

Towards Probabilistic Mineral Resources and Reserves

In the context of project evaluation, reporting standards, audits, and investment decisions

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Executive Summary

The technical event titled *“Towards Probabilistic Mineral Resources and Reserves: In the Context of Project Evaluation, Reporting Standards, Audits, and Investment Decisions”* was held during PDAC 2026 in Toronto, Canada. The initiative was organized by COSMO – Stochastic Mine Planning Laboratory, with support from CRIRSCO – Committee for Mineral Reserves International Reporting Standards, sponsorship from KPMG Canada and KPI Mining Solutions.

The event focused on advancing the adoption of stochastic and probabilistic approaches in mining, highlighting their role in project evaluation, resource classification through simulation, and their implications for risk management, reporting standards, and investment decisions across the mining value chain.

The program was delivered in person at the KPMG Office, bringing together industry professionals, technical experts, and decision-makers. Keynote speakers included Prof. Roussos Dimitrakopoulos, Marcelo Godoy, and Edson Ribeiro, who contributed with valuable insights and perspectives on probabilistic methodologies and their practical applications.

This initiative successfully engaged auditing firms, technical authorities, and industry leaders in meaningful discussions on probabilistic planning and reporting practices, reinforcing the positioning of KPI Mining Solutions and its partners at the forefront of innovation in mining evaluation and risk management.

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 - Probabilistic Methods for Resource Estimation, Classification and Mine Planning: A Competent Person's Decision? - *Edson Ribeiro*
 - Simulation and Stochastic Mine Planning: Fundamentals, Advantages and Challenges - *Prof. Roussos Dimitrakopoulos*
 - Probabilistic methods in support of resource and reserve disclosures - *Marcelo Godoy*

 - Summary and discussion
 - Towards Probabilistic Mineral Resources and Reserves - Technical Presentation and Discussion | PDAC - 2026
 - i. Probabilistic Methods in Resource Estimation - *Edson Ribeiro, Representative with CRIRSCO.*
 - ii. Simulation and Stochastic Mine Planning: Fundamentals, Advantages and Challenges - *Prof. Roussos Dimitrakopoulos, Professor at McGill University and Canada Research Chair - Tier I.*
 - iii. Probabilistic methods in support of resource and reserve disclosures - *Marcelo Godoy, CTO of AngloGold Ashanti.*
 - iv. Opened discussions and Q&A
-

Towards Probabilistic Mineral Resources and Reserves

- In the context of project evaluation, reporting standards, audits, and investment decisions -

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PROBABILISTIC METHODS FOR RESOURCE ESTIMATION, CLASSIFICATION AND MINE PLANNING: A COMPETENT PERSON'S DECISION?

Edson Ribeiro
March 2026

Setting the Context

The use of simulation-based geostatistical techniques for geological modeling, grade estimation, and classification of mineral resources and reserves has been limited for many years due to the lack of mining optimization and sequencing programs capable of dealing with stochastic and non-deterministic block models.

While this obstacle is being overcome thanks to commercial solutions recently launched on the market, other no less important rejection factors need to be equally addressed:

1. Insufficient technical training of most Competent Persons in Mineral Resources and Reserves, including those responsible for MRMR audits and certifications.
2. Lack of knowledge of the rules of the various Codes and Regulations in force.
3. Possible impacts on costs and schedules.

Setting the Context

This workshop aims to:

- Explore the CRIRSCO Template and regulations in Canada and the USA
- Review some basic theory and its potential applications
- Present some real case applications
- Raise questions and concerns, for a common view of the necessary next steps

What not to expect from today:

- Definitive Best Practices and procedures
- Final answers to all questions
- Any short-term decision or results
- The discussion of other equally critical topics

Intrinsic Characteristics of Mining

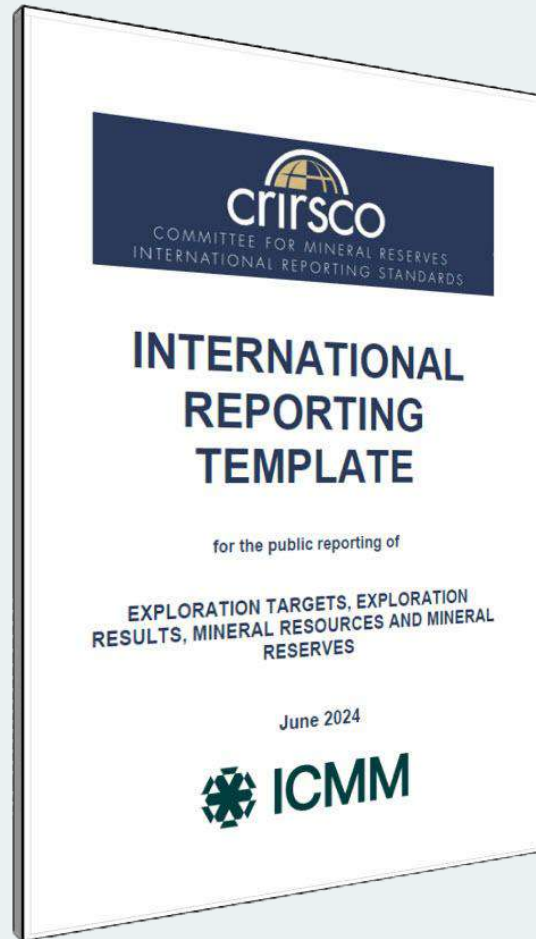
The mining industry is an international business, critical to national security and global development;

It is normally intense in capital and presents relatively long paybacks

*Based on depleting mineral assets: every mineral deposits is unique, and **knowledge is imperfect** before extraction.*

*Requires **clear communication of key uncertainties (risks and opportunities)**: it depends on the trust and confidence of investors and other stakeholders for its financial and operational well-being.*

Why was CRIRSCO created?



After cases of market manipulation and huge financial losses, it was clear the need of global controls to provide extra protection to the investors. CRIRSCO was created by the industry to promote International Best Practice in the Public Reporting of Mineral Exploration Results, Mineral Resources and Mineral Reserves.

It originally aimed to provide the framework for a required minimum standard for the Public Reporting.

Relevant to all solid minerals.

CRIRSCO: more than a Template



CRIRSCO is a **Governance System** adopted by 16 Members, covering the vast majority of the global mineral production and large stock exchanges, providing a common language and minimum standards for risk management and communication.

CRIRSCO: more than a Template

- 3 Basic Principles: Transparency, Materiality and Competence
- Standard Definitions, represented in a simple diagram
- A Global Template for Disclosure of Exploration Results, Mineral Resources and Mineral Reserves
- Governance model structured at four levels:
 - Global Committee
 - National or Regional Reporting Organizations
 - Professional Organizations
 - Qualified Professionals (**Competent Persons**)
- Relevant Experience and Professional Responsibility
- Self-regulated, with a code of ethics and disciplinary procedures



16 Standard Definitions

Public Reports	Clause 2.9	Page 8
Competent Person	Clause 3.6	Page 11
Modifying Factors	Clause 4.7	Page 15
Exploration Targets	Clause 5.1	Page 16
Exploration Results	Clause 6.1	Page 17
Mineral Resources	Clause 7.1	Page 19
Inferred Mineral Resources	Clause 7.4	Page 20
Indicated Mineral Resources	Clause 7.8	Page 21
Measured Mineral Resources	Clause 7.10	Page 21
Mineral Reserves	Clause 8.1	Page 25
Life of Mine Plan	Clause 8.5	Page 25
Probable Mineral Reserves	Clause 8.8	Page 27
Proved Mineral Reserves	Clause 8.10	Page 27
Scoping Study	Clause 9.3	Page 32
Pre-Feasibility Study	Clause 9.7	Page 33
Feasibility Study	Clause 9.8	Page 34

Figure 1: MRMR Categorization

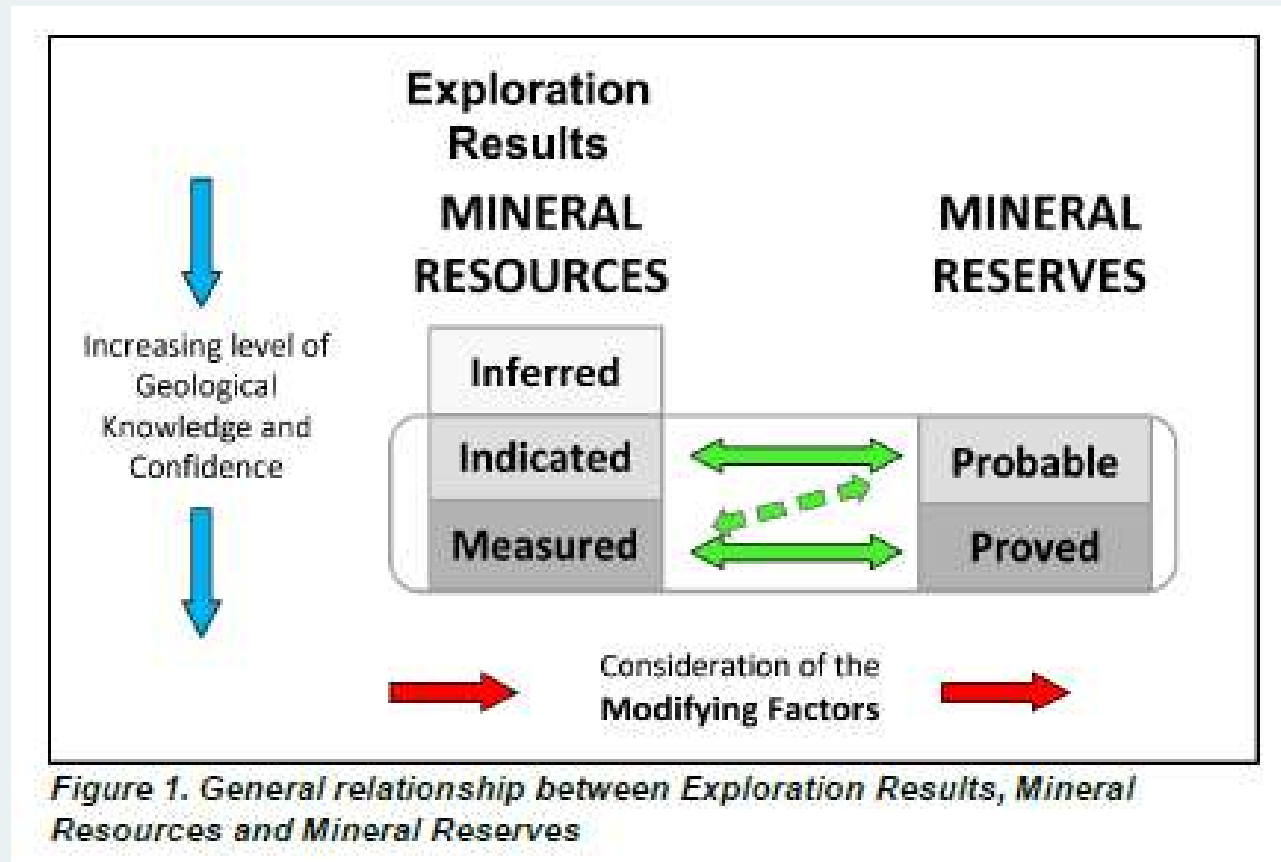


Figure 1. General relationship between Exploration Results, Mineral Resources and Mineral Reserves

The need of judgement

7.1 A Mineral Resource is a concentration or occurrence of material of economic interest in or on the Earth's crust in such form, grade or quality and quantity that there are **reasonable prospects for economic extraction**.

The location, quantity, grade or quality, **continuity** and other geological characteristics of a Mineral Resource are **known, estimated or interpreted** from specific geological evidence and knowledge, including sampling.

Mineral Resources are subdivided, in order of increasing geological confidence into Inferred, Indicated and Measured categories.

*The term 'reasonable prospects for economic extraction' implies a **judgement** (albeit preliminary) by the Competent Person in respect of all Modifying Factors. In other words, a Mineral Resource is not an inventory of all mineralisation drilled or sampled, regardless of cut-off grade, likely mining dimensions, location or continuity. It is a realistic inventory of mineralisation, which, under assumed and justifiable technical and economic conditions, may, in whole or in part, become economically extractable.*

An intentional non-prescriptive language...

An **Inferred** Mineral Resource is that part of a Mineral Resource for which quantity and grade or quality are estimated on the basis of limited geological evidence and sampling.

Geological evidence is sufficient to **infer but not demonstrate** geological and grade or quality continuity.

An **Indicated** Mineral Resource is that part of a Mineral Resource for which quantity, grade or quality, densities, shape and physical characteristics are estimated with sufficient confidence to allow the application of Modifying Factors in sufficient detail to support mine planning and evaluation of the economic viability of the deposit.

Geological evidence is derived from **adequately detailed and reliable** exploration, sampling and testing and is sufficient to **demonstrate** geological and grade or quality **continuity** between points of observation.

A **Measured** Mineral Resource is that part of a Mineral Resource for which quantity, grade or quality, densities, shape, and physical characteristics are estimated with confidence sufficient to allow the application of Modifying Factors to support detailed mine planning and final evaluation of the economic viability of the deposit.

Geological evidence is derived from **detailed and reliable** exploration, sampling and testing and is sufficient to **confirm** geological and grade or quality **continuity** between points of observation.

Reinforces the Role of the Competent Person

The appropriate Mineral Resource category must be determined by a Competent Person.

Mineral Resource classification is a matter for skilled judgement, and CPs should take into account those items in Table 1, which relate to confidence in Mineral Resource estimation.

In deciding between Measured and Indicated Mineral Resources, CPs may find it useful to consider, in addition to the phrases in the two definitions: "...any variation from the estimate would be unlikely to significantly affect potential economic viability".

In deciding between Indicated and Inferred Mineral Resources, CPs may wish to take into account, in addition to the phrases in the two definitions : "Confidence in the estimate (of Indicated Mineral Resources) is sufficient to allow the application of technical and economic parameters and to enable an evaluation of economic viability" which contrasts with the guideline to the definition for Inferred Mineral Resources: "Confidence in the estimate of Inferred Mineral Resources is usually not sufficient to allow the results of the application of technical and economic parameters to be used for planning." and "Caution should be exercised if this category is considered in technical and economic studies".

What is a Competent Person?

Requirements for a Competent Person	A minerals industry professional	Often a geologist or mining engineer
		Active in the extractive industry
		May work locally or internationally
	A member of a Professional Organization or a Professional Organization (RPO) Recognised	Appropriate membership level
		Subject to ethics and disciplinary codes
	Minimum five years relevant experience	Style of mineralization
		Type of deposit
		Activity or area of technical input which that person is undertaking
	Can the Competent Person face their peers and demonstrate competence in the commodity, type of deposit and reporting activity they are undertaking?	

Note: These requirements are also subject to any additional restrictions or conditions which may be required by relevant stock exchanges or governmental/regulatory authorities.

Competent Person responsibilities

Preparing Competent Persons Reports

- Public reports, announcements, statements issued by owners of mineral assets
- Provide information on Exploration Results, Mineral Resources & Mineral Reserves

Exercising judgement in providing external information

- Ensuring that information available is properly considered and reasonable conclusions are drawn, supported by objective views

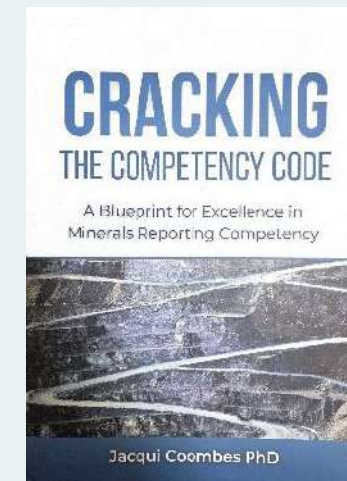
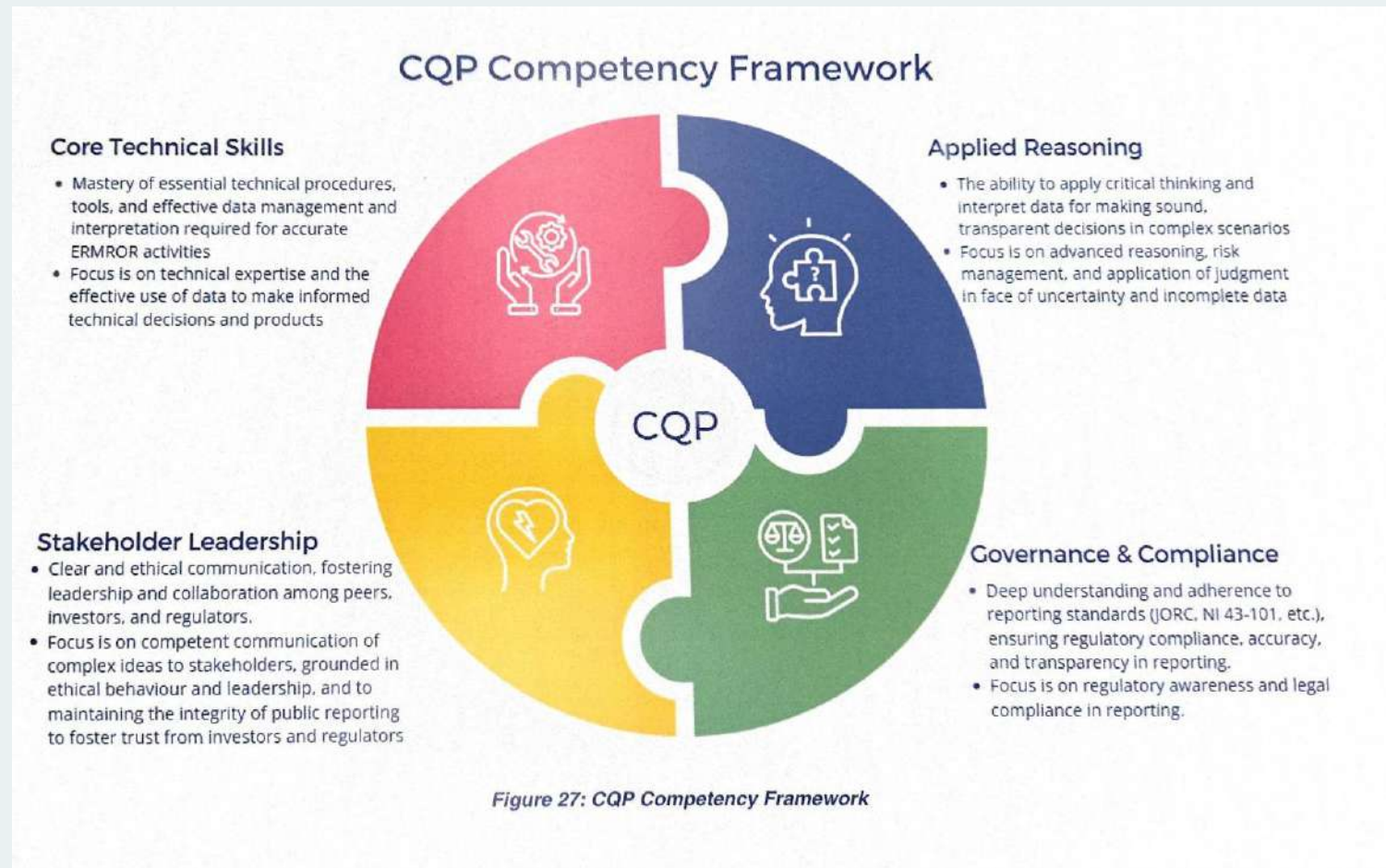
Upholding the principles of transparency, materiality, and competence

