Risk control in ultimate pits using conditional simulations

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Agenda

- Introduction
- Ultimate Pit with Risk Control
- Computational Study
- Conclusions
Introduction
Explicit Risk Control for Open Pit Mine Planning

- Explicit Risk Control:
  - Explore tradeoffs (e.g. efficient frontier)

- First Step:
  - Risk control for ultimate pit problem
  - Only risk from geological uncertainty
  - Geological uncertainty model is from conditional simulation
Traditional Ultimate Pit (U-Pit)

One block model from ordinary kriging

Optimization Software

Ultimate Pit
Ultimate Pit Using Conditional Simulation

Multiple block models from conditional simulations → Optimization Software → Ultimate Pit
Objectives of Study

- Introduce a version of U-pit with explicit risk control
  - 1 risk parameter: want efficient frontier
  - Use probabilistic constraints
- Compare optimal solutions to other risk mitigating approaches
- Study effect of varying number of conditional simulations
Ultimate Pit with Risk Control
Ultimate Pit Optimization

- Pit:
  - Group of blocks satisfying precedence constraints.
- Profit of Pit:
  - Sum of profits of blocks in pit.

$$\begin{align*}
\max & \quad \text{profit}(P) \\
\text{s.t.} & \quad P \text{ is a pit}
\end{align*}$$

- Ultimate Pit:
  - Pit that maximizes profit
Profit and Block Models

- Profit of pit = random variable with 4 equally likely realizations
Risk Control for Random Profit

\[ \text{profit}_\delta(P) := \max z \]
\[ \text{s.t.} \]
\[ \text{Prob}(\text{profit}(P) \geq z) \geq \delta \]

- Quantile/VaR profit
  - Restricts variability
  - One risk parameter
U-Pit with Risk Control

\[
\begin{align*}
\text{max} & \quad \text{profit}_\delta(P) \\
\text{s.t.} & \quad P \text{ is a pit}
\end{align*}
\]

- Solve for several deltas
  - Tradeoffs,
  - Efficient Frontier,
  - Sensitivity, etc.

- Can be modeled as an Integer Programming (IP) problem
  - We denote it as SIP
Computational Study
Test Instance and Software

- Section of Andina copper mine in Chile
- 34140 blocks
- 10 conditional simulations using TBSIM
- Use CPLEX v11 and max-flow solver in EGLIB
- Methods: SIP and three existing approaches
“Average” Approach

- Multiple block models
- One average model
- Optimization software
- Ultimate pit

- Traditional U-Pit with kriging block model
"Simulations" Approach

- Similar to Dimitrakopoulos et al. (2007).

Multiple block models → Optimization software → One pit per model → Pick best pit
“Hybrid” Pit Approach

- Introduced in Whittle and Bozorgebrahimi (2007).
Results for 10 Simulations
Simulations: Only Samples of Random Var

- Are 10 samples enough?
- Possible Test: 
  - Reevaluate solutions using 100 samples
10 Sim Sols Reevaluated with 100 Sims
Results for 100 Simulations
Conclusions
Conclusions

- Propose probabilistic version of Ultimate Pit
  - Very hard to solve for large number of simulations
  - Other approaches are good heuristics but are suboptimal

- Study effect of varying number of simulations
  - Profit of 10 simulation solutions can be cut in half when evaluated with 100 simulations
  - Optimal profits can drop almost 30% from 10 to 100 simulations

- Future work
  - Other risk controls: Conditional value at risk?
  - Efficient solution of SIP
  - Use Sample Average Approximation to mitigate # of simulations effect
  - Other mines, other risk sources
  - Risk control for the complete schedule generation