Abstract

The short-term mine production scheduling problem aims to determine the optimal sequence of extraction of the mining blocks and the optimal destinations of the extracted blocks to meet the quality and quantity requirements of the processing plants in each period, subject to all relevant technical and operational constraints of the mining system. It is carried out at shorter scales of days/weeks/months under the scope of long-term production scheduling. A multi-mine mineral value chain (MVC) in open-pit mining consists of multiple mines upstream supplying materials to a material flow circuit downstream that typically includes stockpiles, waste dumps, and a complex value-added material processing system. An optimal short-term production schedule for MVC involving multiple mines that share the same infrastructure (processing units, stockpiles, waste dumps, etc.) requires coordination across the network of mines. Optimizing the short-term production schedules independently at each mine fails to capture the benefit of collaboratively generating schedules for all the mines, resulting in sub-optimal schedules. In short-term production scheduling, there are fewer blocks and thus fewer binary decision variables compared to the longterm production scheduling. However, this variable reduction is negated by the additional decision variables and constraints incorporated to model the more complex multi-mine MVC short-term production scheduling situations. This makes the industry scale instances computationally intractable for standard mixed-integer programming (MIP) solvers. Furthermore, the mining system is characterized by geological uncertainty, and the model which does not incorporate this uncertainty produces unreliable production schedules.

In this thesis, a customized genetic algorithms (GA) based heuristic approach is developed to obtain near-optimal solutions to the industrial-scale instances of the short-term production scheduling problem of multi-mine MVC within a reasonable computation time. The essential components of the developed solution approach, viz. encoding, population initialization, crossover and mutation operations, have been customized to mold the algorithm to solve the short-term production scheduling problem. In this study, two techniques (Topological sorting technique and Linear Programming (LP) relaxed approach) have been developed to generate the initial population of GA. In

addition, three new crossover operators (Similar before point crossover (SBPX), Similar after point crossover (SAPX) and Similar before and after point crossover (SBA2PX) operators) and two new mutation operators (Local mutation and Global mutation operators) have been developed in this study. The two techniques developed to generate the initial population of GA lead to two GA variants, namely Genetic Algorithms with Topological Sorting (GATS) and Genetic Algorithms with LP-relaxed approach (GALP). These two variants of GA share identical reproduction, crossover and mutation operators and have been independently used to solve industrial-scale instances of the short-term production scheduling problem for multi-mine MVC. A set of fourteen test instances were prepared from the case study mines in the increasing order of complexity to evaluate the efficacy of the two variants of the GA-based solution approach. These instances were then solved using the CPLEX (commercial optimization software) and the GA variants, GATS and GALP, and their objective function values and computation times were compared. The results show that both GATS and GALP provide near-optimal solutions to the industrial-scale instances of the short-term mine production scheduling problem of multi-mine MVC within reasonable computation time while the CPLEX optimizer fails to solve such large-scale problems. For all the smallerscale instances of the short-term production scheduling problem CPLEX solved, the GATS and GALP found solutions, on average, within 1.22 % and 0.78 % of the optimum solutions of CPLEX, respectively, within significantly less computation time, which demonstrates the efficiency of the developed GA variants.

An Indian iron ore mining complex with four operating mines and two processing plants has been selected for the case study in this work. The GA-based solution approach was applied to the case study mines to generate short-term production schedules on a monthly scale. It was found that the solution obtained from the GAbased approach met the tonnage requirements for processing plant-1 for all the periods. For plant-2, there were minor deviations from the tonnage requirements in 5 out of 12 periods. However, marginal deviations within 0.05 % of the lower bound tonnage requirements of plant-2 are observed. Similarly, as far as quality requirements were concerned, the GA met the average grade requirements for iron (Fe %) and alumina ($Al2O3$ %) for both the processing plants in all the periods. However, the grade requirements of silica ($SiO2$ %)

could not be met for any period, and this was attributed to the high average silica content in the case study deposit with respect to the specification range.

Additionally, to illustrate the benefits of incorporating geological uncertainty in the short-term production scheduling model, fifty simulated scenarios of the ore deposit were generated using the geostatistical conditional simulation technique and fed to the stochastic short-term production scheduling model. The stochastic approach was benchmarked against the deterministic approach, and both the approaches were solved using GA-based heuristics. It was found that with better availability of grade variability information in the stochastic model, the GA-based solution approach can manage the risk of not meeting the grade requirements better than the deterministic model and produce robust and reliable short-term production schedules.

Keywords: Short-term mine production scheduling, Multi-mine mineral value chains, Genetic Algorithms, LP-relaxed approach