- The core principles inherent in all CRIRSCO aligned standards

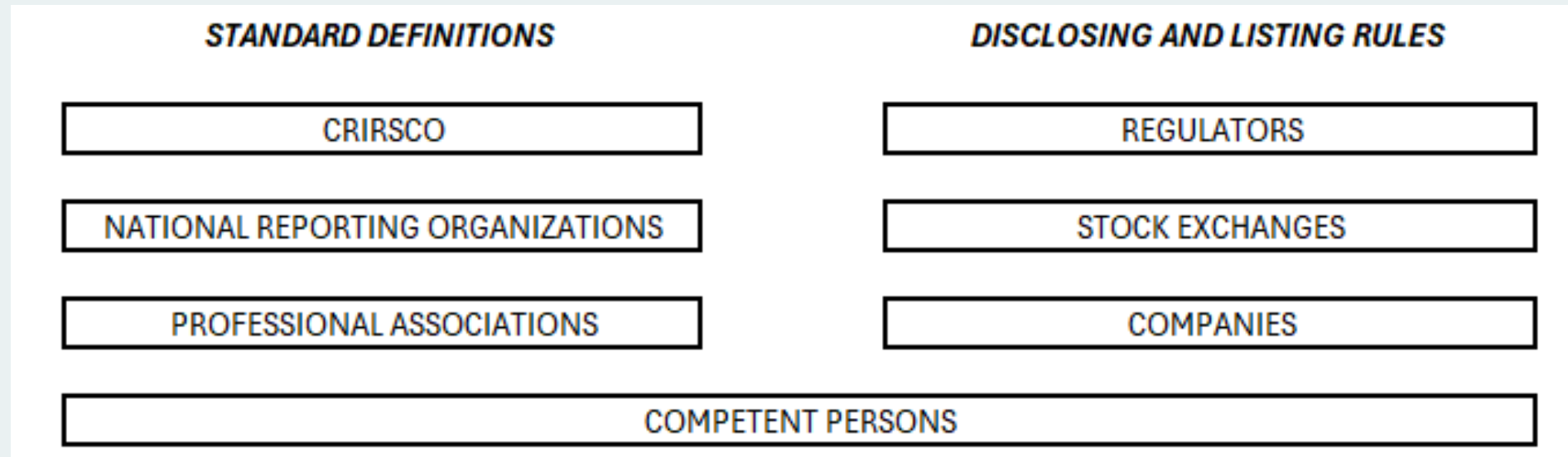
Enabling balanced and reasoned investment decisions

- Information is provided to enable investors and/or professional advisors to make informed decisions

Competent Person: a Holistic Approach

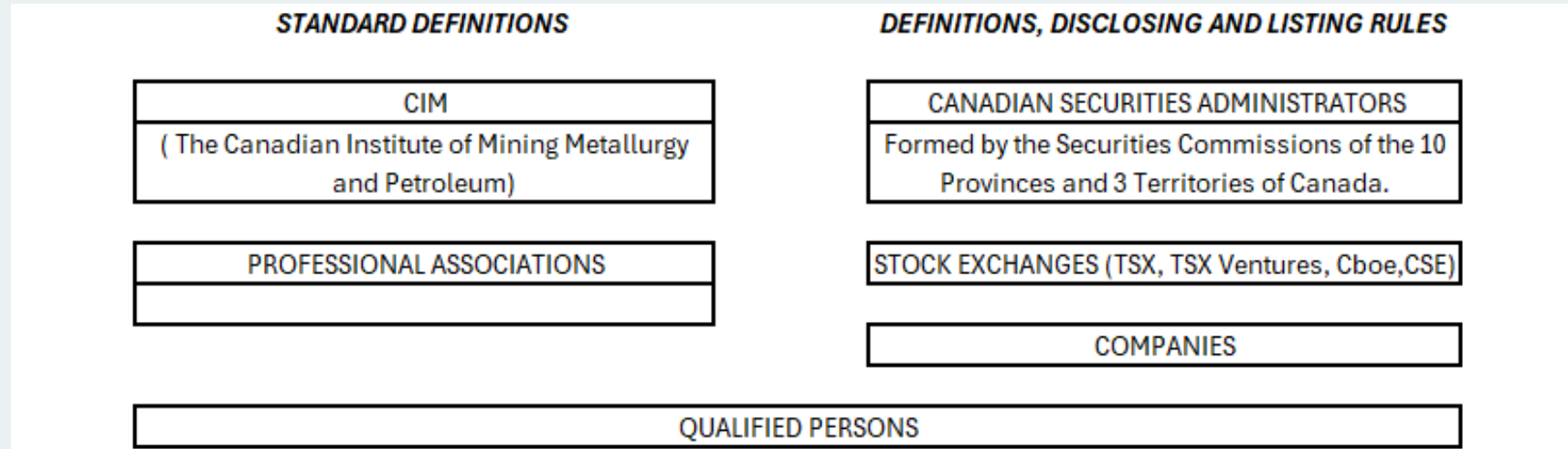


Regulatory Framework



The level of adoption of the CRIRSCO System (including the Template with the Standard Definitions) varies from jurisdiction to jurisdiction, and Regulators have the final call for listing rules to be observed by the Stock Exchanges and listed Companies.

Regulatory Framework: Canada



[Definitions Included in the NI-43.101 \(CSA\)](#)

Professional Association, Preliminary Economic Assessment, Qualified Person are defined in the Instrument, whereas Mineral Resources, Mineral Reserves and their categories, and Mining Studies are referenced to the CIM Standards.

[The CIM Mining Technical Advisory and Monitoring Committee](#)

MTAMC provides advice to the CSA on technical issues relating to NI 43-101 disclosure requirements for the mining industry. The committee also serves as a forum for continuing communication between the CSA and the mining industry. The committee mandate was initially prepared in February 8, 2001 and updated by CSA on March 7, 2018.

CIM Standard Definitions: non-prescriptive

An **Inferred** Mineral Resource is that part of a Mineral Resource for which quantity and grade or quality are estimated on the basis of limited geological evidence and sampling. Geological evidence is sufficient **to imply but not verify** geological and grade or quality continuity.

An **Indicated** Mineral Resource is that part of a Mineral Resource for which quantity, grade or quality, densities, shape and physical characteristics are estimated with sufficient confidence to allow the application of Modifying Factors in sufficient detail to support mine planning and evaluation of the economic viability of the deposit. Geological evidence is derived from **adequately detailed and reliable** exploration, sampling and testing and is sufficient **to assume** geological and grade or quality **continuity** between points of observation.

A **Measured** Mineral Resource is that part of a Mineral Resource for which quantity, grade or quality, densities, shape, and physical characteristics are estimated with confidence sufficient to allow the application of Modifying Factors to support detailed mine planning and final evaluation of the economic viability of the deposit. Geological evidence is derived from **detailed and reliable** exploration, sampling and testing and is sufficient **to confirm** geological and grade or quality **continuity** between points of observation.

CIM Best Practices

*The Practitioners must select appropriate estimation method(s) or techniques for the resource model. Estimation methods include polygonal, nearest neighbour, inverse distance to a power, various kriging approaches (e.g. ordinary kriging, simple kriging, and multiple indicator kriging), **conditional simulation, and other non-linear estimation methods**. The choice of method(s) should be based on the geology, the attribute/variable being modelled, quantity and spatial distribution of data, complexity of grade distribution within the deposit, presence of high-grade outliers, results of reconciliation studies for projects with production histories, and the anticipated end use of the Mineral Resource block model.*

*Mineral Resources are classified into three confidence categories, Measured, Indicated, and Inferred. These terms are defined under the CIM Definition Standards. Since each Mineral Resource estimate contains its own unique set of conditions, **the selection of the criteria** by which the Mineral Resource is assigned to each category **relies on the judgement and experience of the Practitioners**. In selecting these criteria, the Practitioners must have a clear understanding of the practical limitations of the conceptual operating scenario. Important considerations of the classification criteria are spatial aspects including continuity of grade, and the locations, types, and spatial density of the informing data. The **confidence category selection should consider uncertainty and risk** existing in the Mineral Resource estimate.*

Qualified Person (NI-43.101)

“qualified person” means an individual who

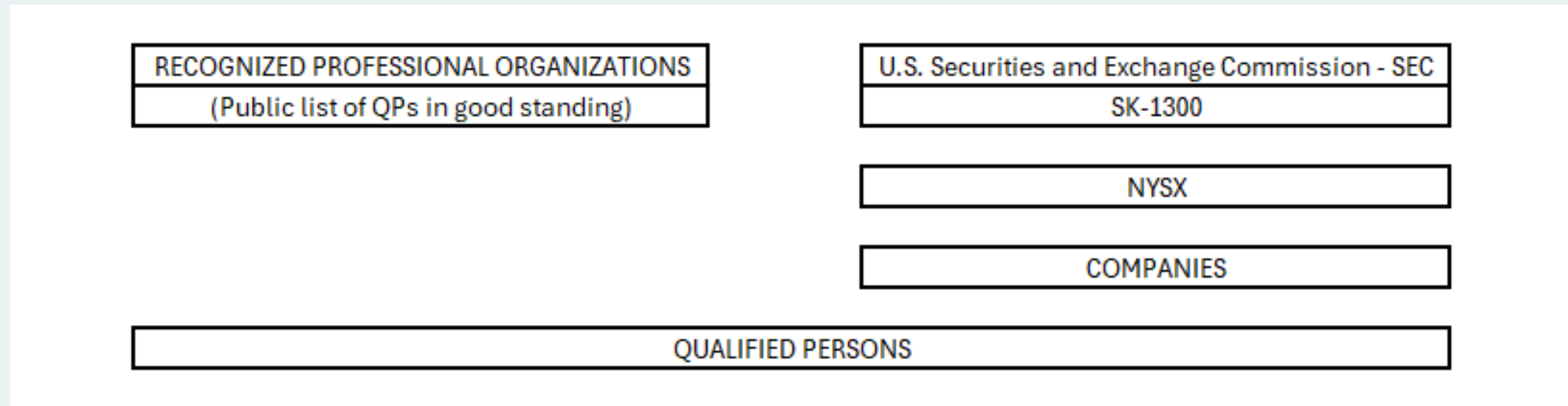
- a) is an engineer or geoscientist with a university degree, or equivalent accreditation, in an area of geoscience, or engineering, relating to mineral exploration or mining;
- b) has at least five years of experience in mineral exploration, mine development or operation, or mineral project assessment, or any combination of these, that is relevant to his or her professional degree or area of practice;
- c) has experience relevant to the subject matter of the mineral project and the technical report;
- d) is in good standing with a professional association; and
- e) in the case of a **professional association in a foreign jurisdiction**, has a membership designation that
 - i. requires attainment of a position of responsibility in their profession that requires the exercise of independent judgment; and
 - ii. requires
 - A. a favourable confidential peer evaluation of the individual’s character, professional judgement, experience, and ethical fitness; **or**
 - B. B. a recommendation for membership by at least two peers, and demonstrated prominence or expertise in the field of mineral exploration or mining;

Professional Association (NI-43.101)

“**professional association**” means a self-regulatory organization of engineers, geoscientists or both engineers and geoscientists that

- a) Is
 - i. given authority or recognition by statute in a jurisdiction of Canada, or
 - ii. a foreign association that is generally accepted within the international mining community as a reputable professional association;
- b) admits individuals on the basis of their academic qualifications, experience, and ethical fitness;
- c) requires compliance with the professional standards of competence and ethics established by the organization;
- d) requires or encourages continuing professional development; and
- e) has and applies disciplinary powers, including the power to suspend or expel a member regardless of where the member practises or resides;

Regulatory Framework: USA



[Definitions Included in the S-K 1300](#)

All Definitions are included in the regulation, including Qualified Persons and Recognized Professional Organizations.

There is no direct reference to the SME Guide. A heavy weight is given to the relevant experience of the Qualified Persons.

S-K 1300 Definitions: still non-prescriptive

Inferred mineral resource is that part of a mineral resource for which quantity and grade or quality are estimated on the basis of **limited geological evidence** and sampling. The level of geological uncertainty associated with an inferred mineral resource is too high to apply relevant technical and economic factors likely to influence the prospects of economic extraction in a manner useful for evaluation of economic viability. Because an inferred mineral resource has the lowest level of geological confidence of all mineral resources, which prevents the application of the modifying factors in a manner useful for evaluation of economic viability, an inferred mineral resource may not be considered when assessing the economic viability of a mining project, and may not be converted to a mineral reserve.

Indicated mineral resource is that part of a mineral resource for which quantity and grade or quality are estimated on the basis of **adequate geological evidence** and sampling. The level of geological certainty associated with an indicated mineral resource is sufficient to allow a qualified person to apply modifying factors in sufficient detail to support mine planning and evaluation of the economic viability of the deposit. Because an indicated mineral resource has a lower level of confidence than the level of confidence of a measured mineral resource, an indicated mineral resource may only be converted to a probable mineral reserve.

Measured mineral resource is that part of a mineral resource for which quantity and grade or quality are estimated on the basis of **conclusive geological evidence** and sampling. The level of geological certainty associated with a measured mineral resource is sufficient to allow a qualified person to apply modifying factors, as defined in this section, in sufficient detail to support detailed mine planning and final evaluation of the economic viability of the deposit. Because a measured mineral resource has a higher level of confidence than the level of confidence of either an indicated mineral resource or an inferred mineral resource, a measured mineral resource may be converted to a proven mineral reserve or to a probable mineral reserve.

S-K 1300 Definitions: additional language

*Limited geological evidence, when used in the context of mineral resource determination, means evidence that is only sufficient to establish that geological and **grade or quality continuity are more likely than not.***

*Adequate geological evidence, when used in the context of mineral resource determination, means evidence that is sufficient to **establish** geological and **grade or quality continuity with reasonable certainty.***

*Conclusive geological evidence, when used in the context of mineral resource determination, means evidence that is sufficient to test and **confirm** geological and **grade or quality continuity.***

The additional language is still non-prescriptive and the Qualified Person must exercise judgement and justify the selected methods and criteria.

S-K 1300: Qualified Person and Professional Organization Definitions

Qualified person is an individual who is:

1. A mineral industry professional with at least five years of relevant experience in the type of mineralization and type of deposit under consideration and in the specific type of activity that person is undertaking on behalf of the registrant; and
2. An eligible member or licensee in good standing of a **recognized professional organization** at the time the technical report is prepared. **For an organization to be a recognized professional organization**, it must:
 - i. Be either:
 - (A) An organization recognized within the mining industry as a reputable professional association; or
 - (B) A board authorized by U.S. federal, state or foreign statute to regulate professionals in the mining, geoscience or related field;
 - ii. Admit eligible members primarily on the basis of their academic qualifications and experience;
 - iii. Establish and require compliance with professional standards of competence and ethics;
 - iv. Require or encourage continuing professional development;
 - v. Have and apply disciplinary powers, including the power to suspend or expel a member regardless of where the member practices or resides; and
 - vi. Provide a public list of members in good standing.

Conclusions

The CRIRSCO Template, the CSA National Instrument and the American SEC regulations all consistent on the basic definitions and in the use of non-prescriptive language, leaving to the Qualified/Competent Person/Professional the choice of the best methods for mineral resource estimation, classification and scheduling.

Geostatistical methods, including conditional simulations and stochastic mining planning are well-known for more than three decades, with several case studies published on tier-1 magazines.

Commercial tools are available in the market for all steps of this process.

Key Questions remain the same:

- If not now, when?
- If not the Competent Person, who?
- What are the necessary steps to move ahead? How can we work together?

Edson Ribeiro

March 2026





Simultaneous Stochastic Optimization of Mining Complexes:

Fundamentals, Advantages and Challenges

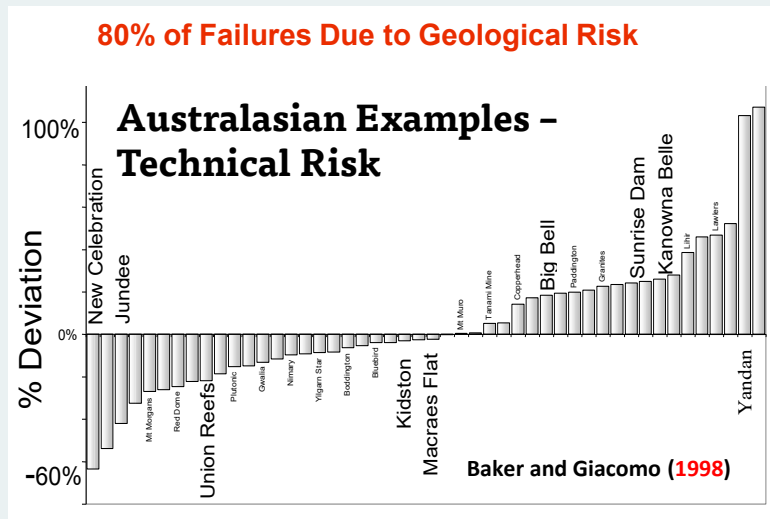
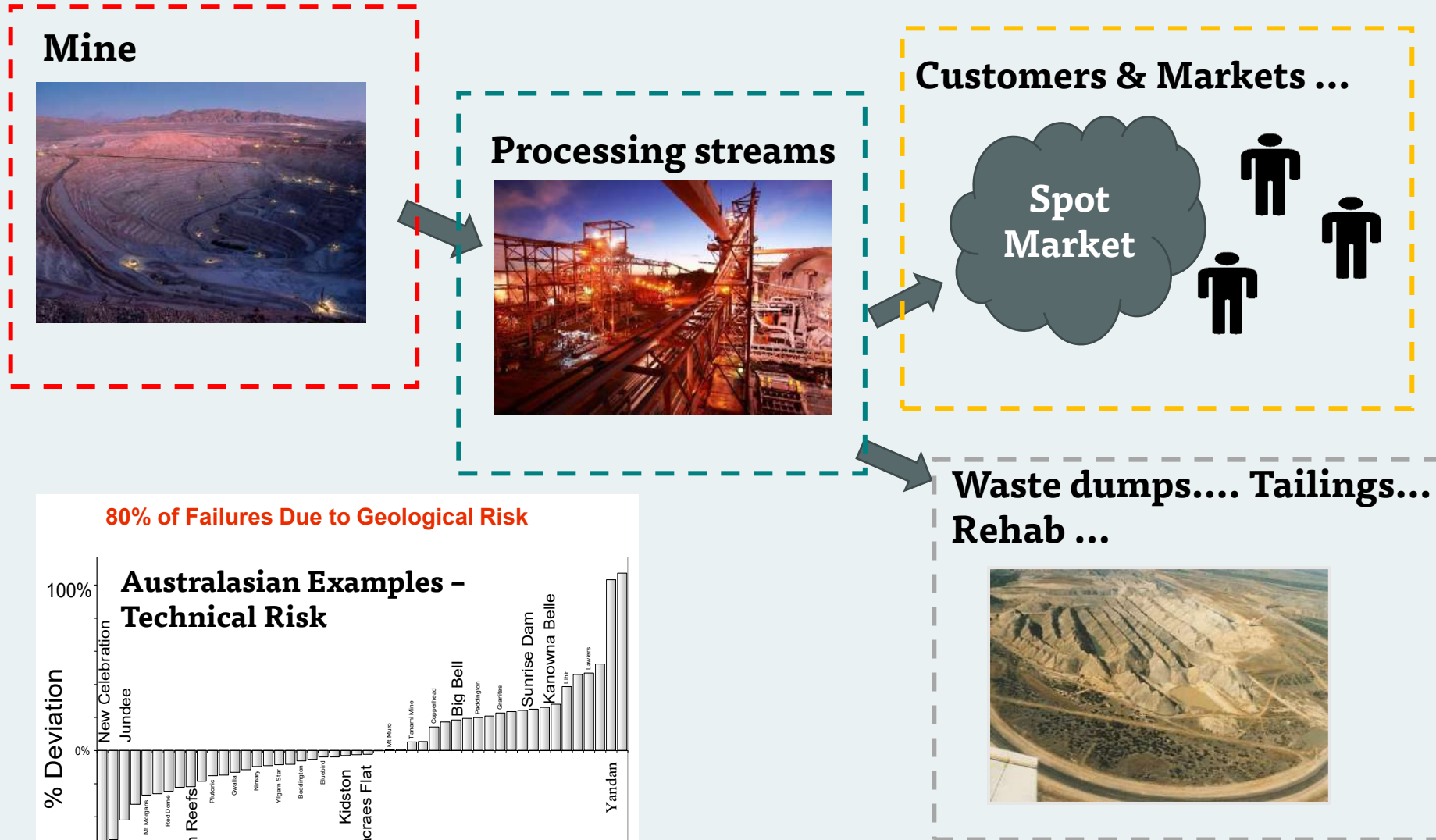
Roussos Dimitrakopoulos

