Artificial Intelligence for Mining Complexes:

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

Roussos Dimitrakopoulos

Content

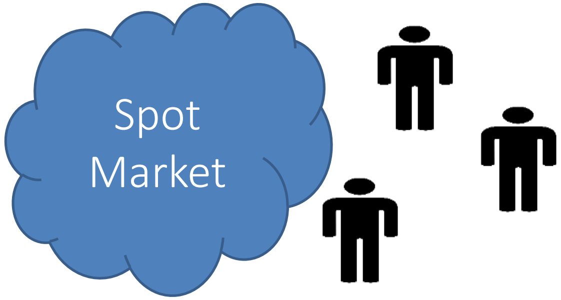
- Mining complexes - Mineral value chains
- New information and production planning
- Reinforcement learning
- Example from a copper mining complex
- Conclusions

Conventional / Deterministic Workflows

Mine

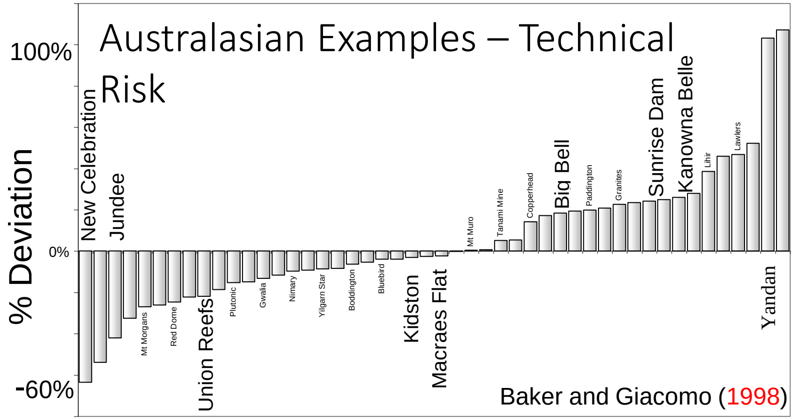
Processing streams

Customers & Markets …



Waste dumps…. Tailings… Rehab …

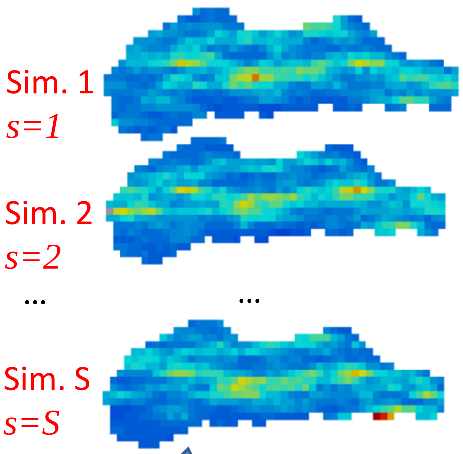
80% of Failures Due to Geological Risk



Stochastic Workflows

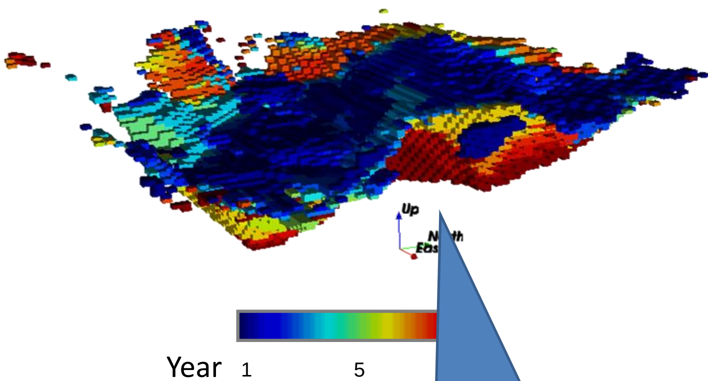
Stochastic Orebody Modelling → Stochastic Mine Design & Production Scheduling → Financial & Production Forecasts

Simulated Orebody Models



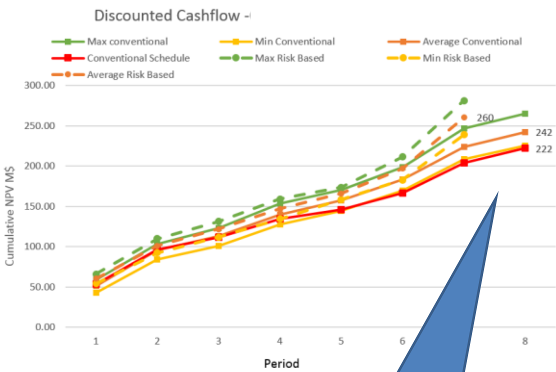
A set of simulations describe geological uncertainty and *grade variability*

