

Development of a Sustainable Mine Planning Framework for Optimal Pit Design

ABSTRACT

The ultimate pit limit (UPL) is the most fundamental strategic decision in open-pit mine planning, delineating the final boundary of the deposit that is economically and technically feasible to extract. Conventional UPL methods, such as the Lerchs-Grossmann algorithm, optimize exclusively for undiscounted profit and ignore the social and environmental consequences of the selected pit. Existing sustainability-oriented approaches rely on multi-criteria selection from a small set of pre-generated nested pits and use linear normalization that cannot capture the diminishing returns, threshold effects, and non-linear trade-offs inherent in sustainability assessment. A generative optimization framework is therefore needed that directly searches the combinatorial space of feasible pits under a non-linear multi-criteria objective.

This thesis develops a novel memetic algorithm (MA) framework for sustainable UPL determination, integrating three components: (a) a MIVES-based assessment of 13 indicators across economic, social, and environmental pillars, aggregated into a Global Sustainability Score (GSS) through a two-level hierarchy weighted by Z-Fuzzy AHP; (b) a customized MA hybridizing a genetic algorithm with greedy local search and simulated annealing, followed by a five-phase post-optimization refinement; and (c) constraint programming (CP)-based hint seeding to warm-start the evolutionary search. Precedence-aware crossover and mutation operators guarantee feasibility with respect to over a million slope-stability constraints. The framework is applied to a real-world iron-ore case study with 138,110 blocks across 39 bench levels. The MA-optimized pit (32,047 blocks, GSS = 0.7073) outperforms the profit-maximized UPL (GSS = 0.6949) by 1.78% and the best nested pit (GSS = 0.7062) by 0.16%. Compared to the profit-maximized UPL, it sacrifices only 3.4% in normalized economic performance (a 3.21% raw profit reduction) while delivering 21.5% higher environmental performance and extracting 21.2% fewer blocks. Sensitivity analysis across six pillar-weight scenarios confirms the MA pit's dominance in four. Vectorised fitness evaluation yields a 1,800× speedup, keeping total runtime under 60 minutes. The study establishes the first application of memetic algorithms and the MIVES framework to open-pit mine design, providing mine planners with a practical tool for balancing economic viability with social and environmental stewardship.