<http://cosmo.mcgill.ca/>

Introduction & Basics

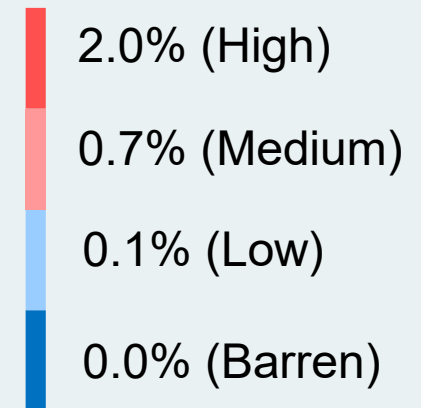
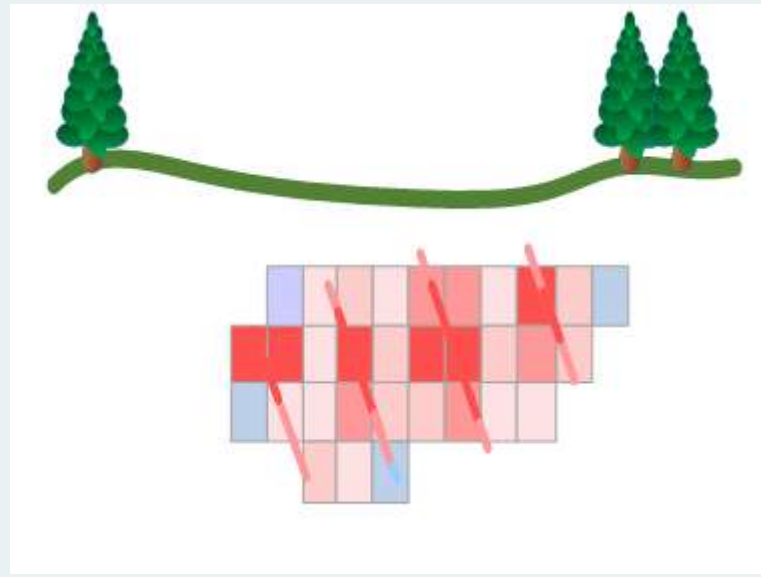
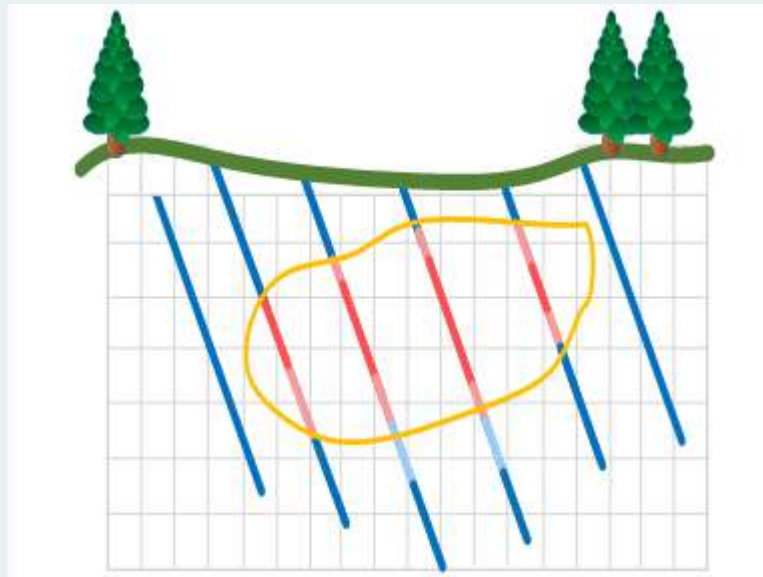
- Conventional long-term planning
- Orebody models
- Major limits
- Stochastic workflow

Conventional / Deterministic Workflows

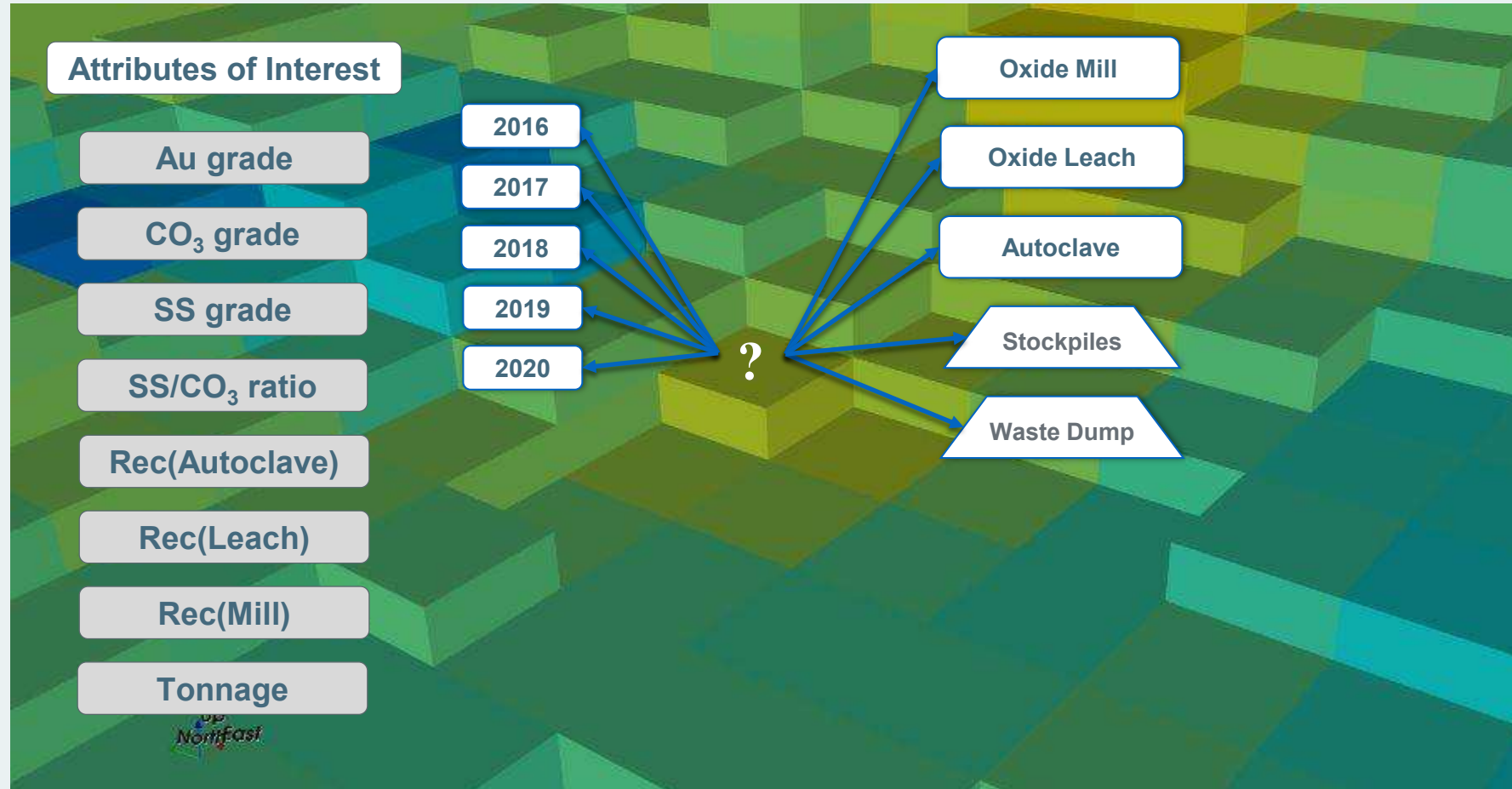


Introduction

- From drill-holes to mines: discretize the model into 3D mining blocks, simulate models for the metal content, material types... per block in the orebody



Introduction – The Mining Decision



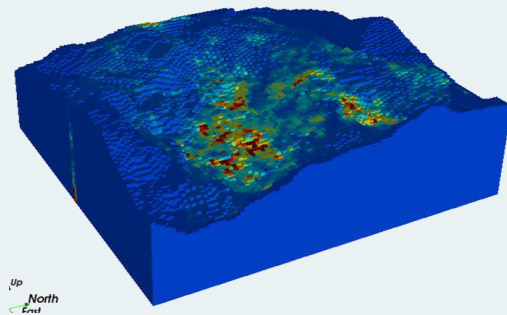
Traditional production scheduling methodologies neglect uncertainty and variability!

Source: M.Godoy, Newmont, SME 2016

Introduction – Deterministic Workflow

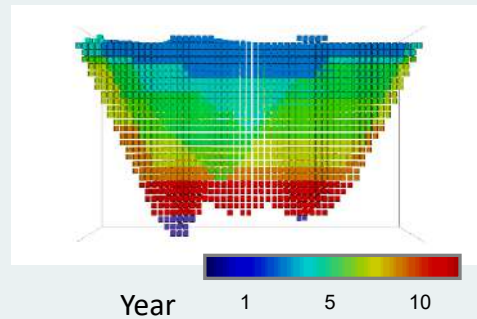


Estimated Orebody Model



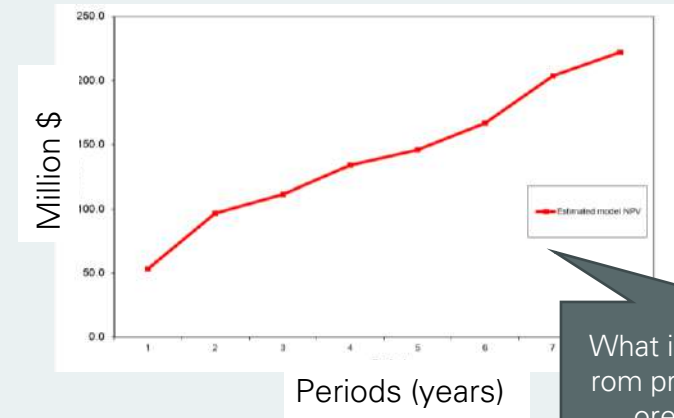
Can a single estimated model represent a mineral deposit?
(Grade variability, uncertainty)

Deterministic Design

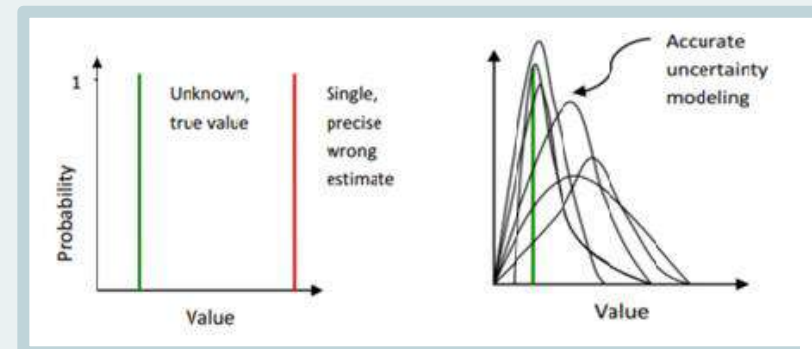


Is this design the optimal / 'best'?

Production Forecast

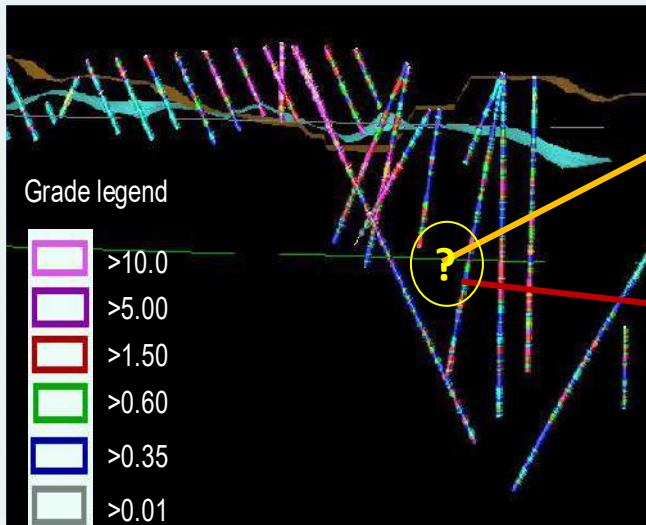


What is the risk of deviating from production forecasts on ore, metal, NPV ... ?



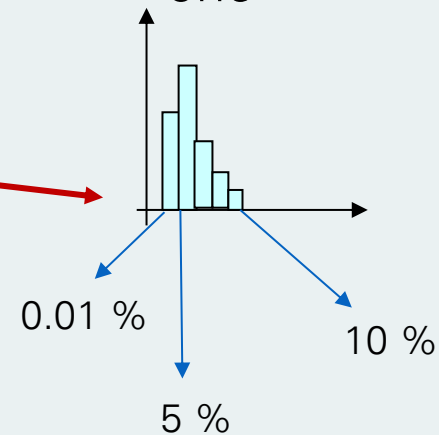
Traditional Orebody Models

Conventional models DO NOT account for uncertainty....
and variability....



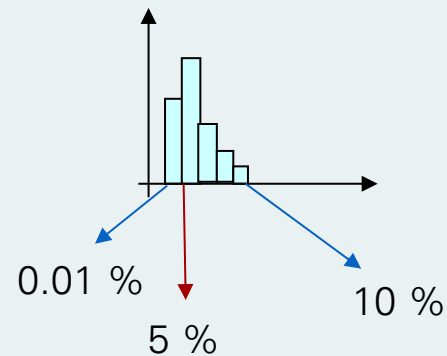
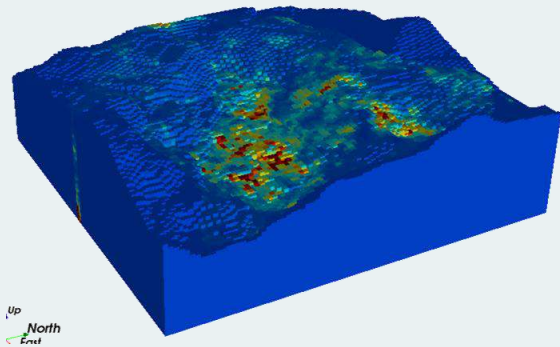
5 % ?

Estimation methods try to approximate some average grade value ... not the actual one



Estimation vs Simulation

- Estimated Orebody Model



Quantifying Uncertainty

- Simulated Orebody Models. This is a Monte Carlo type simulation ...



A mature, well drilled and understood gold deposit

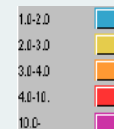


3 simulated scenarios of the same section (SMU grade)

Model characteristics:

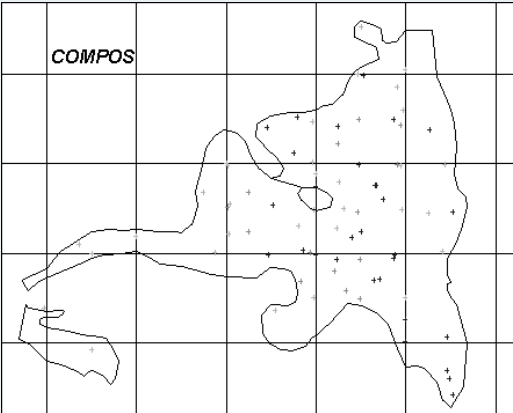
- o Large number of blocks
- o Multiple domains
- o 20 simulations: 557 million nodes

27 million mining blocks



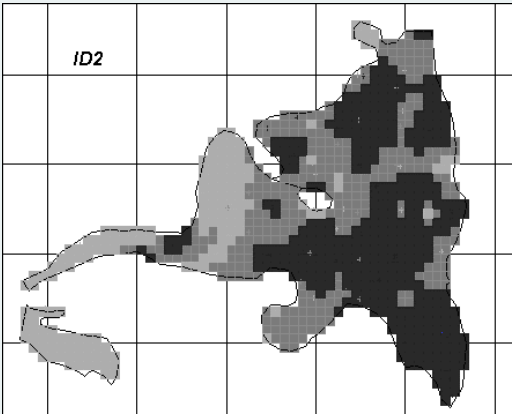
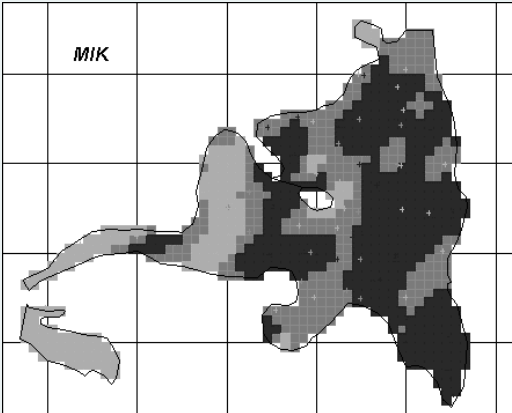
Traditional Orebody Models - Limits & Shortcomings

Bench in a gold deposit being mined

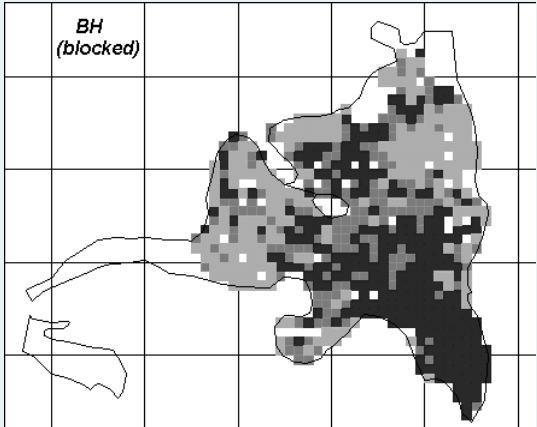


Black indicates DDH grade above 1.3 g/t and grey between 0.7 and 1.3 g/t

Estimated deposit bench, 2 methods



Real blast hole data

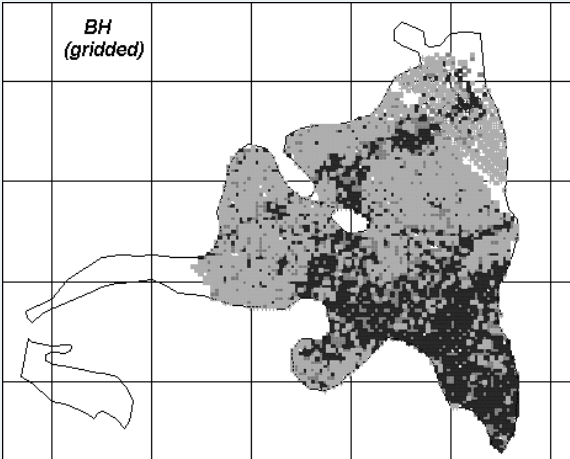


Real mineral deposits are highly variable, not smooth

10x10x5m blocks

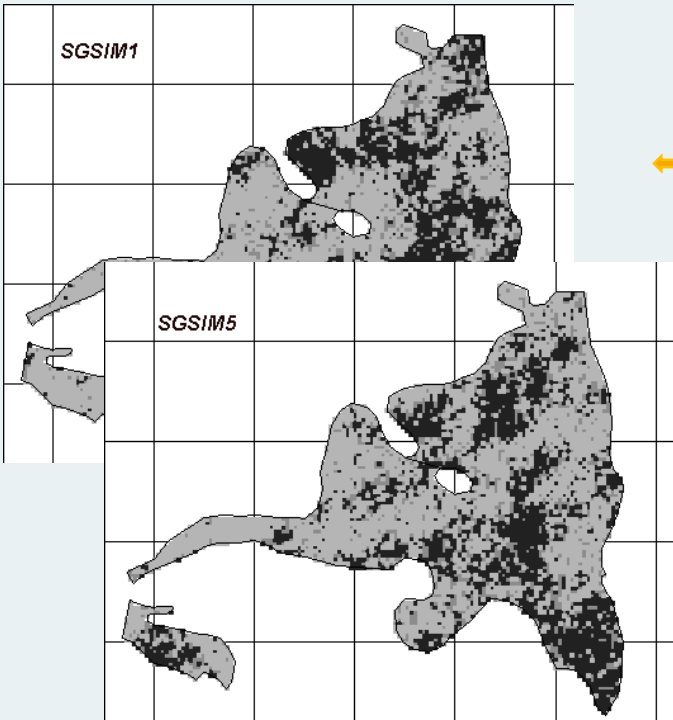
Traditional Orebody Models - Limits & Shortcomings

