Artificial Intelligence for Mining Complexes:

Self-learning, deep neural networks and real-time adaptation of production scheduling

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Content

- Mining complexes - Mineral value chains
- New information and production planning
- Reinforcement learning
- Example from a copper mining complex
- Conclusions
Conventional / Deterministic Workflows

80% of Failures Due to Geological Risk

Australasian Examples – Technical Risk

Baker and Giacomo (1998)
A set of simulations describe geological uncertainty and grade variability

A single mine design and production schedule accounting for uncertainty and managing risk

A better NPV is always obtained through the use of stochastic mine planning in comparison with conventional methods

Stochastic Orebody Modelling

Stochastic Mine Design & Production Scheduling

Financial & Production Forecasts

Simulated Orebody Models

Stochastic Design & Production Schedule

Probabilistic Reporting
Simultaneous Optimization

One Stochastic Mathematical Programming Formulation for the whole Mineral Value Chain
A mining complex may be seen as an *integrated business* starting from the extraction of materials to a set of sellable products delivered to various customers and/or spot market.

Simultaneous optimization of the mining complex/value chain.
In Petroleum Reservoir Engineering:

Smart Oil Fields

Source: https://smartfields.stanford.edu/

Dept of Energy Resources Engineering
Stanford University
The Self-learning Mining Complex and Updating Short-term Production Plans
New Information - Mining Complexes

- Sensor generated information
- Equipment (Truck, Shovel)
- Crushers
- Conveyor belt
- Processing plant
- Blasthole data
- New exploration data
New Information: Workflow

New Information Collected
- Material extracted
- Delerterious elements
- Shovel performance
- Material loaded
- Truck performance
- Material crushed
- Material hauled
- Material leached
- Leach performance
- Material processed
- Plant performance

Update Short-term Production Plan

Update Uncertainty Models

Feedback to Mining Complex

New Information

Material extracted
- Material hauled
- Material leached
- Leach performance
- Material processed
- Plant performance

Processing Stream
- Fleet Assignment
- Extraction Sequence
- Destination Policy

Big Data

Machine Learning Methods

Update Short-Term Production Decisions
Updating Uncertainty Models

Stochastic Simulations

Drillhole Information

Ensemble Kalman Filter

1. Prediction Step
\[ AZ^t(x) \]

2. Correction Step
\[ Z^{t+1}(x) = Z^t(x) + K(l + w^r - AZ^t(x)) \]

New Information

- Material extracted
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- Crusher performance
- Material processed
- Plant performance

Updated Stochastic Simulations
Performance of Components

Supply Uncertainty
- Block properties
- Block tonnage
- Deleterious elements
- Material crushed
- Material leached

Equipment Uncertainty
- Shovel performance
- Truck performance
- Crusher performance
- Plant performance
- Leach performance

Where to send
What to extract
Where to send
Decision Space Complexity

Decision tree grows exponentially
Solution: Reinforcement Learning using Monte Carlo Tree Search
Reinforcement Learning using MCTS

Deep Neural Network

Monte Carlo Tree Search (MCTS)

Performance of Components

- Block properties
- Block tonnage
- Deleterious elements
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Monte Carlo Tree Search:

1. Selection
2. Expansion
3. Evaluation
4. Simulation
5. Backup
Results – A Copper Mining Complex

Mine 1

Mine 2

Waste Dump

Crusher 1

Mill -3

Crusher 2

Mill -2

Crusher 3

Mill -1

Crusher 4

Oxide Leach Pad

Cathode Plant

Sulphide Leach Pad
Parameters

• Weekly time scale - 13 weeks of production plan updated

• Supply of materials and equipment uncertainty are considered

• Extraction and destination decisions for each block

• Elements considered: Cu, As, Au, other

• 25 stochastic simulations for each mine (15 for training and 10 for testing the performance)
Updated Production Plan

Extraction Sequence

Initial Production Plan

Updated Production Plan Plan

Weeks

1 13
Updated Production Plan

Cumulative Cash Flows

Initial Production Plan

Updated Production Plan

- P90
- P50
- P10

Cumulative Cash Flow Graphs
Updated Production Plan

Copper Production

Initial Production Plan

Updated Production Plan

P90

P50

P10
Conclusions

• The Self-Learning Mining Complex
• A Reinforcement Learning Framework
• Adaptive Framework for Short-term Production Plan
• Example at a Copper Mining Complex
  • 13% increase in cash flow and 9% in copper from the updated production plan over 13 weeks
  • Very fast (<4 min for updating 13 weeks of production plan)
• A Continuous and Fast Updating Framework
• More to Expect and More Research Needed
Thanks are in order to our

COSMO Industry Members

And

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