular reasoning problem in order to maximize NPV of an open pit mining project. In this study, an attempt has been made to interlink these two problems and solution methodology is derived to produce ultimate pit and production scheduling simultaneously by developing a genetic algorithm based meta-heuristic algorithm.

To develop an efficient algorithm some innovative concepts are incorporated in the designed methodology of the algorithm. This includes the algorithm started with good initial solutions of pit and schedule. Three different mechanisms: forward aggregation based schedule, backward aggregation based schedule and block based random schedule are used to generate initial population of solutions. Moreover, customized crossover and mutation operators specific to mine scheduling problem are implemented in this study. A mechanism of updating the pit and the schedule is included in the designed algorithm to produce the final pit and schedule simultaneously. Before the performance testing of the

algorithm, the critical GA parameters are selected by conducting an experiment using case study mine data.

In order to evaluate the efficacy of the algorithm in different types of ore deposit formations, the performance of the algorithm is examined on various hypothetical block models. These hypothetical block models, akin to three prominent ore deposit formations such as single vein type, double parallel vein type and flat tabular type, are prepared using contrived data set of ore grade, cost and revenue. For each deposit type, 10 different sizes (500 to 100000) of block models are generated using geostatistical simulation algorithm, which helps to ascertain the time efficiency of the algorithm with respect to block model size. The algorithm is implemented on: (i) full block model (Case II), (ii) reduced block model using bounding technique 1 (Case III) and (iii) reduced block model using bounding technique 2 (Case IV). Using the bounding technique 1, the reduced block model is obtained by scanning the full block model with an inverted cone such that the cone does not miss any positive valued block. Whereas, for bounding technique 2, the reduced block model is derived by imposing a bounding on the basis of nested pit heuristic considering a revenue factor 1.05. This bounding is slightly larger than that of pit outline which could have been obtained using network flow algorithm. Further possibility of improvement in NPV is explored by applying a post-processing algorithm using maximum flow algorithm on the pits and schedules from the above three cases. The updated cases are referred as Case V, Case VI and Case VII respectively. These six cases are compared with a reference pit and schedule (Case I) obtained using conventional approach. A sensitivity analysis with respect to discount factor, mining capacity and block model properties (mean and variance) is also carried out to understand the influence of these factors on the final pit and schedule as well as on the NPV. The algorithm is then implemented on a real case study to produce pit and schedule simultaneously.

Based on the study results, it is observed that running of the algorithm on full block model produces the pits and schedules which are inferior to the reference pit for all the hypothetical model studies. The situations are much poorer for the vein type deposits than the flat tabular case. For example, the NPVs for Case II are, on an average, 58%,

34.8%, and 0.02% lower than the Case I. In comparison with full block model, a substantial improvement in NPV for resulted pit and schedule is observed to occur for the reduced block model obtained from the bounding technique 1. However, the NPVs are still in lower side than the Case I for both the single and the double parallel vein type deposits. On the other hand, the bounding technique 1 does not show any impact on the flat tabular type deposit. The real benefits are achieved by running the algorithm on the reduced block model obtained from the bounding technique 2. The NPVs, on an average, for this case (Case IV) are 1.80%, 2.18% and 1.16% higher than the reference case for single vein, double parallel vein, and flat tabular type hypothetical models studied. It is further noticed that the post-processing algorithm for all the cases improve the NPV of the pit and schedule. It is also revealed that the Case VII produces the highest NPV pit and schedule. The NPVs for the Case VII are, on an average, 2.31%, 2.29% and 1.17% higher than the reference case for single vein, double parallel vein and flat tabular type deposit models studied. The algorithm is also practically implementable for big open pit mine as the best NPV case (Case VII) is executed within 10 minutes, 25 minutes, and 1 hour 8 minutes respectively for single vein, double parallel vein, and tabular type of deposit models of 100000 block size, which are scheduled to be extracted in six uniform periods. The sensitivity analysis indicates that the discount factor has the influence on the NPV of the resulted pits and schedules. Additionally, it may also bring changes in the pit size for certain range of discount factor values. For the case study mine, the pit and schedule for the reference case has resulted the NPV of Rs. 26949 million. On the other hand, the best case scenario of the algorithm (Case VII) yields the NPV of Rs. 32640 million. Hence, there is a direct benefit of 21.11% improvement in NPV using the designed approach. Study on imposing the penalty for the targeted ore tonnage and grade violations for the case study mine indicates that with an imposition of low penalty cost, the ore tonnage target may be met on regular basis; however, even with high penalty is imposed, the Al_2O_3% target grade specification cannot be met for the mine. Imposing penalty, the NPV of the pit is slightly affected.