Real blast hole data

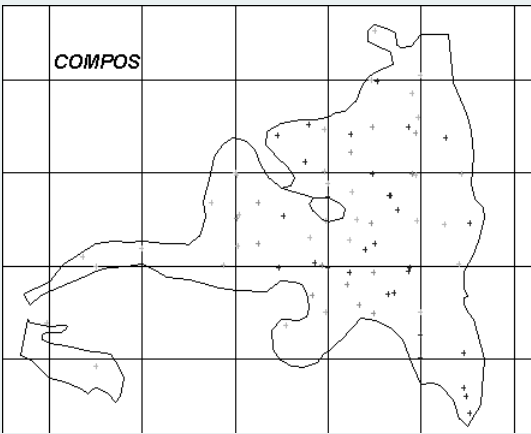


Black indicates DDH grade above 1.3 g/t and grey between 0.7 and 1.3 g/t

Simulated deposit bench from DDH



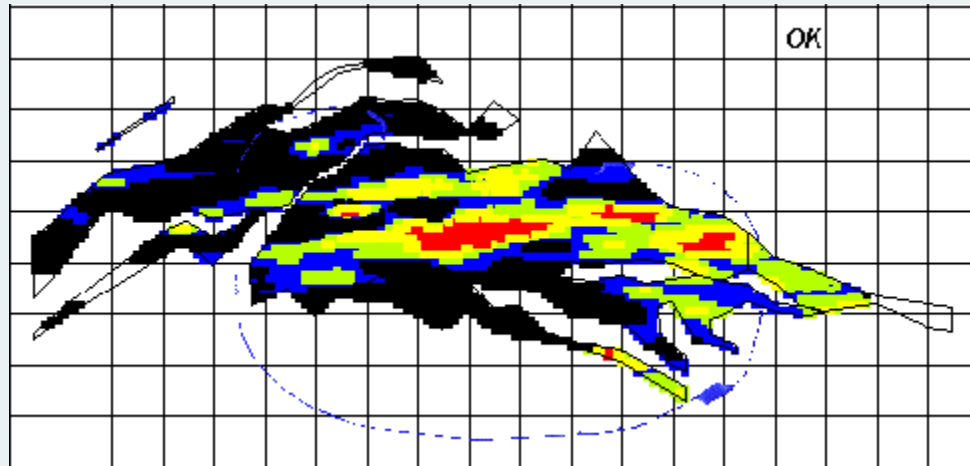
Exploration Drill Hole Data



Traditional Orebody Models - Limits & Shortcomings

- The Geostatistical Contribution
 1. Simulated models represent the actual *spatial variability* of the deposit which scheduling optimization should use
 2. A group of simulated models *quantifies the uncertainty* in the description of a mineral deposit that we *need to manage* suitably while scheduling

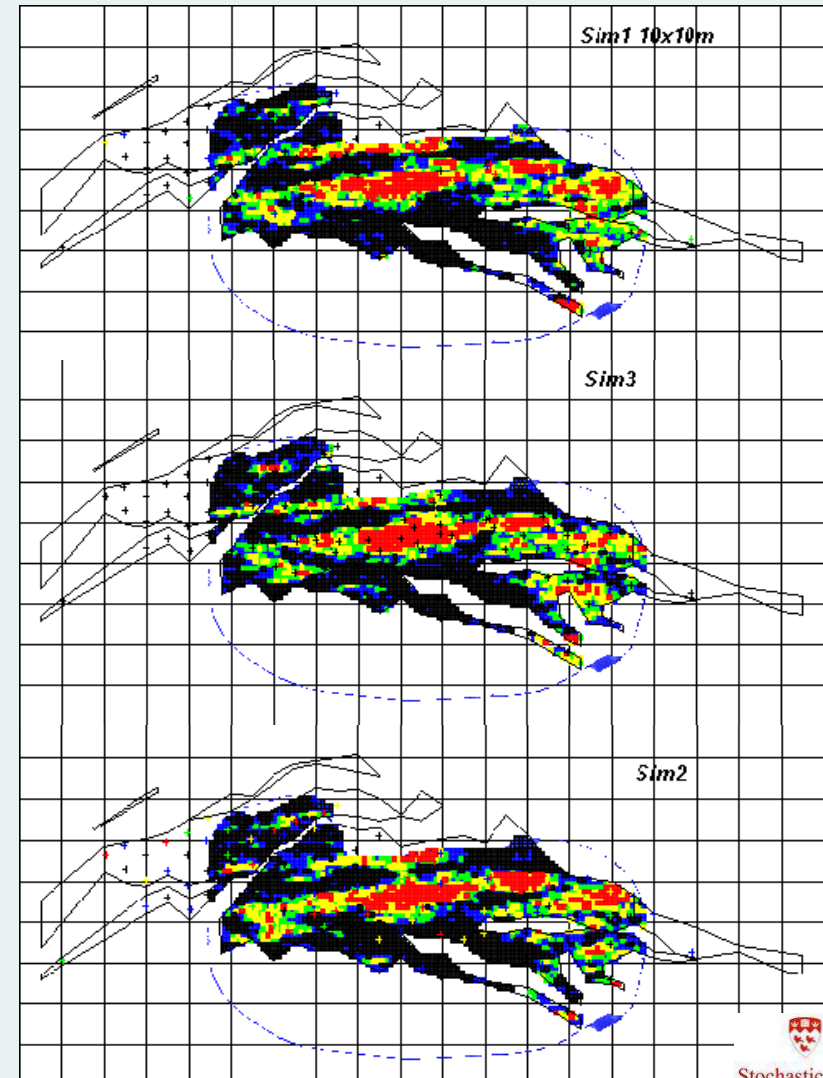
Estimation



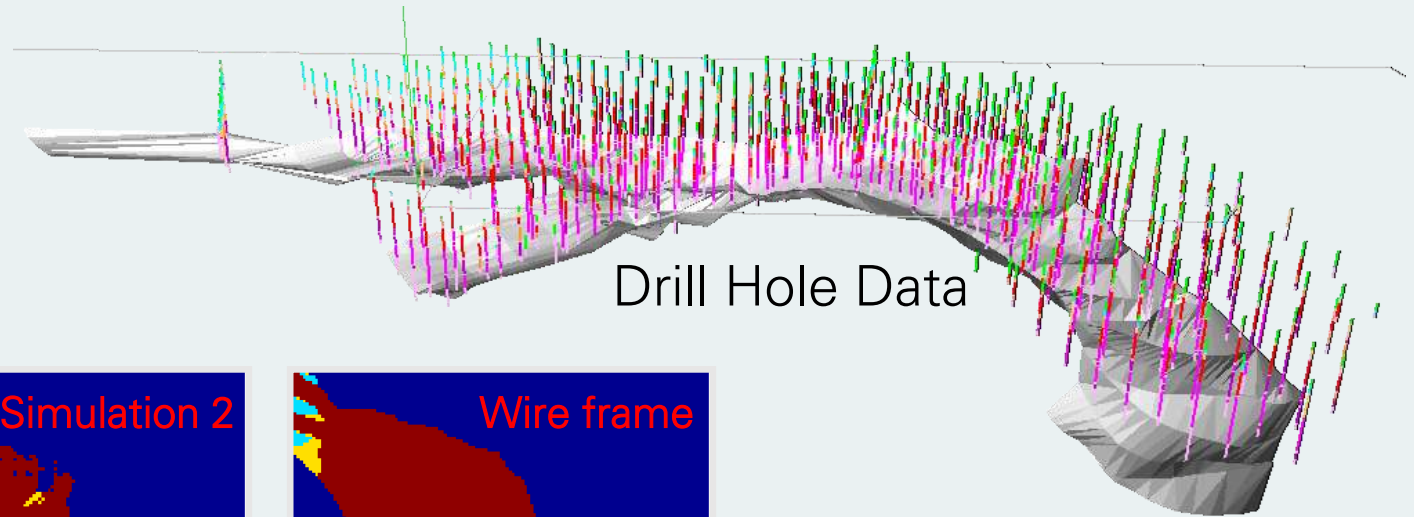
A Copper Deposit

Colors are Cu% (read is highest)

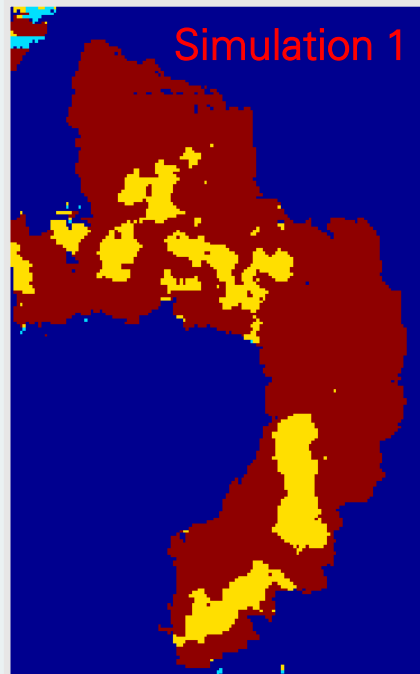
Simulation



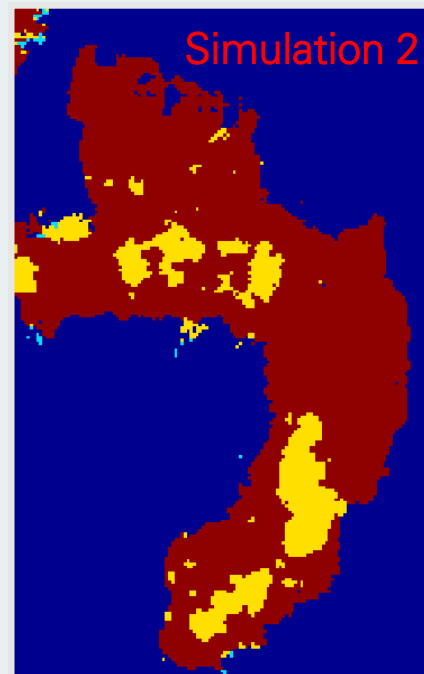
Simulating Geology - Yandi Iron Ore Deposit



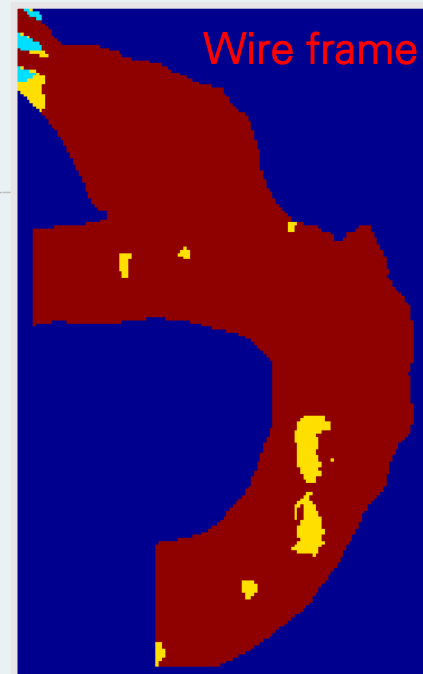
Drill Hole Data



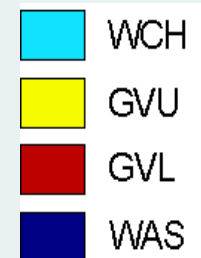
Simulation 1



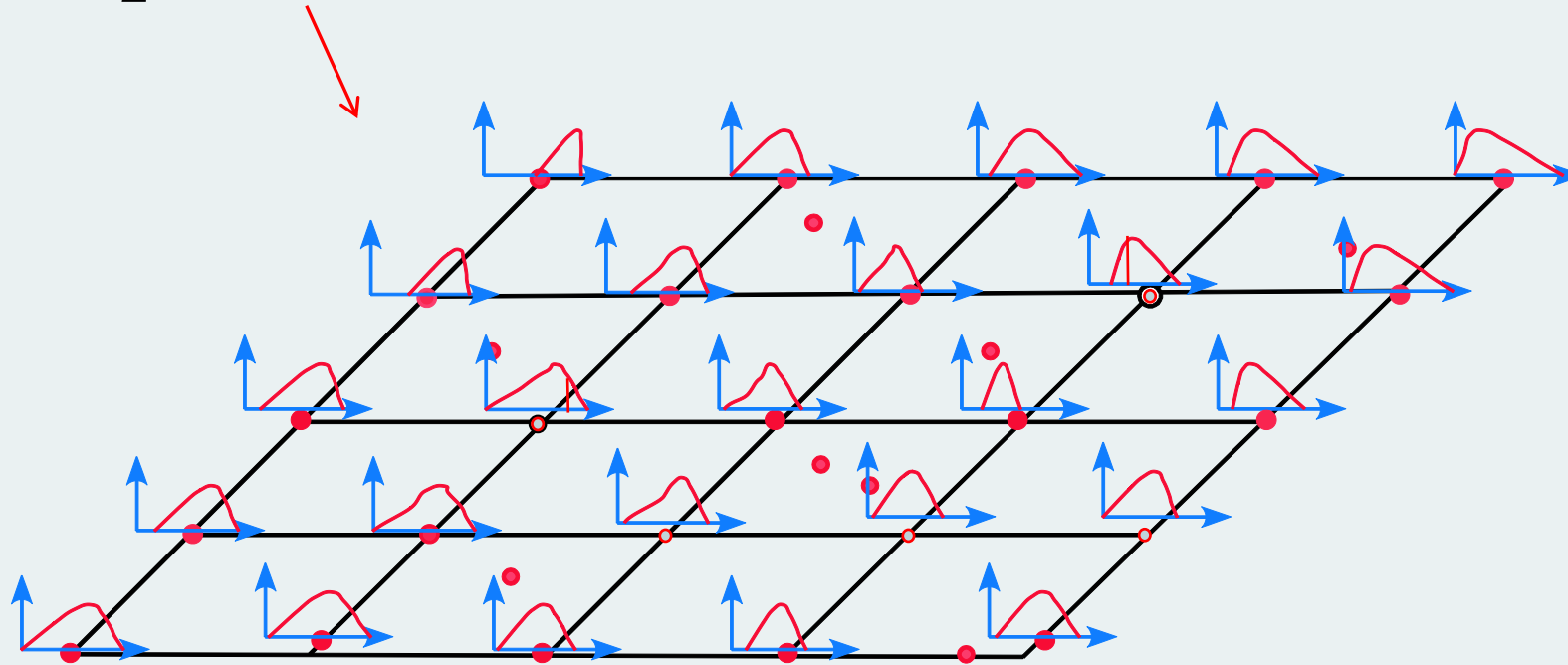
Simulation 2



Wire frame



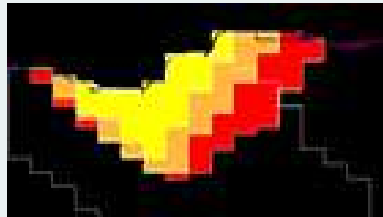
Sequential Simulations



$$\begin{array}{lll}
 \Delta_0 = \{\mathbf{d}_n\} & \Delta_1 = \{\mathbf{d}_n, z^{(l)}(\mathbf{u}_1)\} & \Delta_N = \{\mathbf{d}_n, z^{(l)}(\mathbf{u}_1), \dots, z^{(l)}(\mathbf{u}_N)\} \\
 f_Z(\mathbf{u}_1; z | \Delta_0) & f_Z(\mathbf{u}_2; z | \Delta_1) & \dots & f_Z(\mathbf{u}_N; z_N | \Delta_{N-1}) \\
 Z(\mathbf{u}_1) = z^{(l)}(\mathbf{u}_1) & Z(\mathbf{u}_2) = z^{(l)}(\mathbf{u}_2) & & Z(\mathbf{u}_N) = z^{(l)}(\mathbf{u}_N)
 \end{array}$$

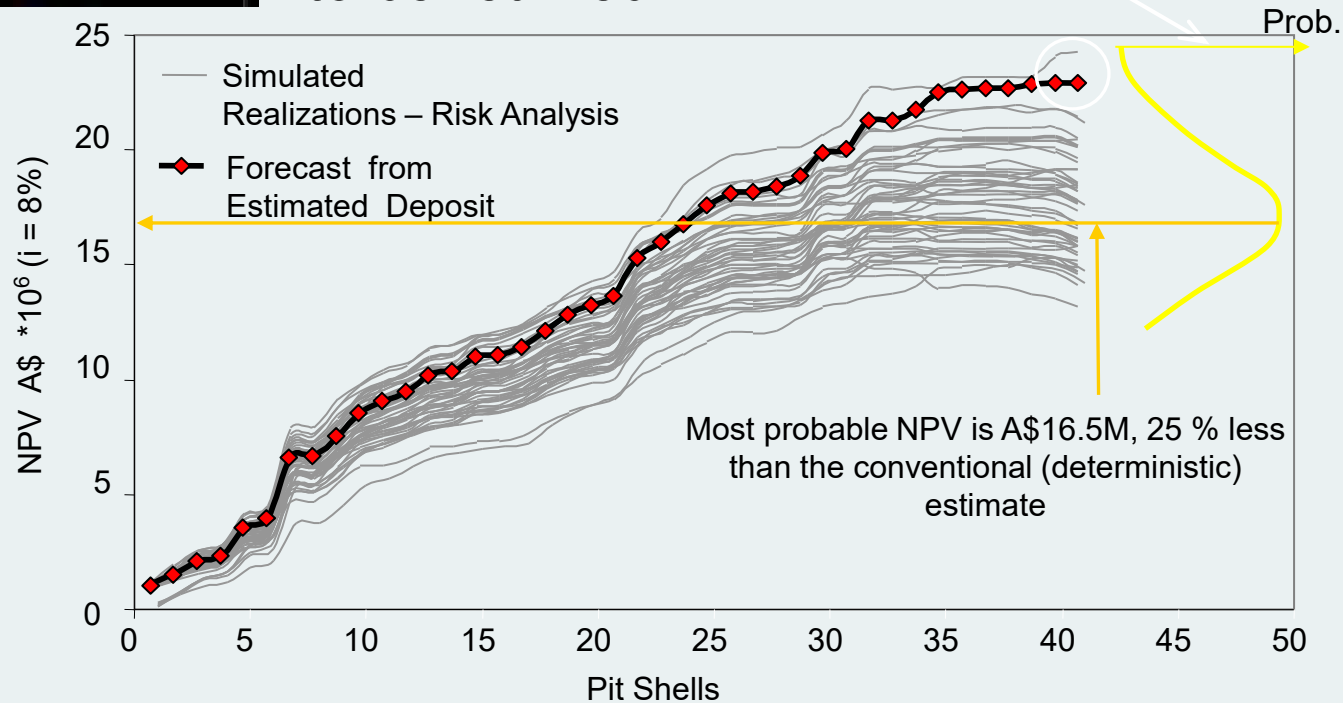
Introduction - Estimation vs Simulation

does it Matter?

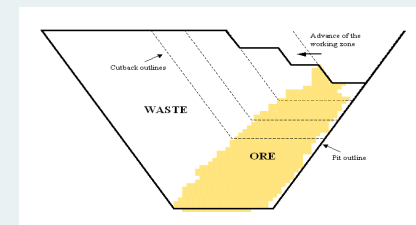


A recall from 1998

The expected project NPV has only 2-4% probability to be realized

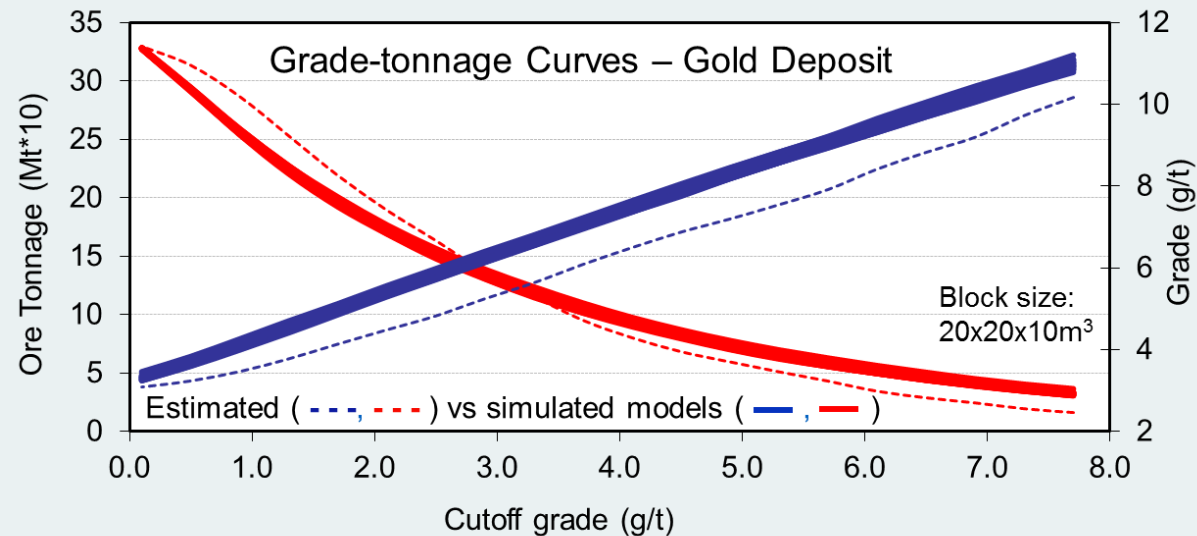


Why this? Smoothing - estimation misrepresents volumes of different grade ranges ... and more ...