Stochastic Design & Production Schedule



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

Probabilistic Reporting



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

Simultaneous Optimization

Mines

Processing streams

Customers & Markets …

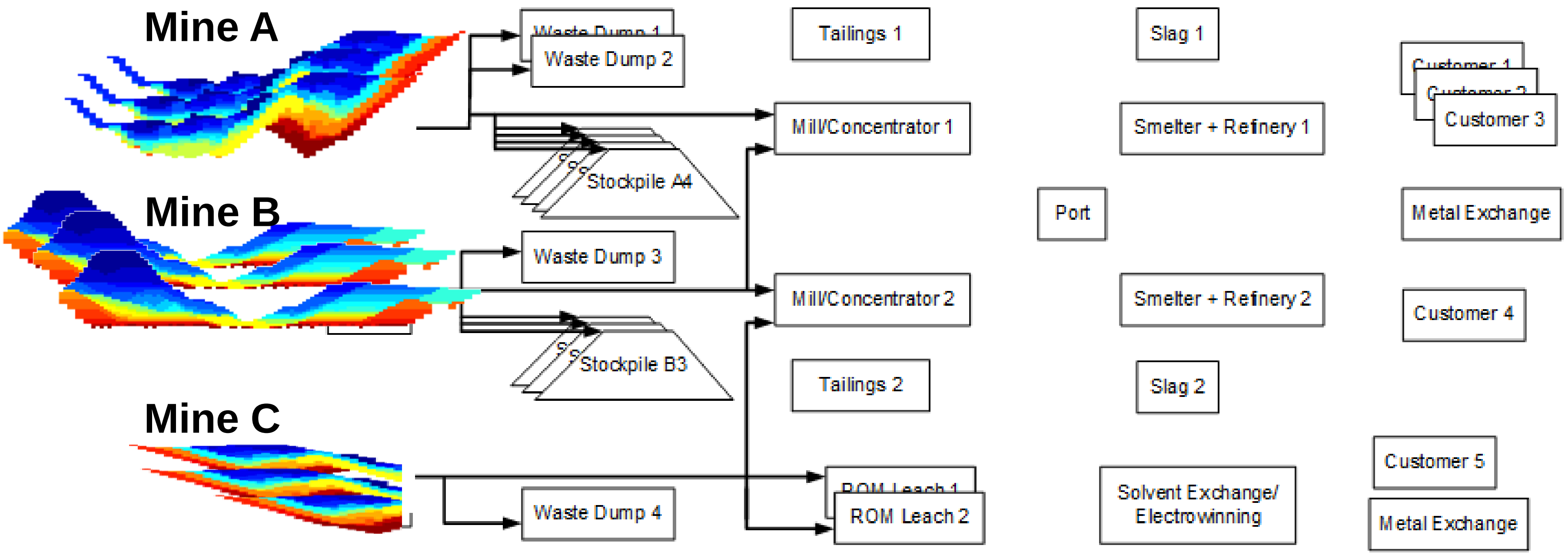
Waste dumps…. Tailings… Rehab …

One **Stochastic Mathematical Programming Formulation for the whole Mineral Value Chain**

Mining Complexes - Mineral Value Chains

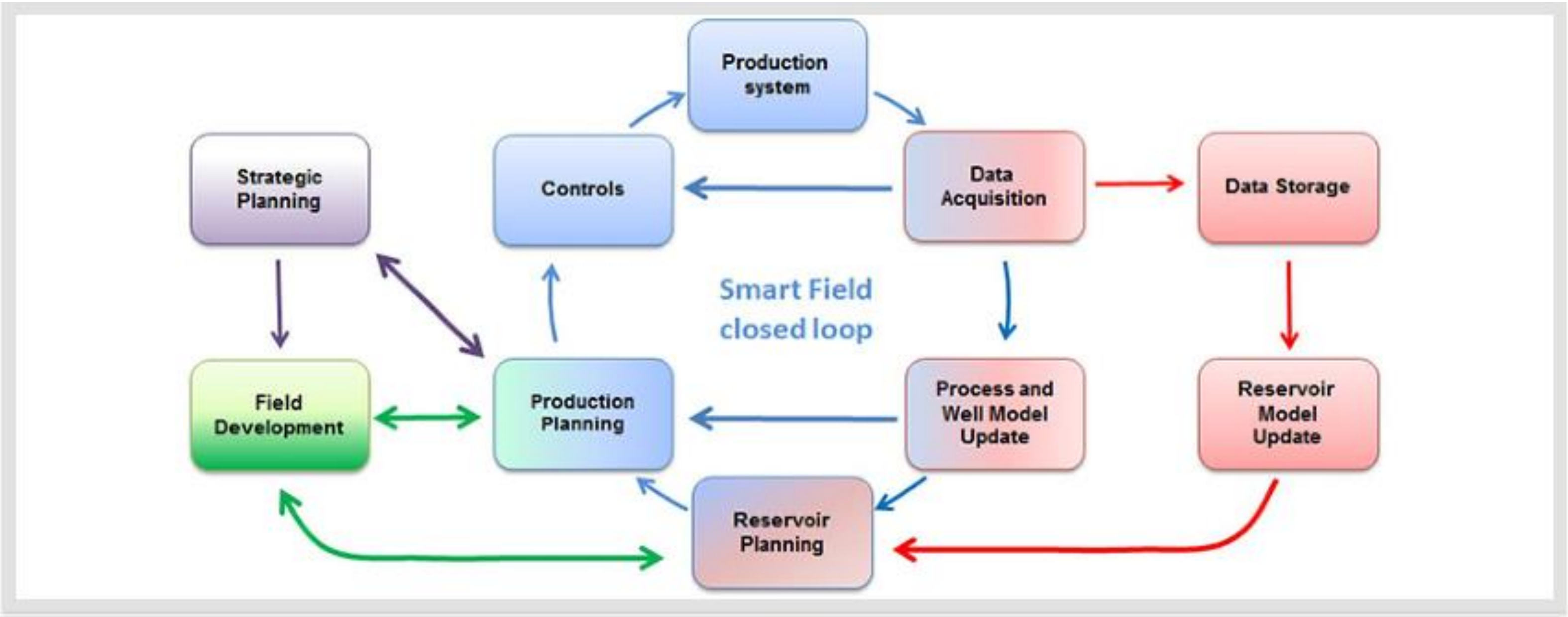
A mining complex may be seen as an *integrated business* starting from the extraction of materials to a set of sellable products delivered to various customers and/or spot market

Simultaneous optimization of the mining complex/value chain



In Petroleum Reservoir Engineering:

Smart Oil Fields



Smart Fields Consortium

Dept of Energy Resources Engineering
Stanford University

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

Mining Complexes - Mineral Value Chains

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

Sensor Information

Trucks

Crusher

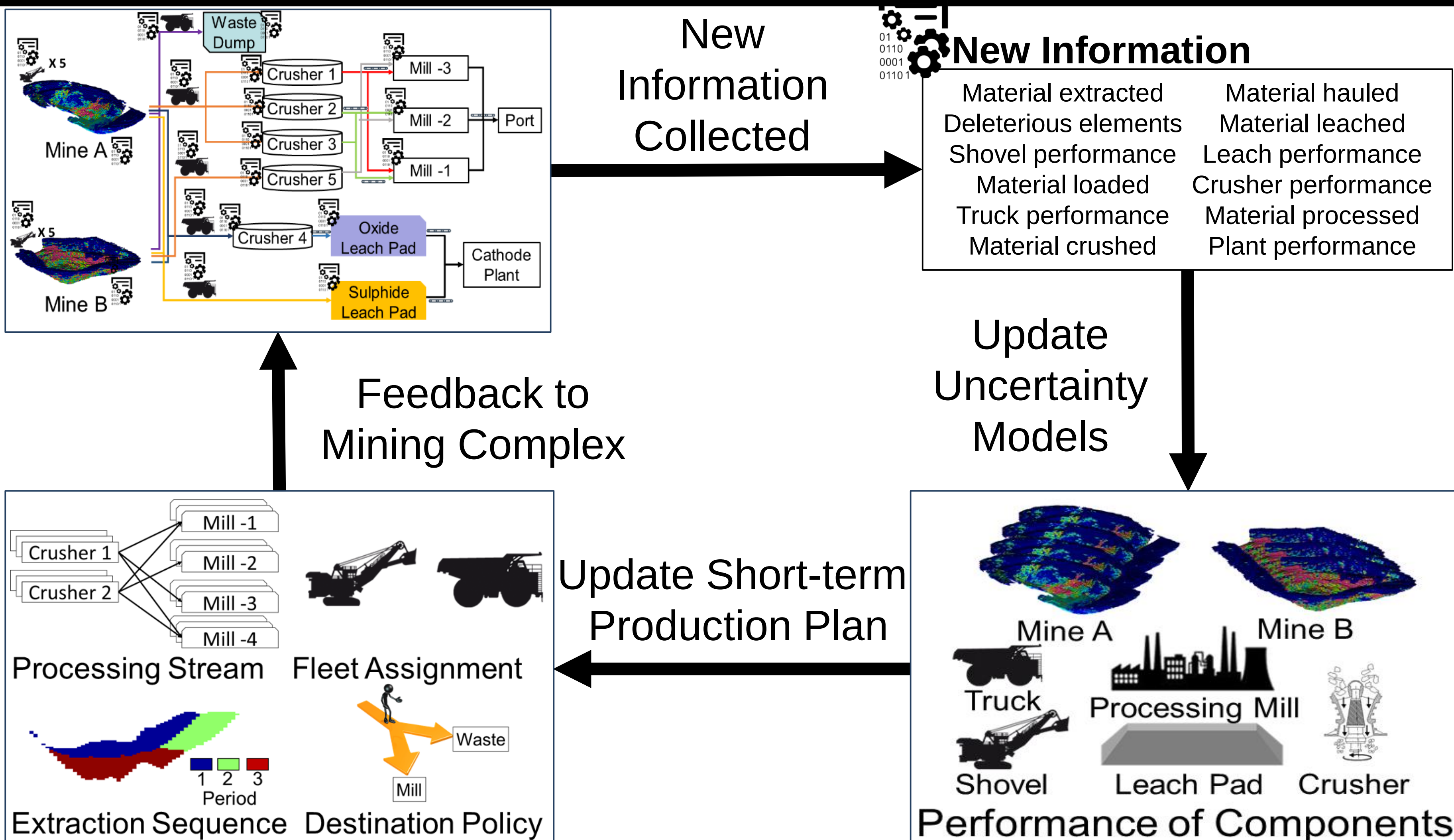
Shovels

Conveyor Belt

Exploration

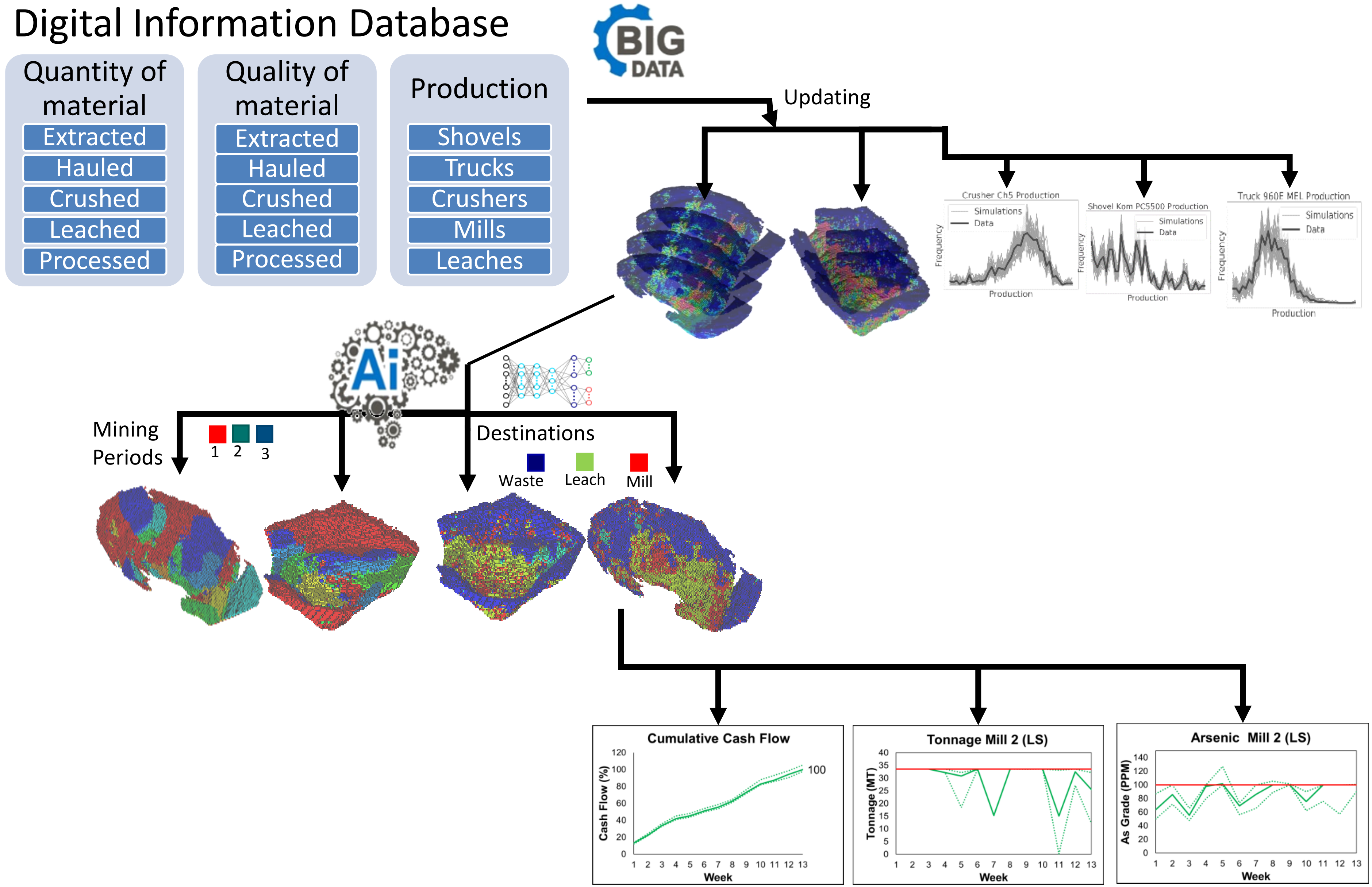
Blasthole

New Information: Workflow

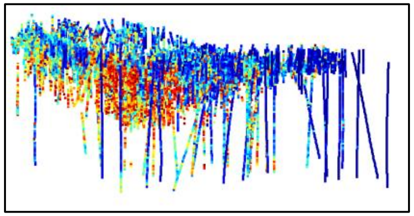


Big Data → Machine Learning Methods → Update Short-Term Production Decisions

The Self-Learning Mining Complex

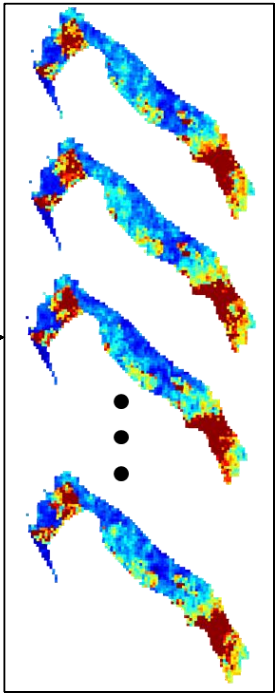


Updating Uncertainty Models



Drillhole Information

Stochastic Simulations



New Information

Material extracted	Material hauled
Deleterious elements	Material leached
Shovel performance	Leach performance
Material loaded	Crusher performance
Truck performance	Material processed
Material crushed	Plant performance

