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Metaheuristics and hyperheuristics for large-scale optimization of mining complexes

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Abstract : An industrial mining complex is an integrated value chain includes the excavation, transportation, processing, and distribution of mineral products as well as the storage of waste products. Critical sources of uncertainty include the characterization of the mineral deposits, commodity prices, equipment performance, and processing facility performance. To maximize long-term value of the mining complex, an optimization model is formulated, accounting for decisions in block extraction, material destination policy, downstream material flow, capital investments, and major operating modes. The size of the model, number of binary and integer variables, and the presence of non-linear transformations in the formulation make optimization with exact methods highly impractical. Metaheuristics have been used to provide good solutions in reasonable execution times. Hyperheuristics have extended these capabilities, using online learning to accelerate optimization. Algorithms amenable for parallel computing present opportunities to scale hardware and further improve optimization results while reducing execution times. The present work reviews these developments and explores how they can be combined for the application of optimizing mining complexes.

Metaheuristics and Hyperheuristics for Large-Scale Optimization of Mining Complexes

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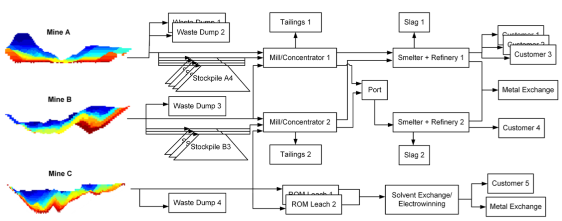
Background

- An industrial mining complex is an integrated value chain that includes the excavation, transportation, processing, and distribution of mineral products as well as the storage of waste products
- To maximize long-term value of the mining complex, an optimization model is formulated, accounting for all decisions simultaneously
- Capital investments are major decisions that have a significant impact on the outcome of the mining project
- Critical sources of uncertainty need to be considered in the inputs to manage risk; these can be quantified using conditional simulation
- A sophisticated solution approach is needed to handle the large optimization problem

Overview of Mining Complex



Sources of Uncertainty

- Geostatistical: distribution of key material properties (e.g. metal grades, grindability, minerology, material type,…)
- Geometallurgical: performance of processing facilities (e.g. comminution energy consumption, metal recovery, reagent consumption, tailings properties,…)
- Economic: commodity prices
- Equipment: availability, utilization, efficiency

Stochastic Integer Programming Formulation

Key Decision Variables

Mine block b in period t	$x_{bt} \in \{0,1\}$
Send cluster c to destination j in period t	$z_{cjt} \in \{0,1\}$
Send portion of material from i to j in period t, scenario s	$y_{ijts} \in [0,1]$
Number of CAPEX options k taken in period t	$w_{kt} \in \{0,1,2,\dots\}$
Use operating mode a at process facility i in period t	$u_{iat} \in \{0,1\}$
Upward and downward deviations from production target h at location i in period t and scenario s	$d^+_{hits}, d^-_{hits} \geq 0$

Objective Function

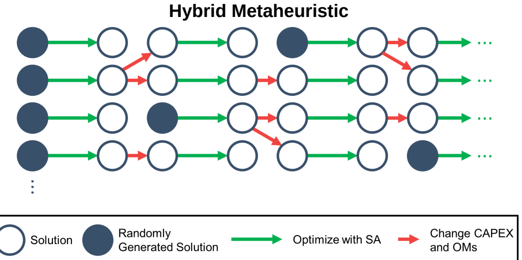
$$\max \underbrace{\frac{1}{|\mathbb{S}|}\sum_{s\in\mathbb{S}}\sum_{i\in\mathcal{N}}\sum_{h\in\mathbb{H}}\sum_{t\in\mathbb{T}} p_{hit}\cdot v_{hits}}_{\text{Discounted cashflow}} - \underbrace{\sum_{k\in\mathbb{K}}\sum_{t\in\mathbb{T}} p_{kt}\cdot w_{kt}}_{\text{CAPEX Costs}} - \underbrace{\sum_{i\in\mathcal{P}}\sum_{a\in\mathbb{A}_i}\sum_{t\in\mathbb{T}} p_{iat}\cdot u_{iat}}_{\text{Operating Mode Costs}}$$

$$- \underbrace{\frac{1}{|\mathbb{S}|}\sum_{s\in\mathbb{S}}\sum_{i\in\mathcal{N}}\sum_{h\in\mathbb{H}}\sum_{t\in\mathbb{T}} [c^+_{hit}\cdot d^+_{hits} + c^-_{hit}\cdot d^-_{hits}]}_{\text{Penalties}}$$

Solution Framework

- Number of (integer and binary) variables and nonlinear components in the formulation make exact solvers impossible
- Simulated Annealing provides a base to start developing a solution method for this problem
- CAPEX and operating mode decisions pose a challenge for perturbation-based metaheuristics because changing them requires many changes to other variables
- Idea 1: Always accept perturbations to CAPEX and operating mode decisions but make these tabu for a fixed duration afterwards
- Idea 2: Run multiple executions in parallel with different starting solutions to capitalize on hardware resources, taking the best single solution at the end
- Idea 3: Allow the executions to communicate when perturbing CAPEX and operating mode decisions, keeping or perturbing the best and discarding the worst solutions, creating an evolutionary algorithm with simulated annealing embedded into each generation
- Idea 4: Use online learning to improve heuristic selection during simulated annealing phase and mutation selection during the evolutionary phase to accelerate optimization performance

Hybrid Metaheuristic



Online Learning Hyperheuristic