Traditional Orebody Models

Some Limits and Shortcomings



Smoothing/misrepresentation from any estimation on grade-tonnage curves has adverse effects on deterministic optimization

A good reason why

WE USE SIMULATED DEPOSITS IN MINE PLANNING OPTIMIZATION

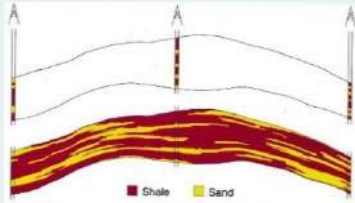
Introduction – Deterministic Workflow



Limits of current-generation optimizers:

1. Evaluating the \$ value of the block independently of others
2. Ignore non-linear transformations in the processing stream that act on the blend of materials (e.g. non-linear grade-recovery)
 - **Average in \neq Average out**
3. Can substantially undervalue the resource by ignoring the power of blending
4. Uncertainty and variability in material types, chemistry, grades, rock properties is ignored

Introduction - Cross Disciplinary Learning

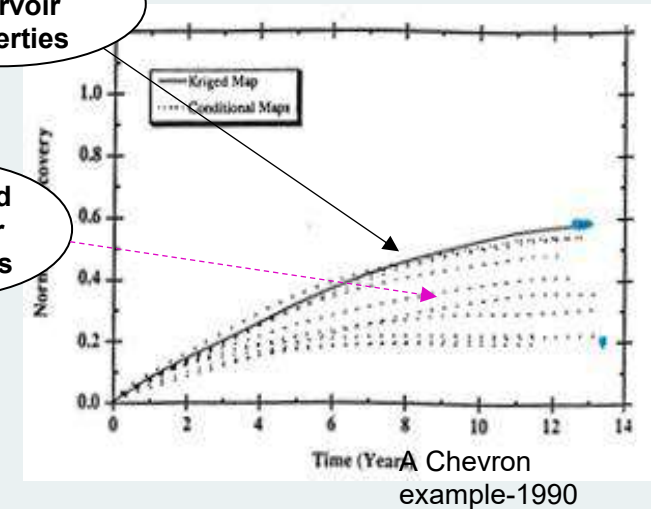
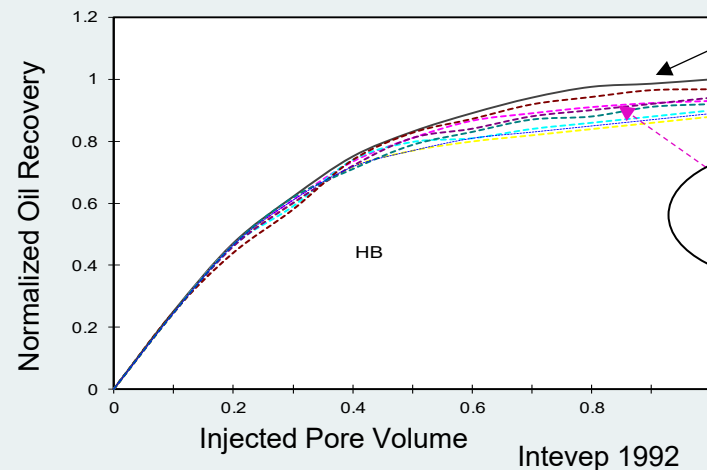


Other fields of Engineering: Industry practice in Petroleum Reservoir Engineering has moved away from estimation models since the late 1980's (stemming from the Stanford University related research - Prof. A. Journel)

Oil recovery forecasting (EOR) – Production forecasts:

Examples

Forecasts come from multiphase flow simulation



Estimation does no longer exists in reservoir forecasting
Average in \neq Average out P90 in \neq P90 out

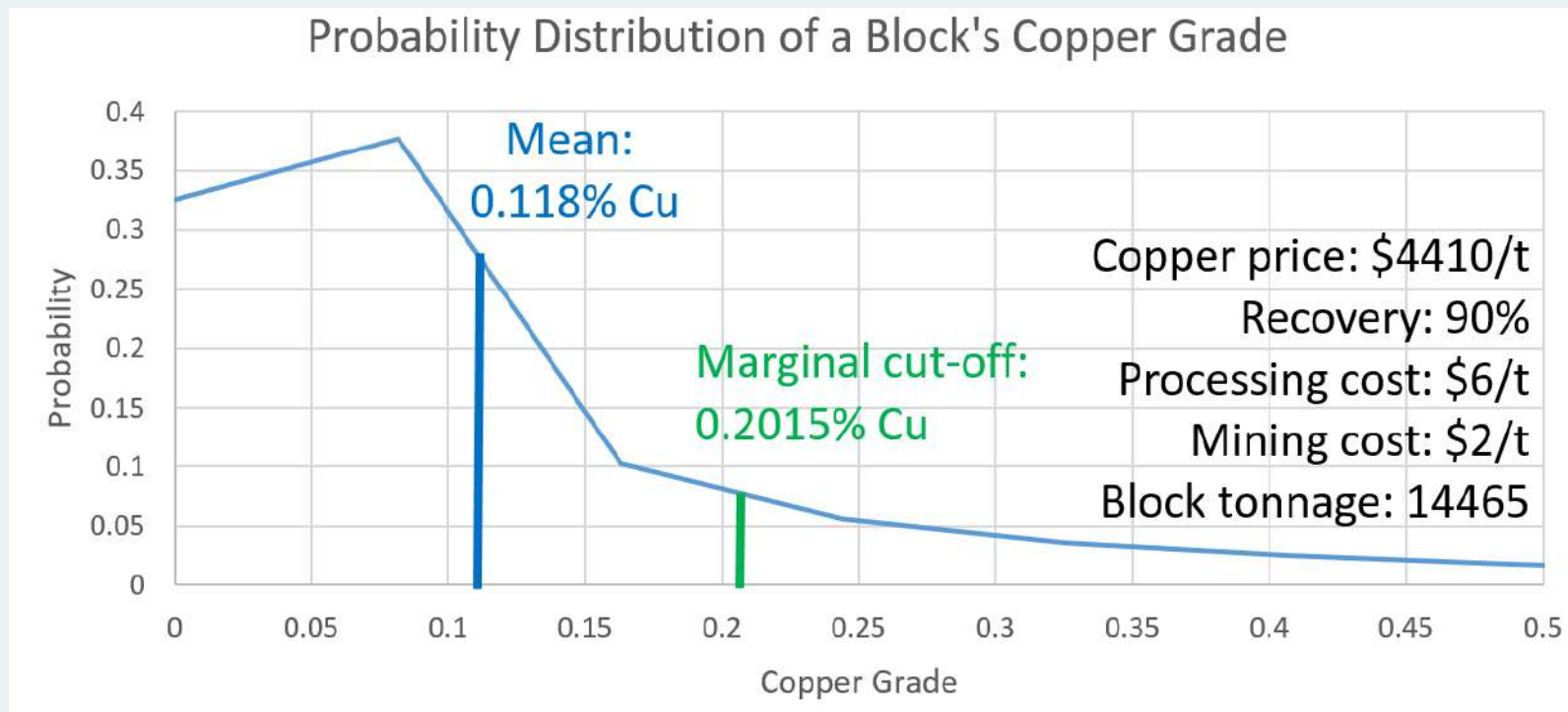
Wonder Why?

- A simple example
- MIP vs SIP in mine scheduling optimization

Approaches to Uncertainty

- An Example:

Calculating the economic value of a block using a marginal cut-off grade



Deterministic Approach to Uncertainty

A block's economic value, according to a deterministic optimizer

Copper price: \$4410/t (\$2/lb Cu)

Recovery: 90%

Processing cost: \$6/t

Mining cost: \$2/t

Block tonnage: 14465 t



Estimated (expected)
grade: 0.118% Cu

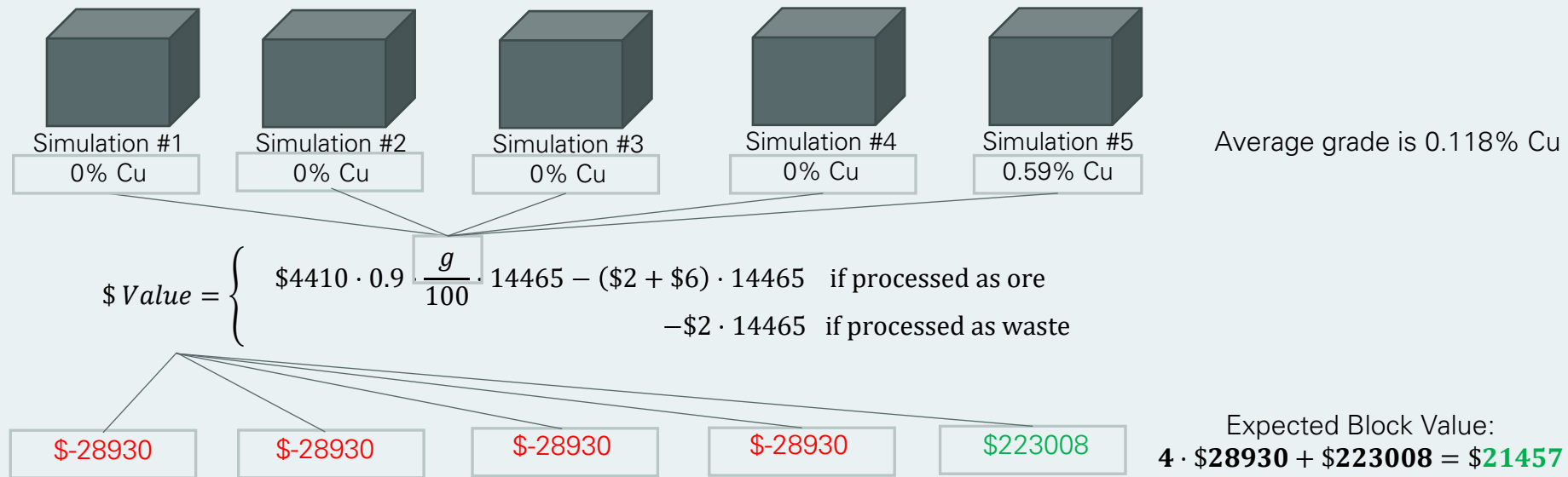
$$\$ \text{ Value} = \begin{cases} \$4410 \cdot 0.9 \cdot \frac{0.118}{100} \cdot 14465 - (\$2 + \$6) \cdot 14465 = \$ - 47974 & \text{if processed as ore} \\ -\$2 \cdot 14465 = \$ - 28930 & \text{if processed as waste} \end{cases}$$

This block's estimated grade lies below the marginal cut-off grade.

A deterministic optimizer will *only* mine this block as waste, with a value of **-\$28930**.

Stochastic Approach to Uncertainty

A block's economic value, according to a stochastic optimizer



A stochastic optimizer *may* choose to mine this block with an expected value of **\$21,457**. However, this is a risky block if we wish to feed a mill up to its capacity

Stochastic optimizers account for this risk, in addition to its potential value

Deterministic Mine Planning

Integer Programming

Objective function

Maximize total \$ value

$$(c_1x_1^1 + c_2x_2^1 + \dots) \dots$$

Subject to constraints

$$c_1x_1^1 + c_2x_2^1 + \dots \geq b_1$$

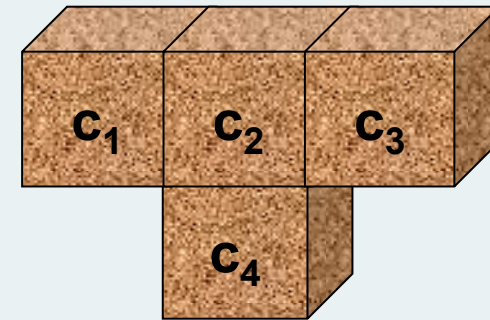
⋮

$$c_1x_1^p + c_2x_2^p + \dots \geq b_p$$

→ Period 1

→ Period p

Estimated Orebody Model



C = \$ value of a block

X_1^1 = 1 if mined in $t=1$ else 0

Stochastic Mine Planning (start)

Stochastic Integer Programming (SIP)

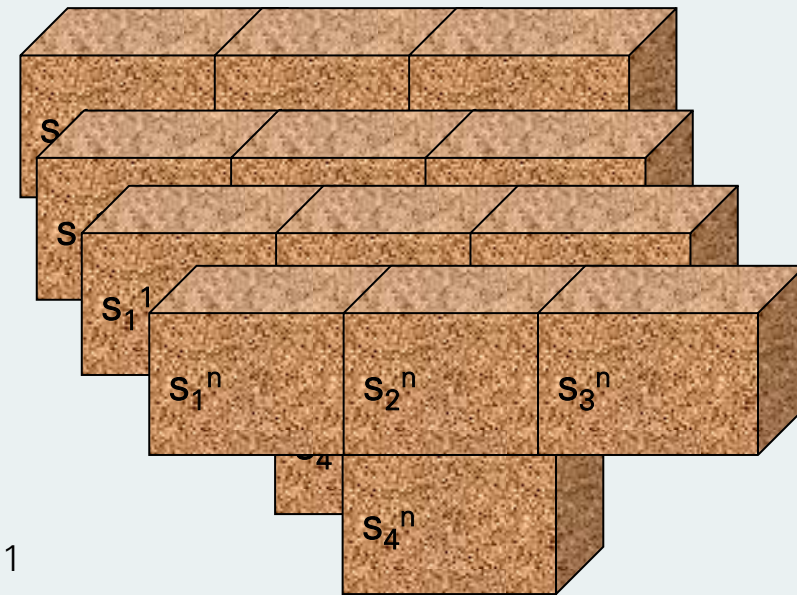
The objective function **now is**

Maximize total \$ value

$$(s_{11}x_1^1 + s_{21}x_2^1 + \dots + s_{12}x_1^1 + s_{22}x_2^1 + \dots) - (\dots) \dots$$

Subject to

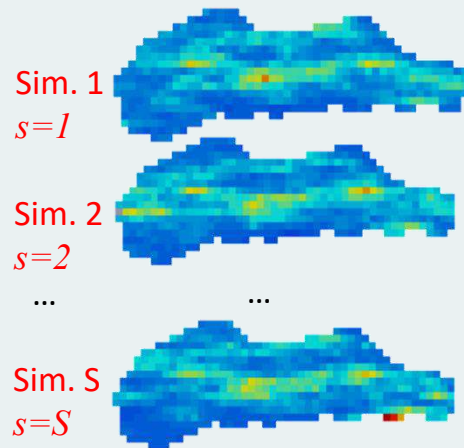
$$\left. \begin{aligned} s_{11}x_1^1 + s_{21}x_2^1 + \dots &= b_1 \\ \vdots \\ s_{11}x_1^p + s_{21}x_2^p + \dots &= b_1 \\ s_{12}x_1^p + s_{22}x_2^p + \dots &= b_1 \\ s_{1r}x_1^p + s_{2r}x_2^p + \dots &= b_1 \end{aligned} \right\} \begin{array}{l} \longrightarrow \text{Period 1} \\ \text{Simulated model 1} \\ \text{Simulated model 2} \\ \text{Simulated model } r \\ \longrightarrow \text{Period } p \end{array}$$



Introduction – Stochastic Workflow

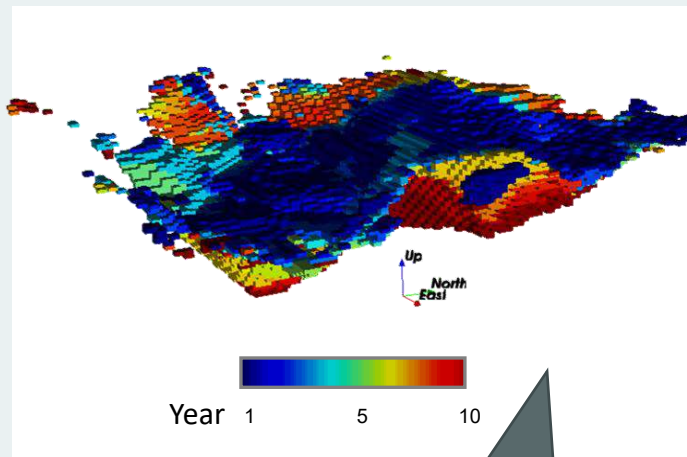


Simulated Orebody Models



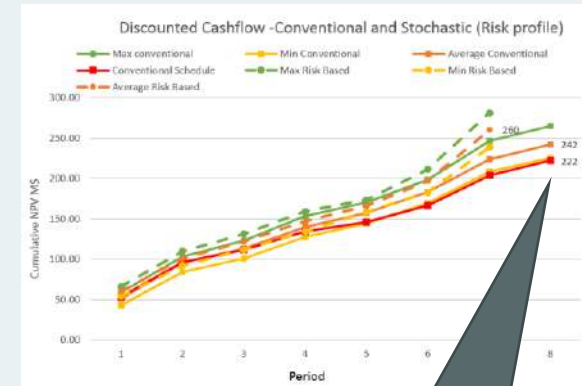
A set of simulations describe geological uncertainty and grade variability

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

Introduction – Stochastic Workflow

If we can optimize mine designs with the established conventional (deterministic) tools, we can also develop and optimize with stochastic optimizers:

Stochastic Mine Planning

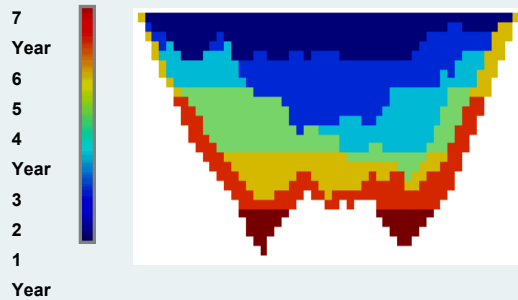
1. Lower risk in meeting financial and production forecasts.
2. Higher value for less risk.
3. More metal.

Introduction - Stochastic Mine Planning

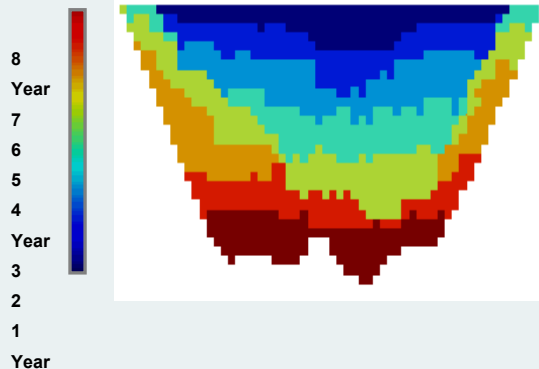
Stochastic vs Deterministic optimizers: Performance comparison

- how will the related schedule perform vs possible scenarios of the orebody in the ground?