Ensemble Kalman Filter

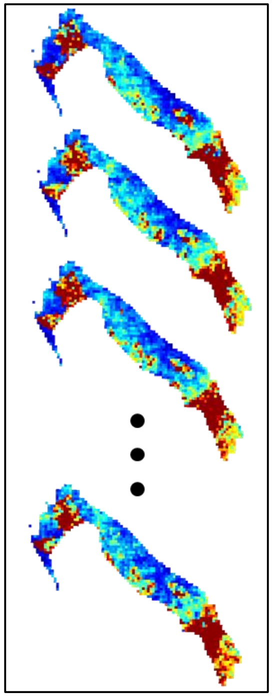
1. Prediction Step

$$AZ^t(x)$$

2. Correction Step

$$Z^{t+1}(x) = Z^t(x)$$
$$+K(l + w^r - AZ^t(x))$$

Updated Stochastic Simulations

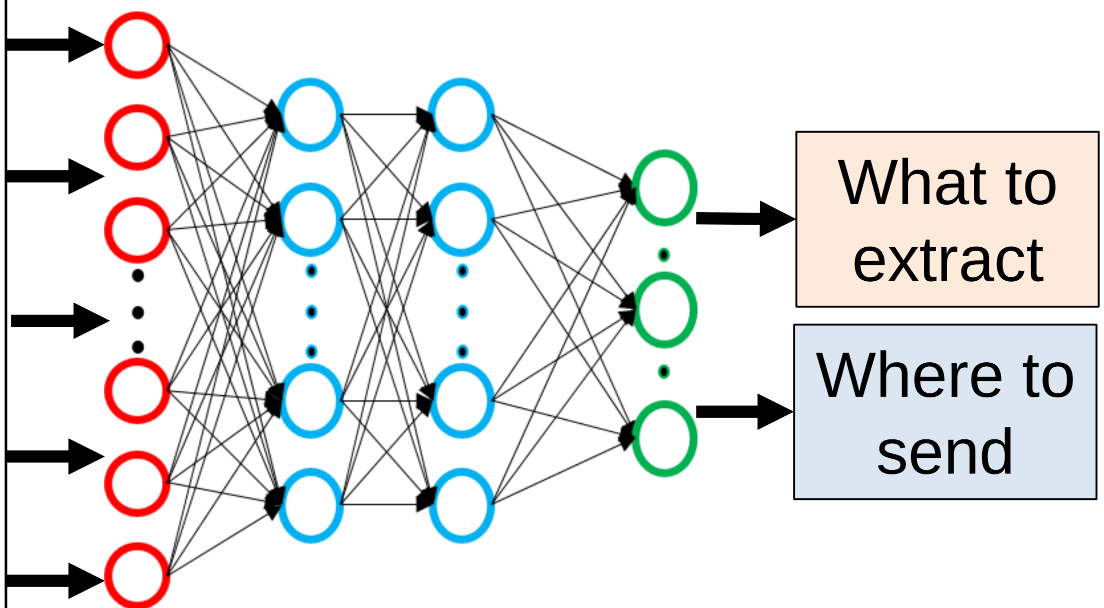


Updating Short-term Production Plan