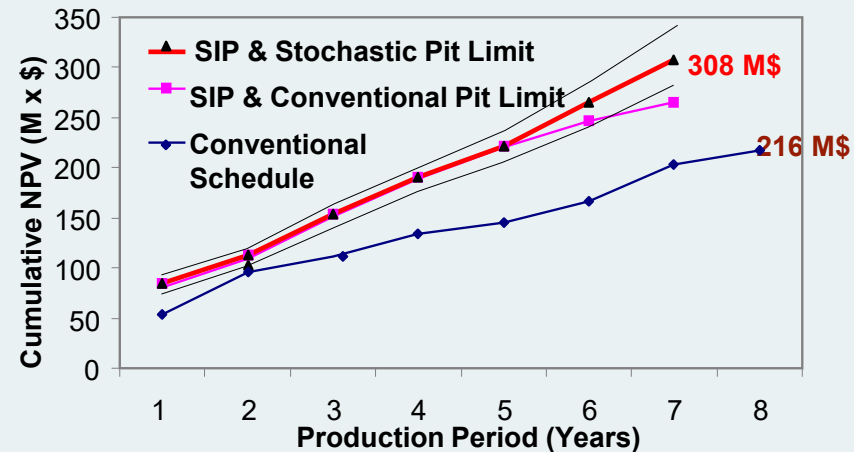
Stochastic schedule within the
Deterministically optimal pit limits



Stochastically optimal pit limits



Stochastic vs Deterministic Scheduling Approaches

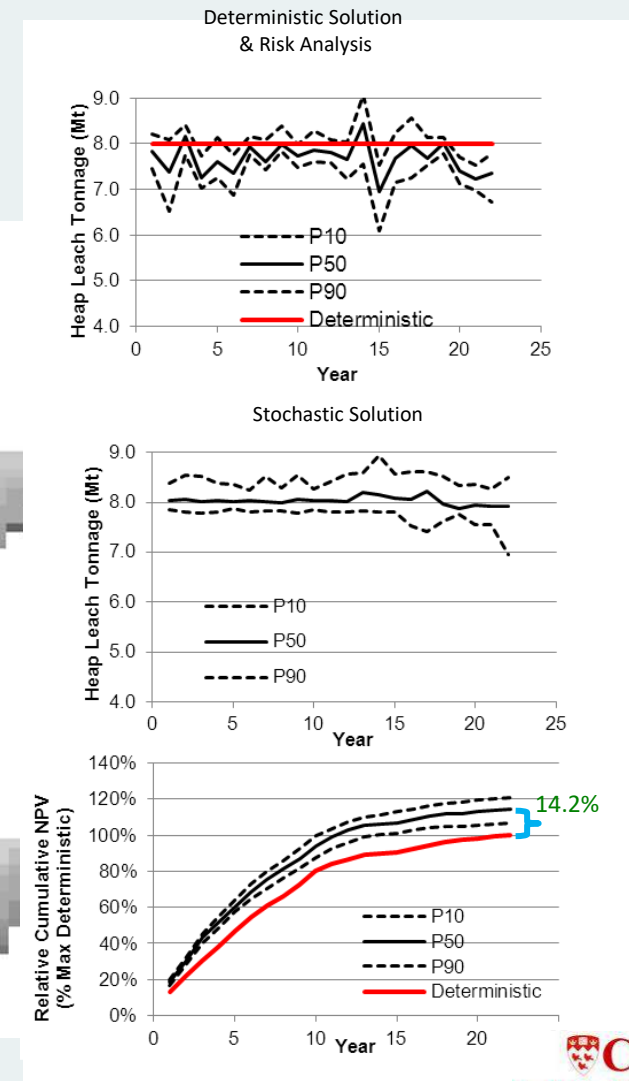
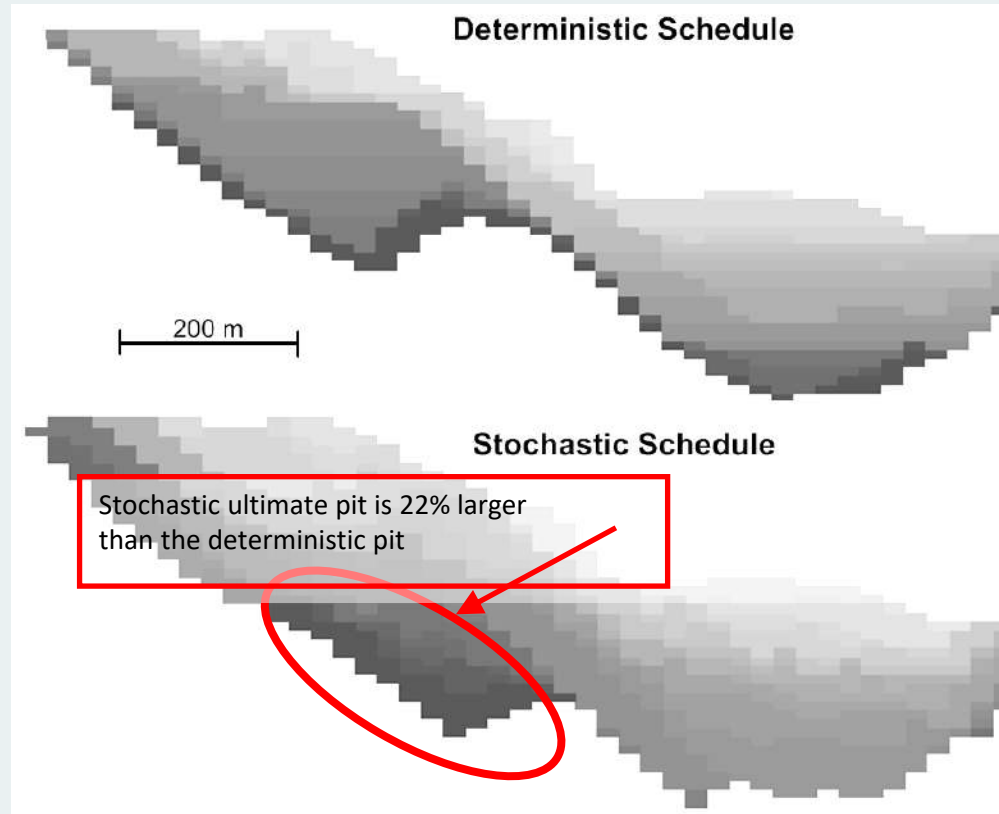


- Lower risk in meeting forecasts
- Higher value for less risk
- Larger pit limits
- More metal

Introduction - Estimation vs Simulation

does it Matter?

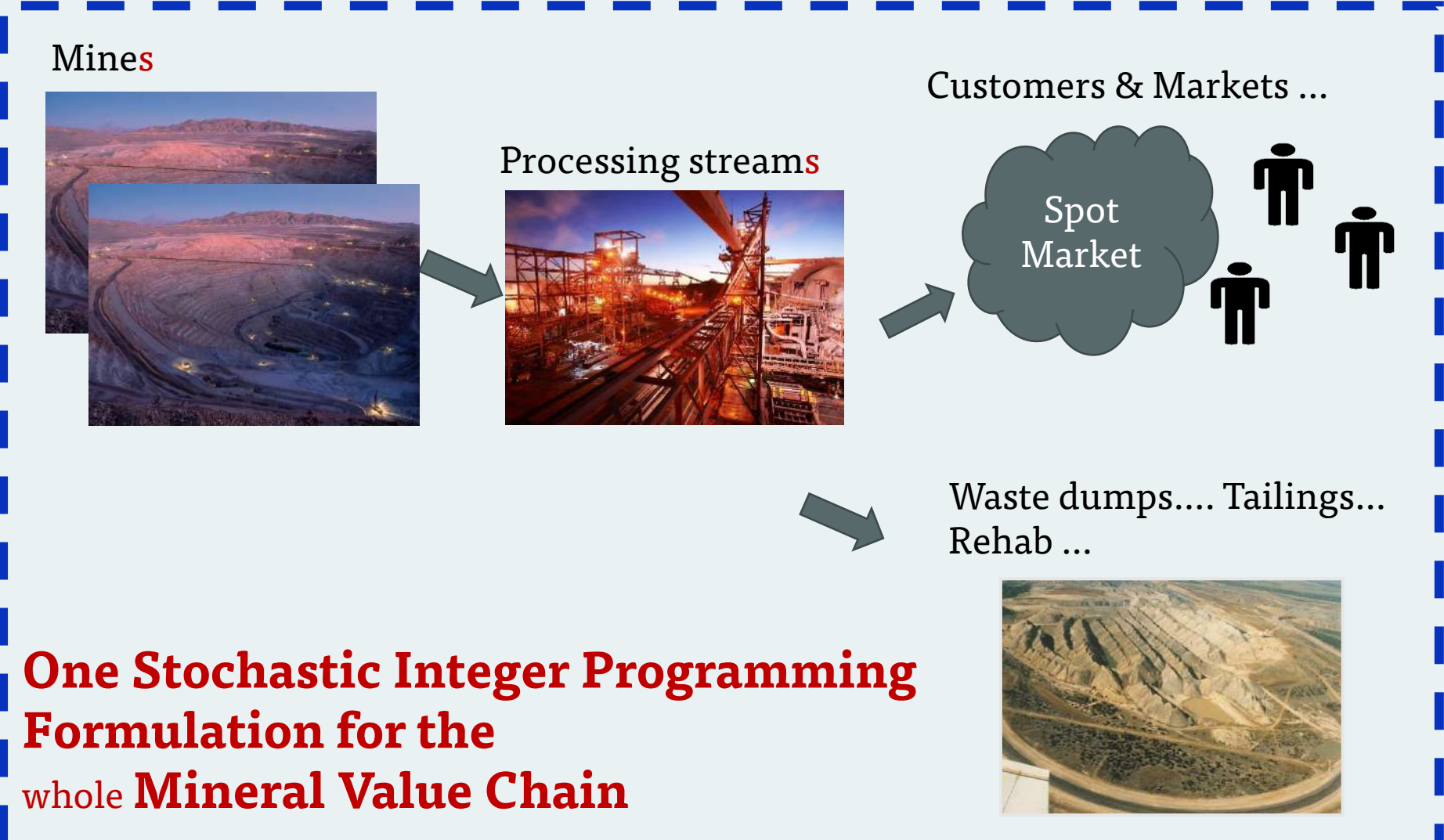
- **Stochastic** vs Conventional Optimization:
Less risk and higher reward!



Simultaneous Stochastic Optimization of Mining Complexes - Mineral Value Chains for Decision Support

Extending models & capitalizing on
synergies

Simultaneous Optimization

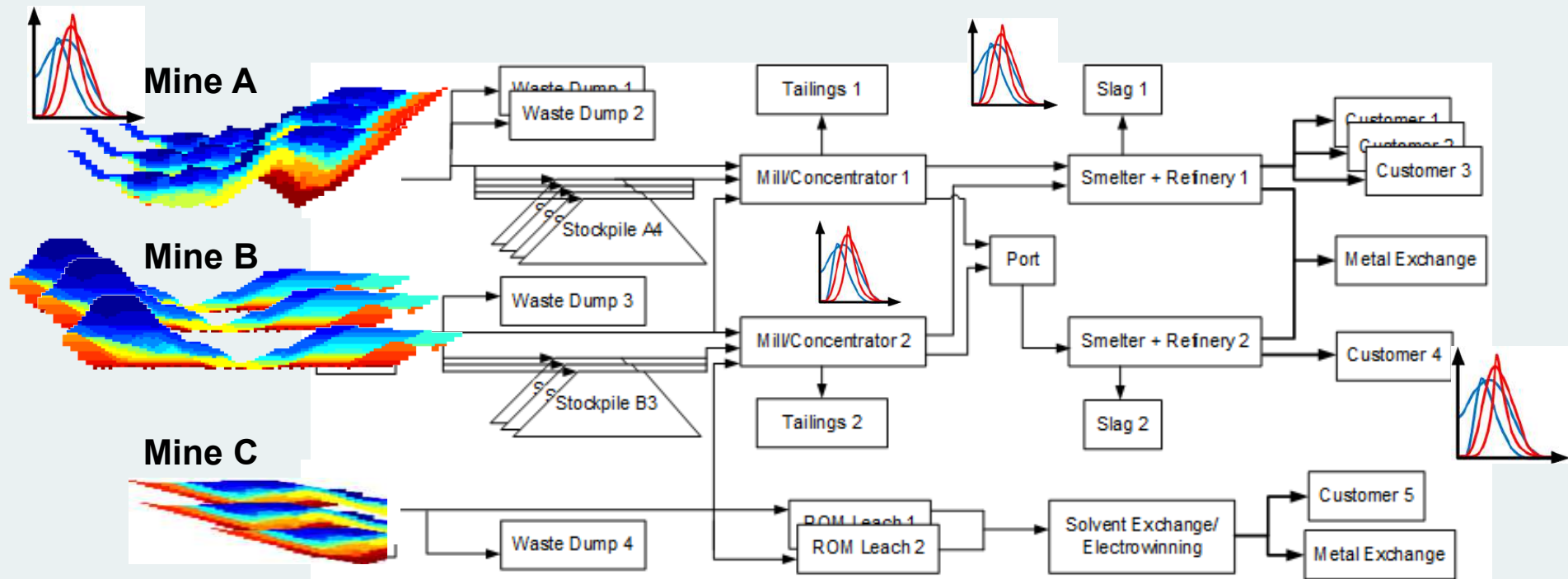


One Stochastic Integer Programming Formulation for the whole Mineral Value Chain

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 stochastic optimization of the mining complex/value chain



Simultaneous:

- a. One optimization model to *capitalize on synergies*,
- b. \$ value of products sold no \$ value of individual blocks

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 focuses on the

\$ value of products sold

rather than the

\$ value of individual blocks

and

Generates the optimal cutoff grades

Simultaneous Stochastic Optimization Formulation

- Adaptable two-stage stochastic integer programming model with CAPEX:

$$\max \underbrace{\frac{1}{\|S\|} \sum_{t \in T} \sum_{s \in S} \sum_{a \in A} p_{a,t} \cdot v_{a,t,s}}_{\text{Attributes of interest}} - \underbrace{\frac{1}{\|S\|} \sum_{t \in T} \sum_{s \in S} \sum_{a \in A} (c_{a,t}^+ \cdot u_{a,t,s} + c_{a,t}^- \cdot l_{a,t,s})}_{\text{Penalties for deviations from targets}}$$

Attributes of interest

- Revenues from metal sale
- Mining, processing & stockpiling costs

Penalties for deviations from targets

- Mining, stockpile, processing capacities
- Blending constraints
- Deleterious elements

$$- \underbrace{\sum_{t \in T} \sum_{k \in K} p_{k,t} \cdot w_{k,t}}_{\text{CAPEX}}$$

- Risk reduction.
- Risk deferral (geological risk discounting).

Simultaneous Stochastic Optimization Formulation

- Adaptable two-stage stochastic integer programming model with CAPEX:

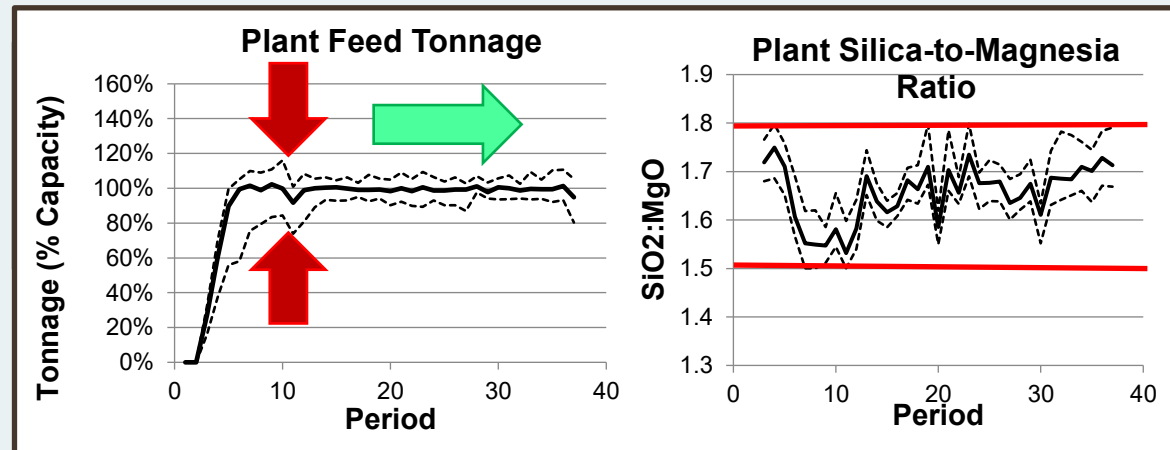
$$\max \frac{1}{\|S\|} \sum_{t \in T} \sum_{s \in S} \sum_{a \in A} p_{a,t} \cdot v_{a,t,s} - \frac{1}{\|S\|} \sum_{t \in T} \sum_{s \in S} \sum_{a \in A} (c_{a,t}^+ \cdot u_{a,t,s} + c_{a,t}^- \cdot l_{a,t,s})$$

Attributes of interest

- Revenues from metal sale
- Mining, processing & stockpiling costs

$$- \sum_{t \in T} \sum_{k \in K} p_{k,t} \cdot w_{k,t}$$

CAPEX

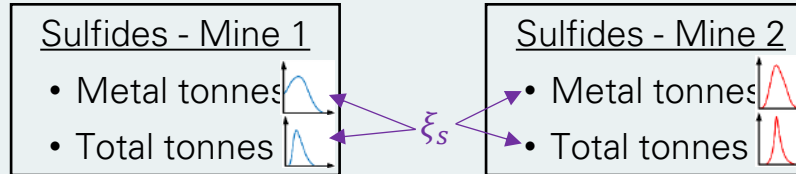


- Risk reduction.
- Risk deferral (geological risk discounting).

Modelling Mining Complexes with Risk Management



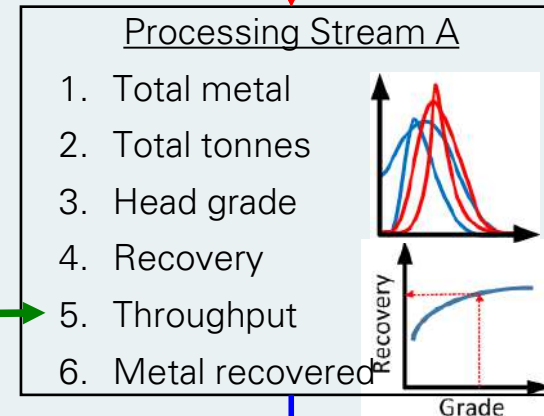
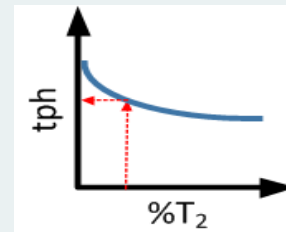
Production schedule



No Economic Values for Mining Blocks Used

Destination policies

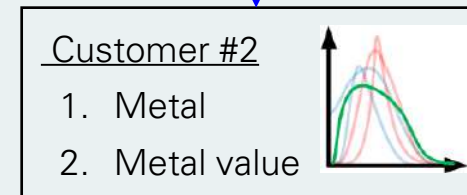
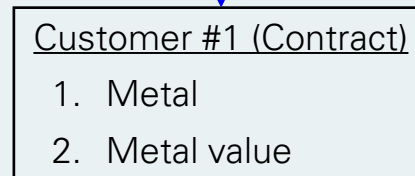
Processing streams



Decisions, Blending, GEOMET... .. All topics related to materials mined move here

Uncertainty can be quantified at any stage

Product Value



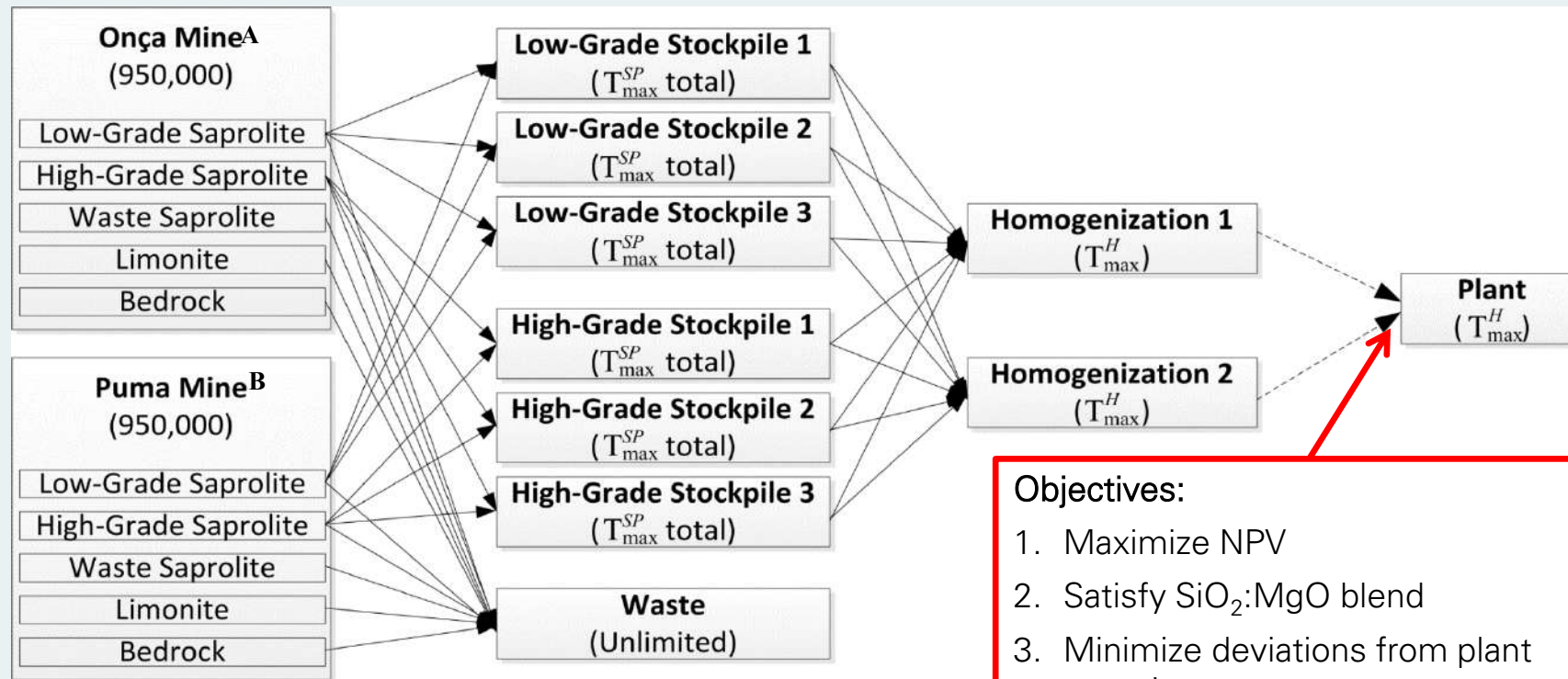
Cash flows are calculated here using products

The life-of-asset(s) strategic plan is the output of the optimization

Simultaneous Optimization of a Mining Complex

Example:

Nickel laterite mineral value chain - Blending policy optimization

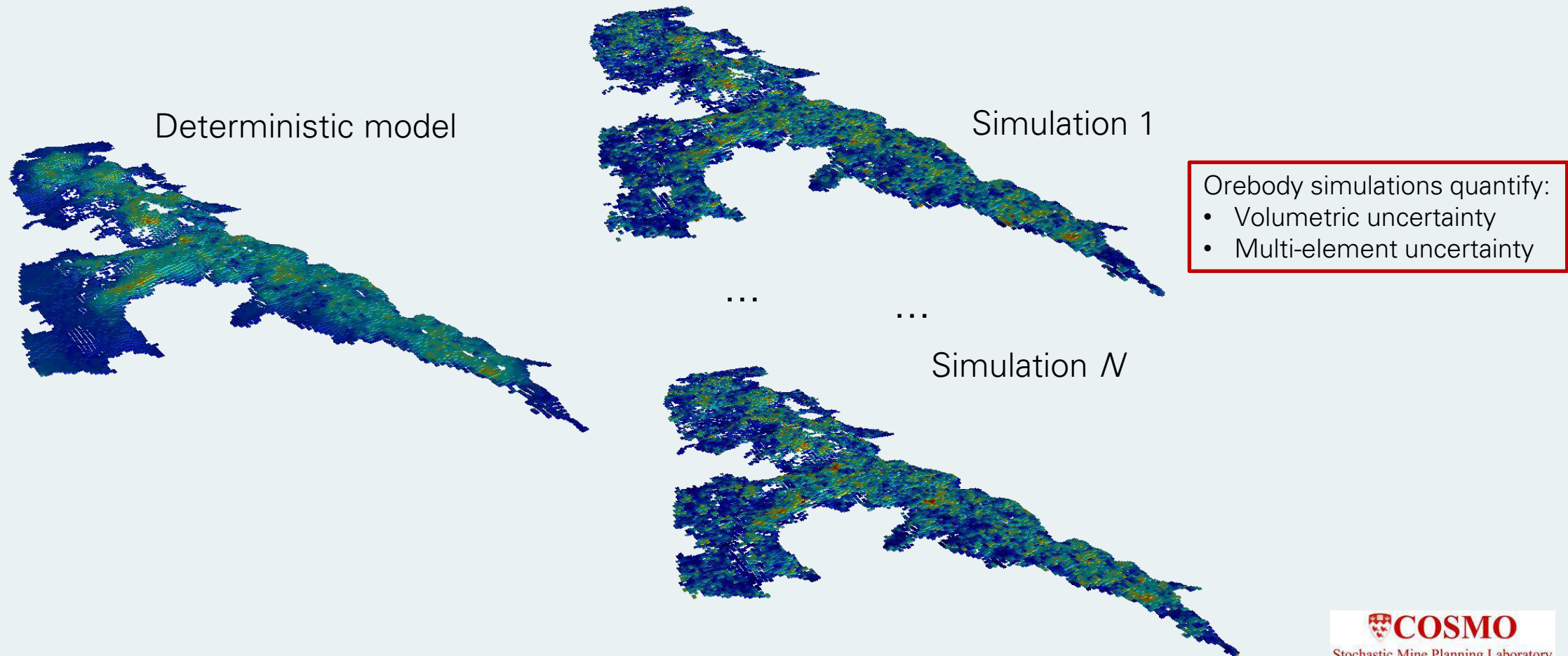


* T_{max} is the maximum plant feed tonnage

- Objectives:
1. Maximize NPV
 2. Satisfy SiO₂:MgO blend
 3. Minimize deviations from plant capacity target

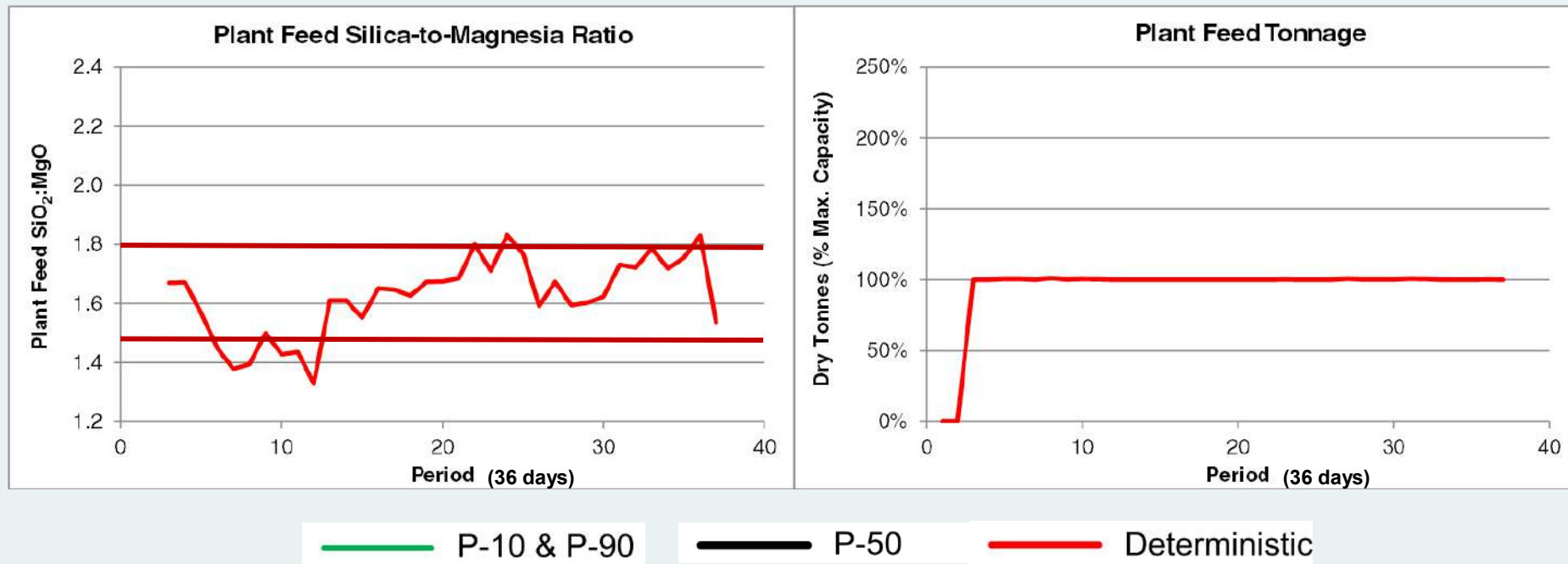
Simultaneous Optimization of a Mining Complex

Nickel Laterite Complex – Risk Analysis of Deterministic Design



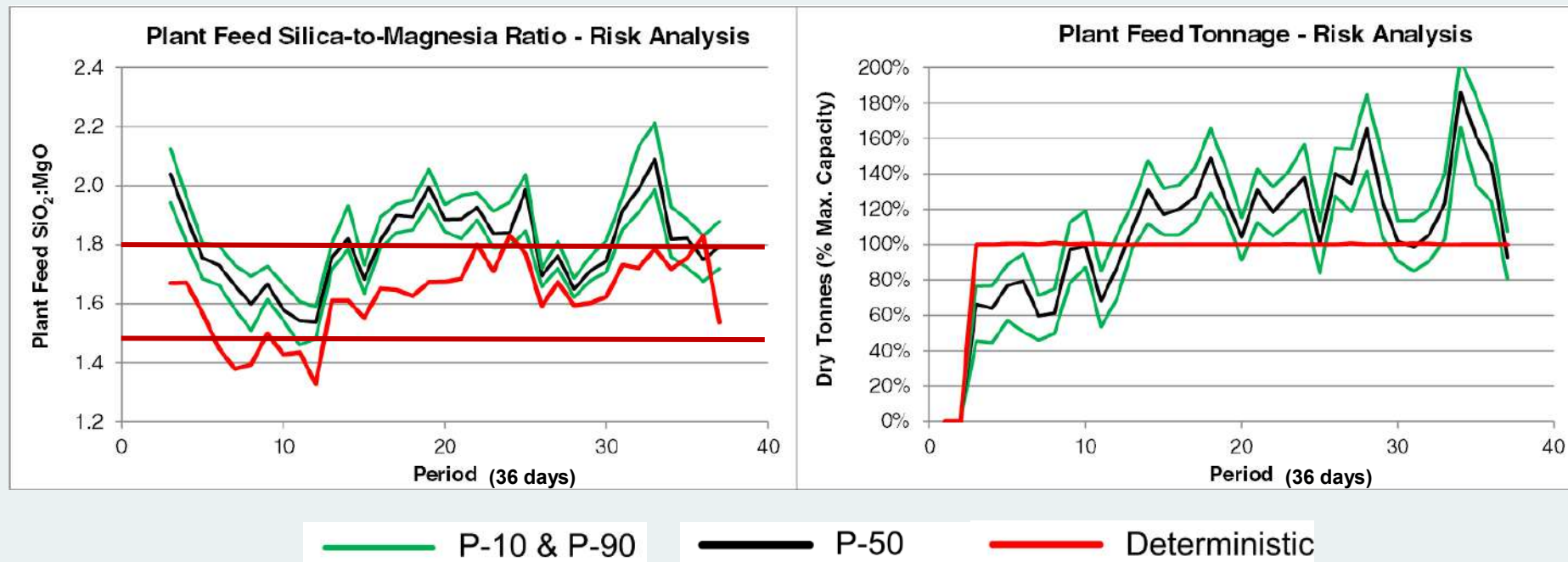
Simultaneous Optimization of a Mining Complex

Nickel Laterite Complex – Risk Analysis of **Deterministic** Design

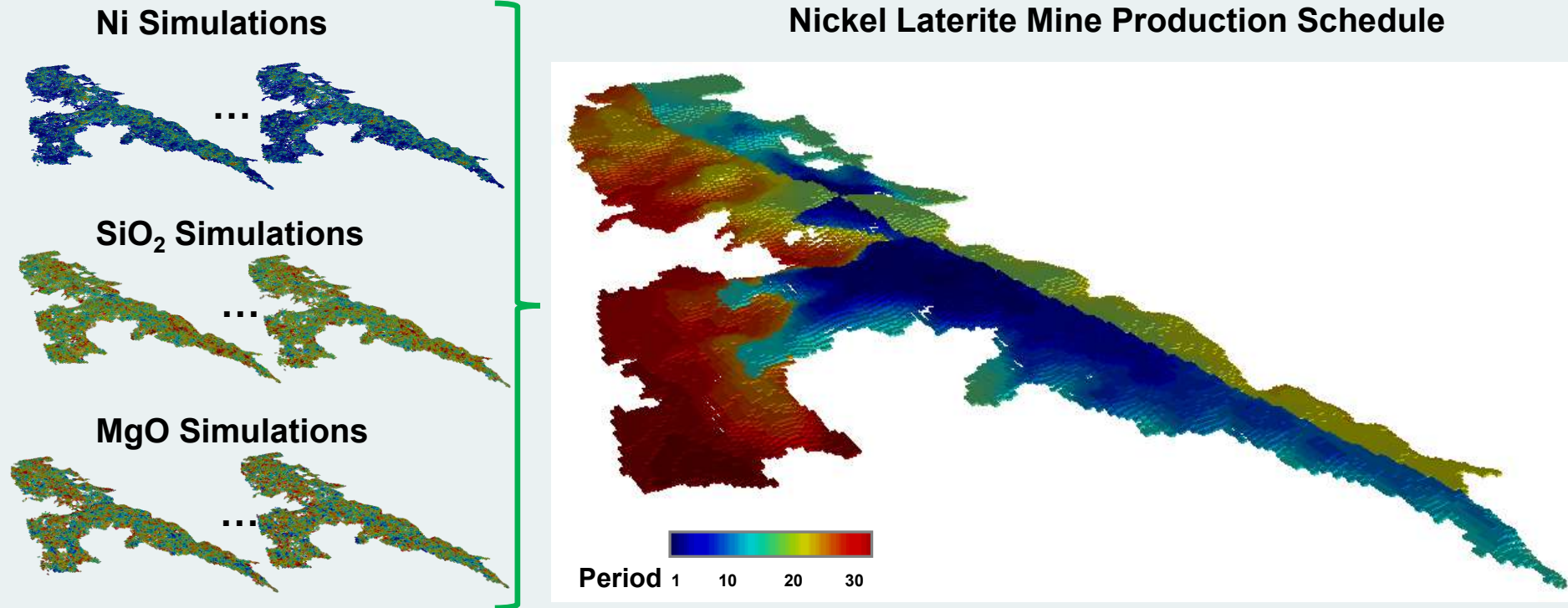


Simultaneous Optimization of a Mining Complex

Nickel Laterite Complex – Risk Analysis of **Deterministic Design**

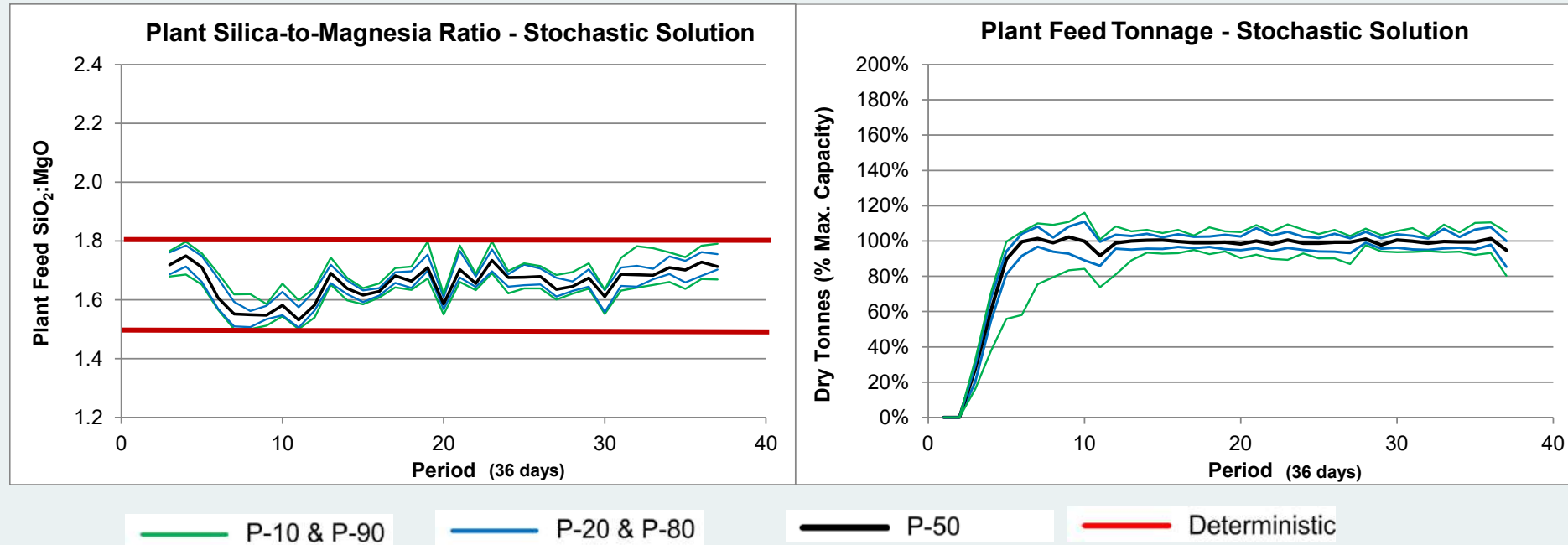


Simultaneous **Stochastic** Optimization



Simultaneous Stochastic Optimization

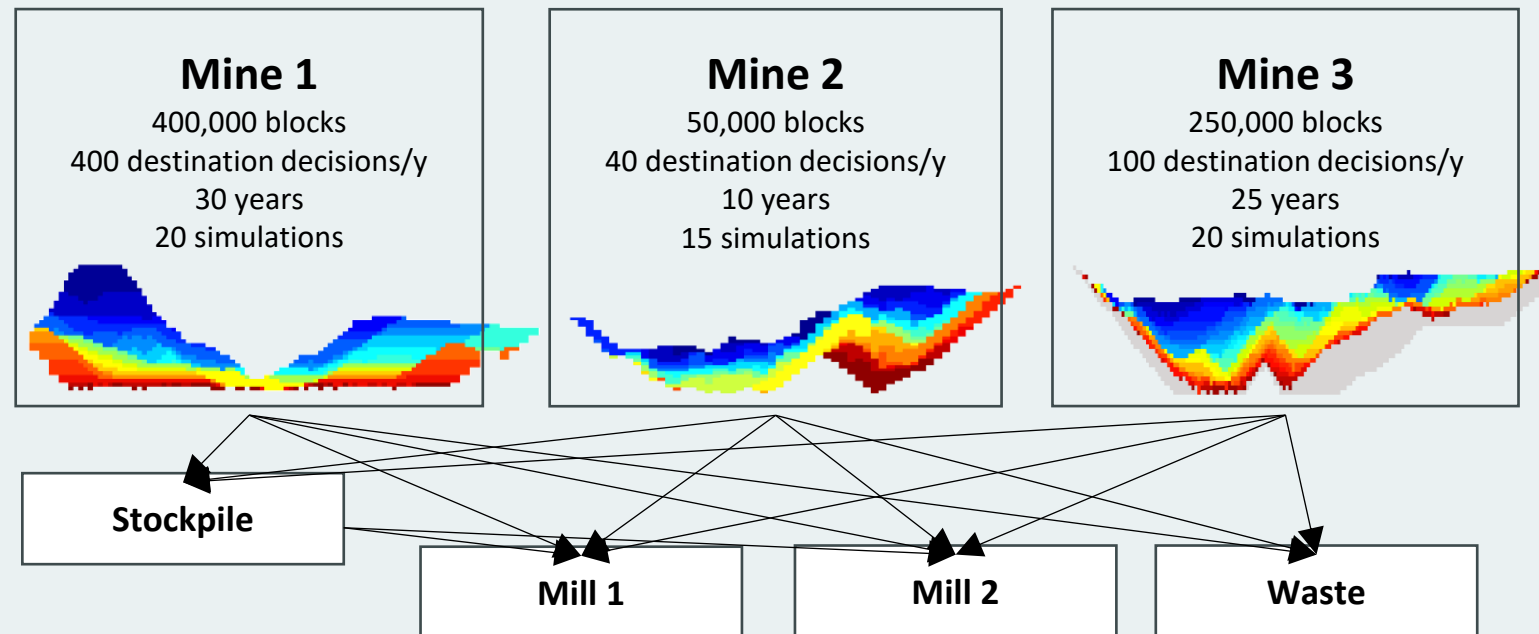
Nickel Laterite Complex - Simultaneous Stochastic Optimization



Algorithmic Optimization with Metaheuristics

Computationally prohibitive optimization models, **BELONG TO THE PAST**

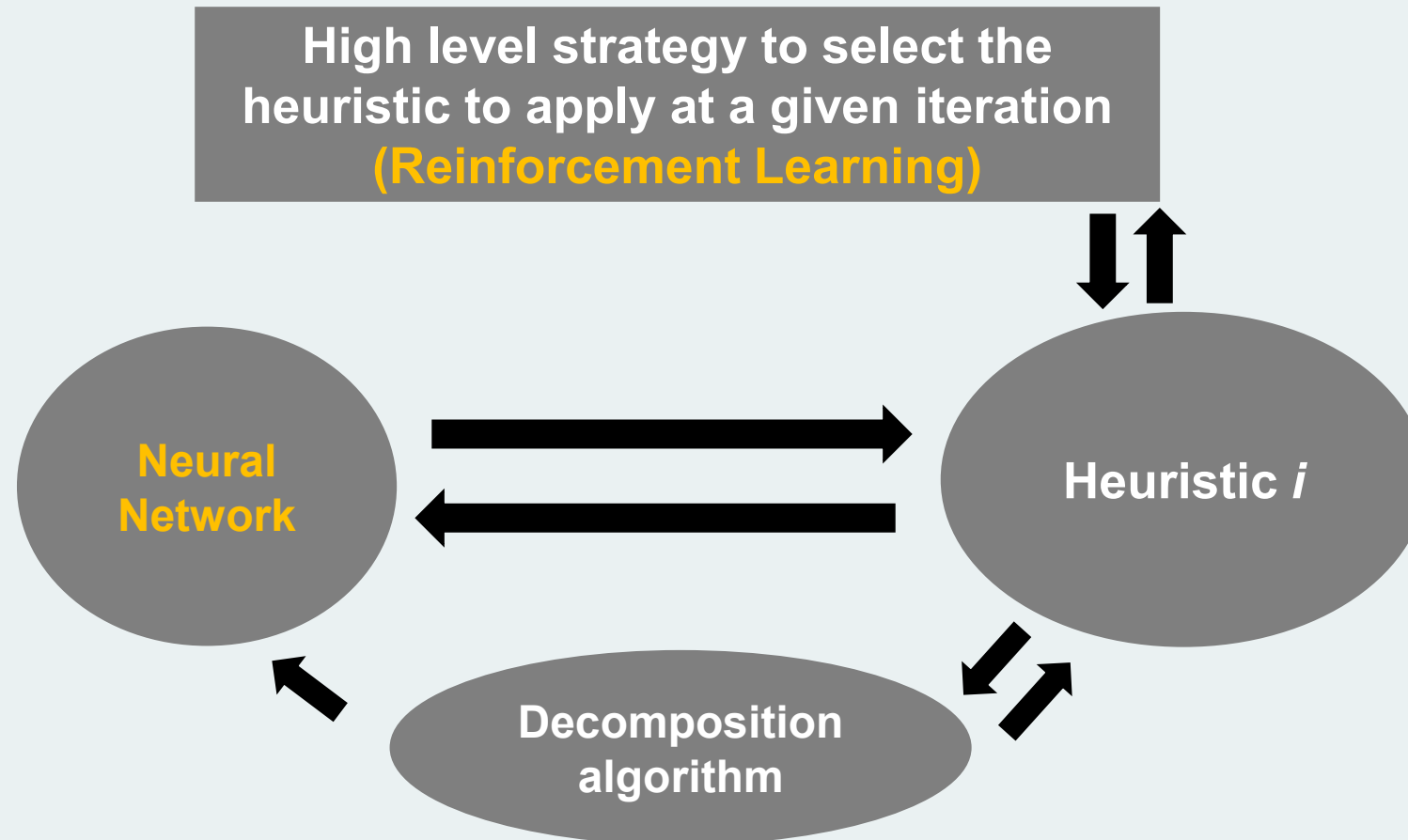
Example?