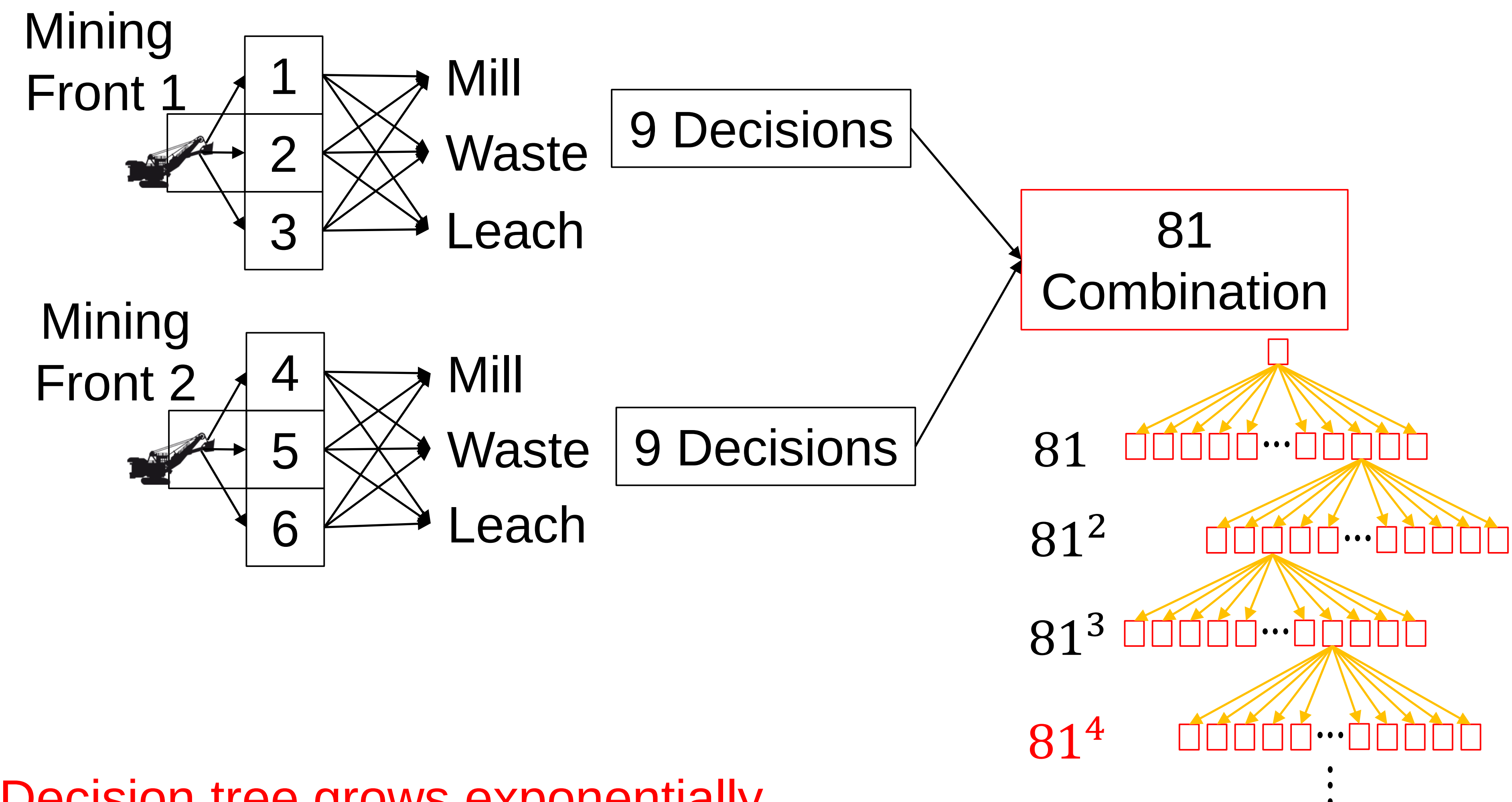
Performance of Components

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

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



Decision Space Complexity

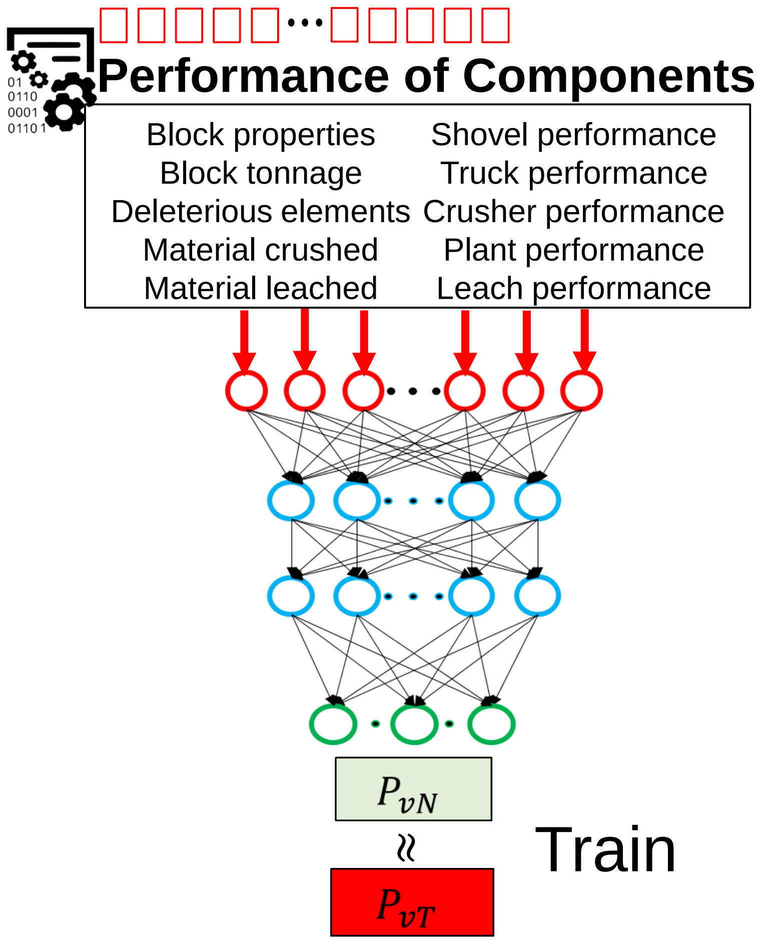


Decision tree grows exponentially

Solution: Reinforcement Learning using Monte Carlo Tree Search

Reinforcement Learning using MCTS

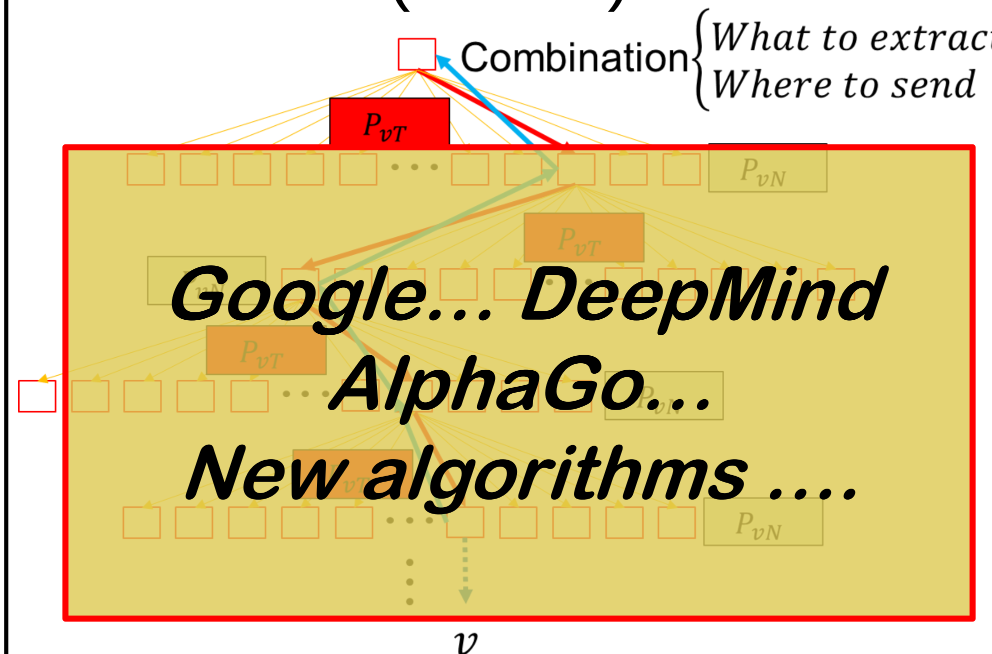
Deep Neural Network



Train

Reinforcement Learning using MCTS

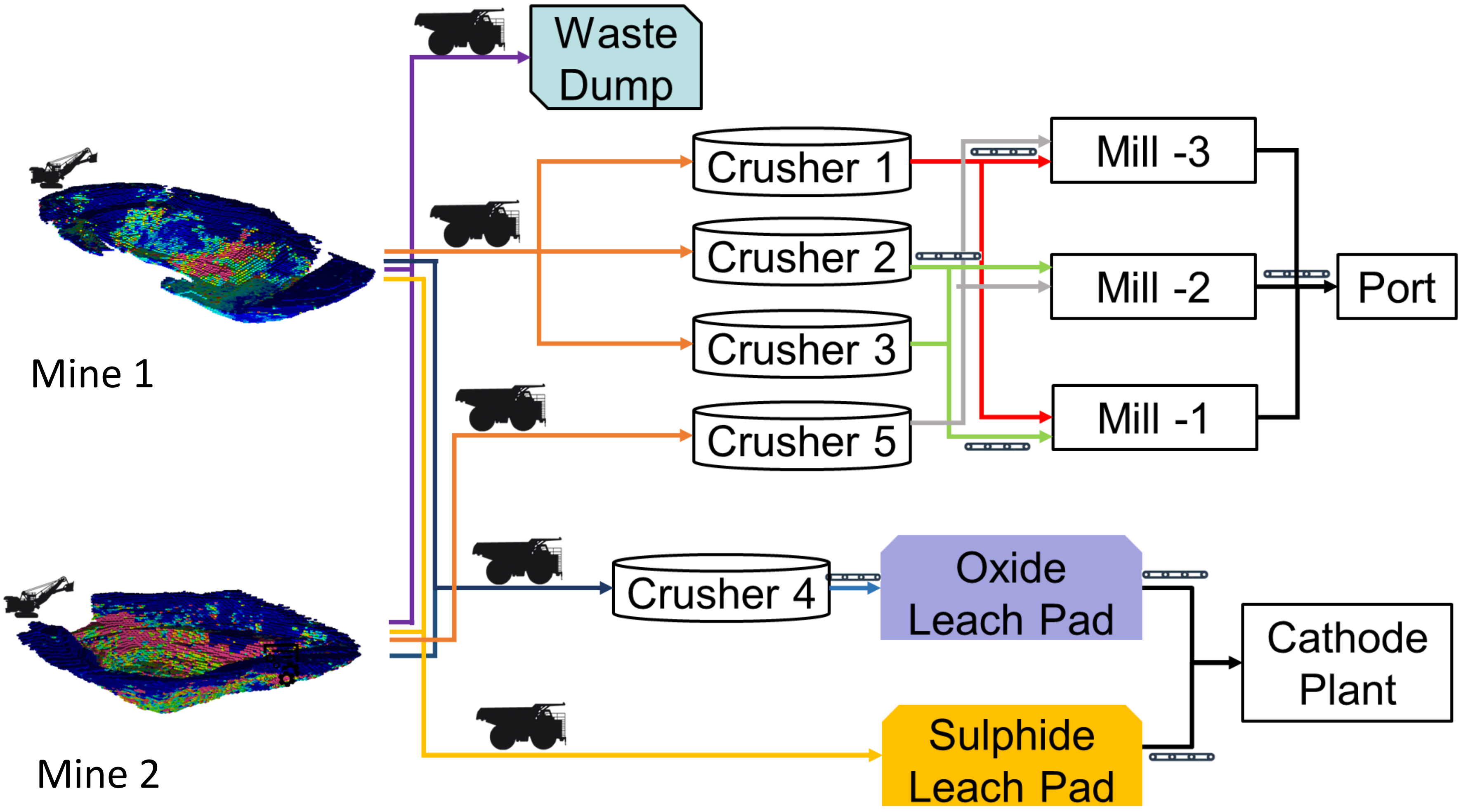
Monte Carlo Tree Search (MCTS)



Monte Carlo Tree Search:

1. Selection
2. Expansion
3. Evaluation
4. Simulation
5. Backup

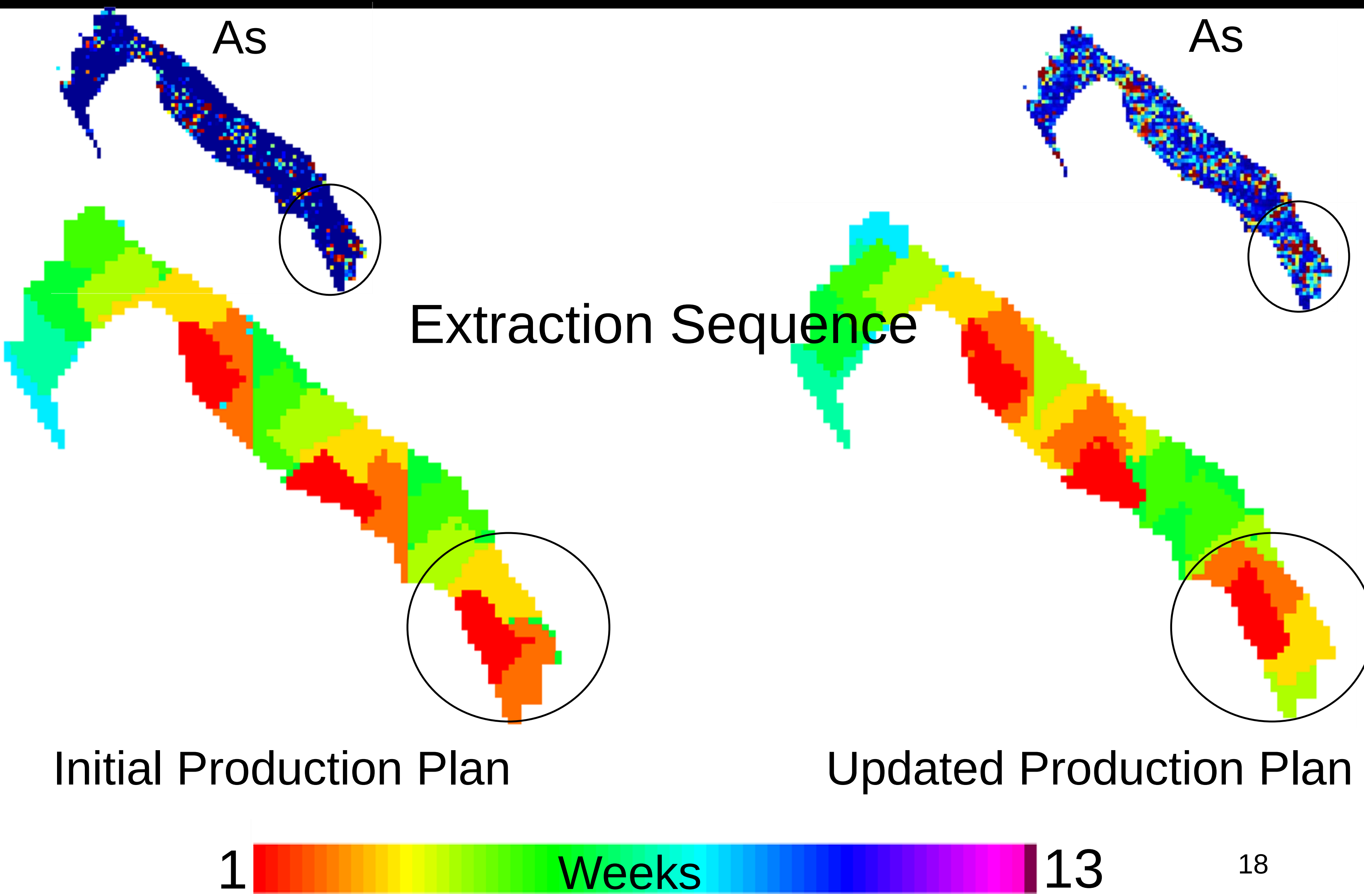
Results – A Copper Mining Complex



Parameters

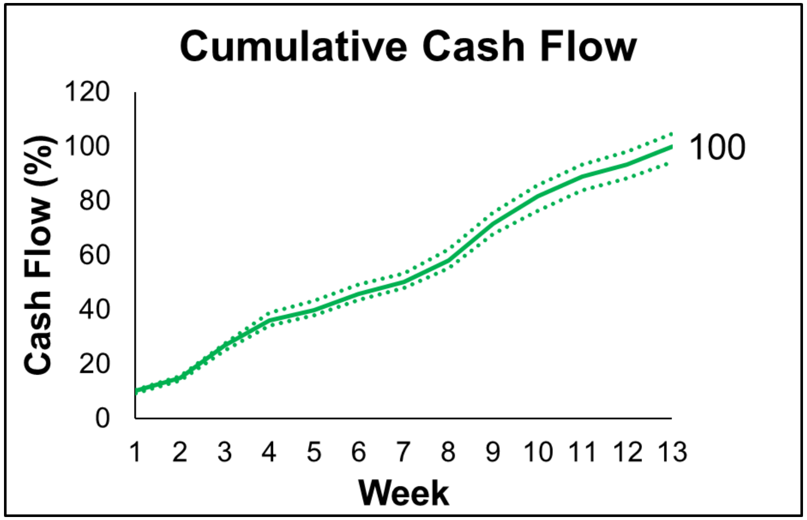
- Weekly time scale - 13 weeks of production plan updated
- Supply of materials and equipment uncertainty are considered
- Extraction and destination decisions for each block
- Elements considered: Cu, As, Au, other
- 25 stochastic simulations for each mine (15 for training and 10 for testing the performance)

Updated Production Plan

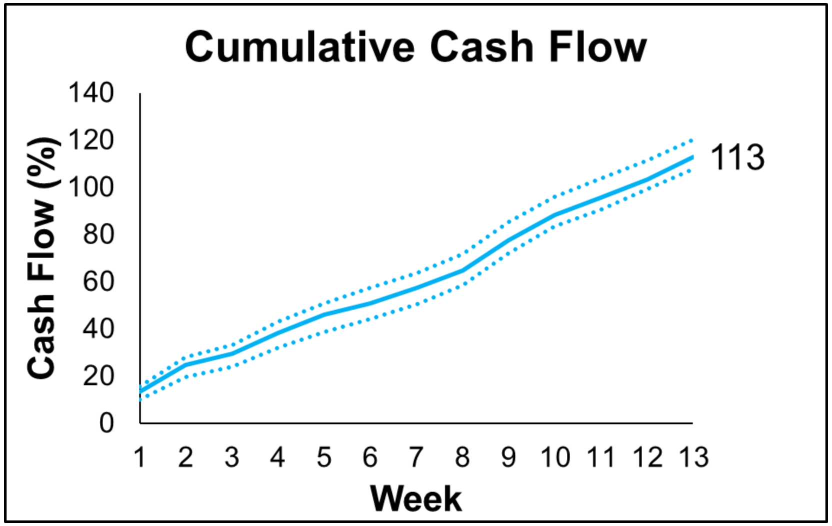


Updated Production Plan

Cumulative Cash Flows



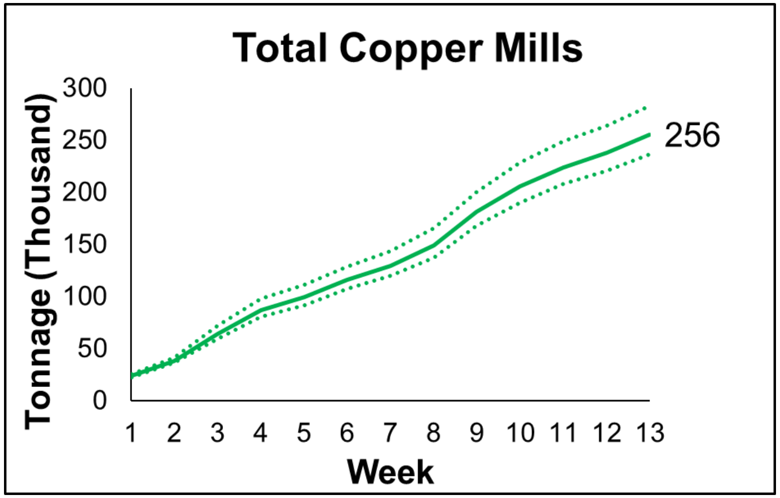
Initial Production Plan



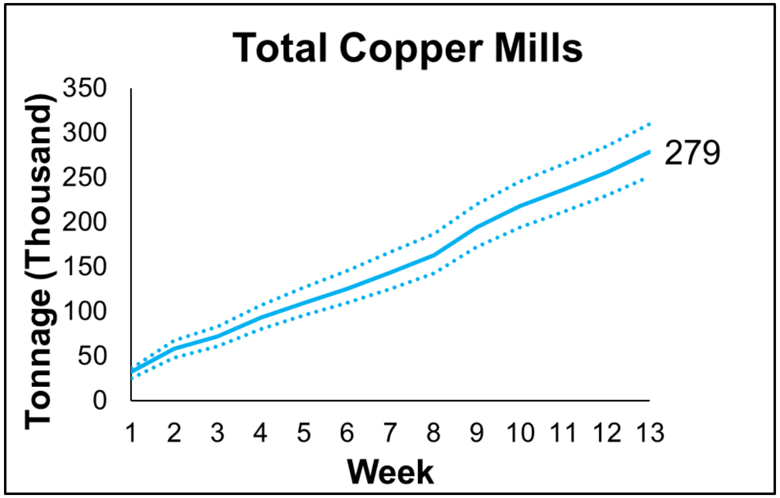
Updated Production Plan

Updated Production Plan

Copper Production



Initial Production Plan



Updated Production Plan

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 coper 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

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AngloGold Ashanti
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BHP
De Beers
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KINROSS
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And

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