- 9,000 joint scenarios
- 18,750,000 scheduling decision variables
- 62,500 destination policy variables
- 540,000 processing stream variables

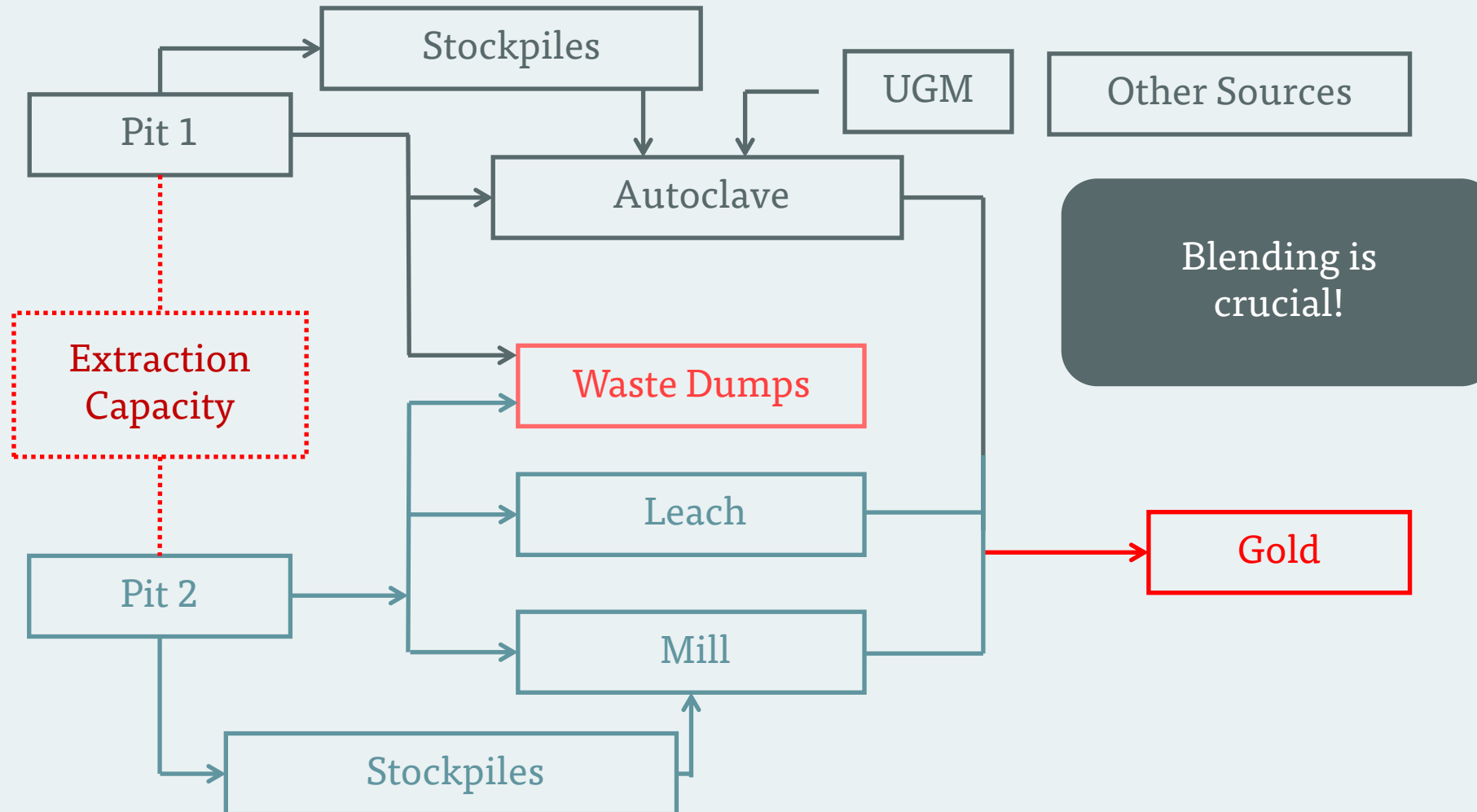
New Research - AI based Optimization Solutions

For Mineral Value Chain optimization formulations

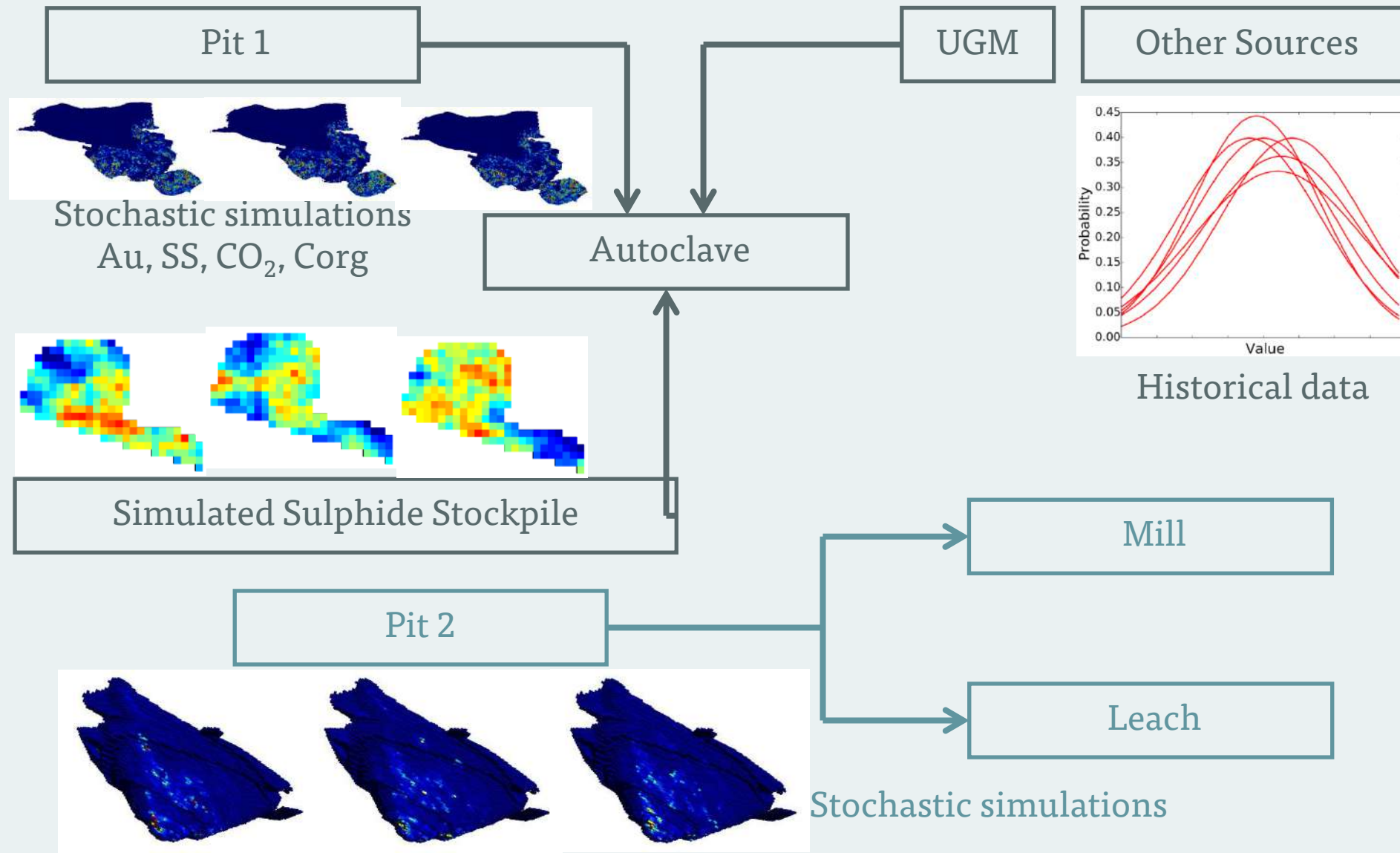


An Operating Gold Mining Complex

A Gold Mining Complex



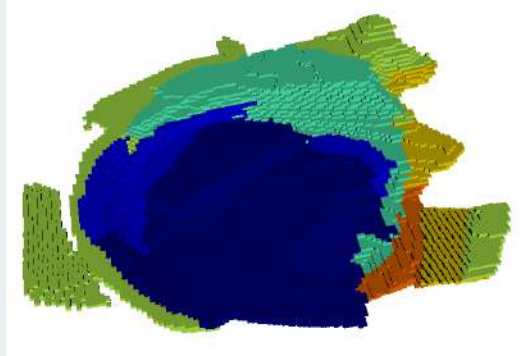
Base Case - Sources of Supply Uncertainty



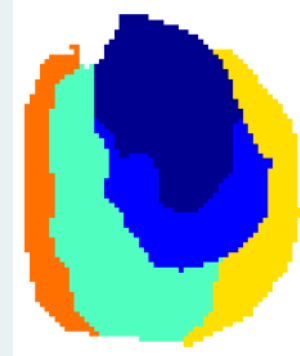
Practical Stochastic Schedule - Example

Practical
Stochastic
plan

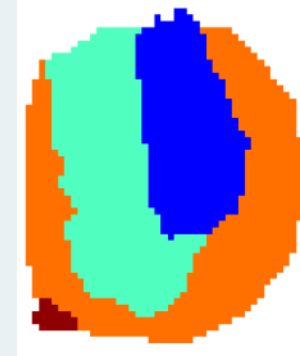
Full View



Bench A

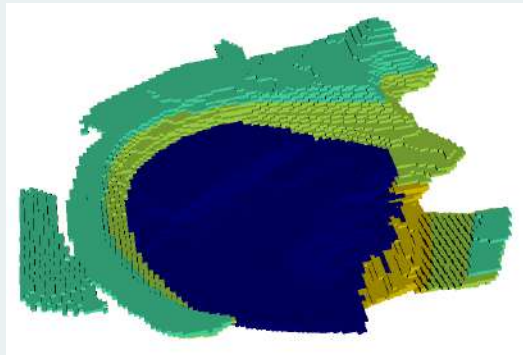


Bench B



Colours represent production years

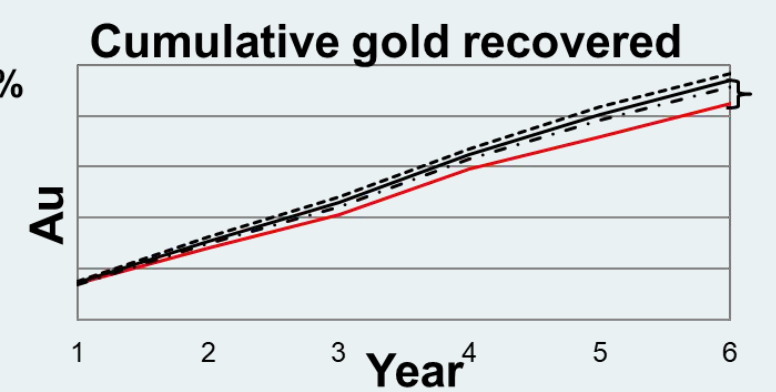
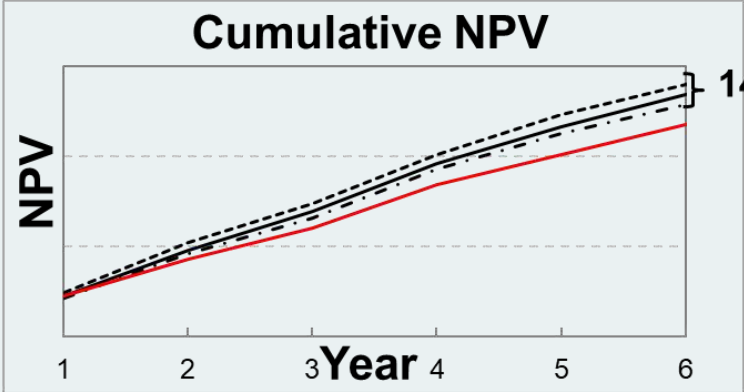
The Mine's P
ractical
plan



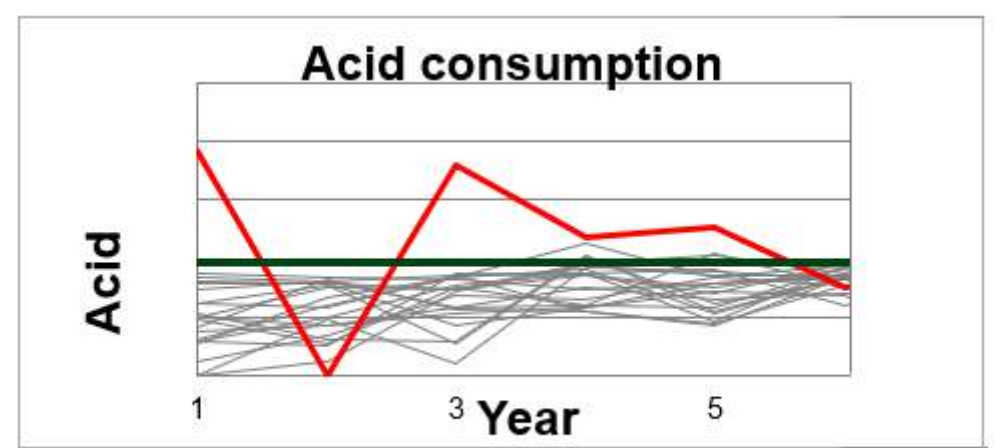
Stochastic vs conventional schedules:

Substantially different parts of the pit are mined at the same year

Stochastic Schedule



— Mine's schedule
 - - - - P10
 ——— P50
 - - - - P90 of Stochastic schedule



— Mine's
 ——— Stochastic
 ——— Limit

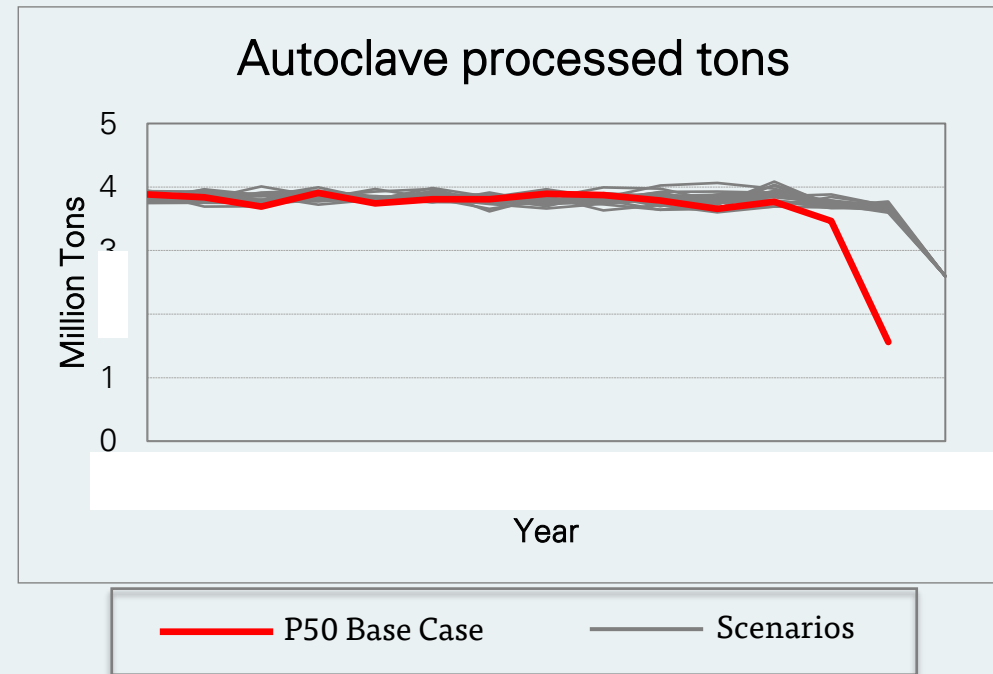
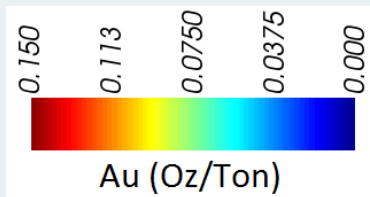
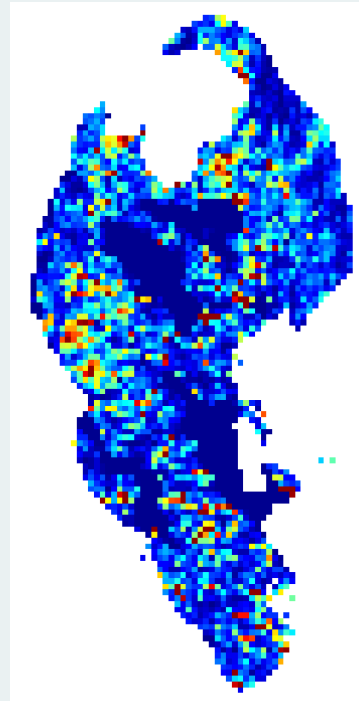
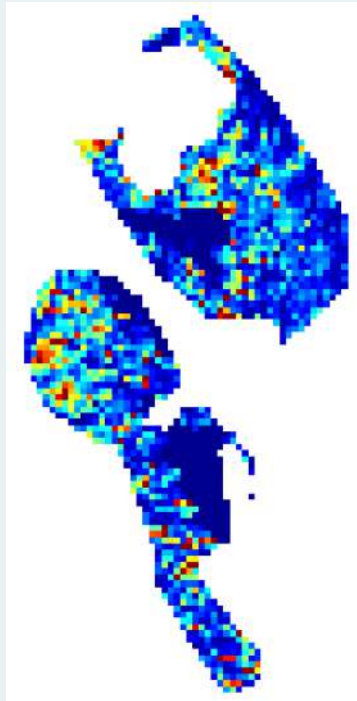
Stochastic Schedule: Even More Pre, Larger Pit

Pit A – Bench X

1 extra year of ore to the autoclave

Conventional

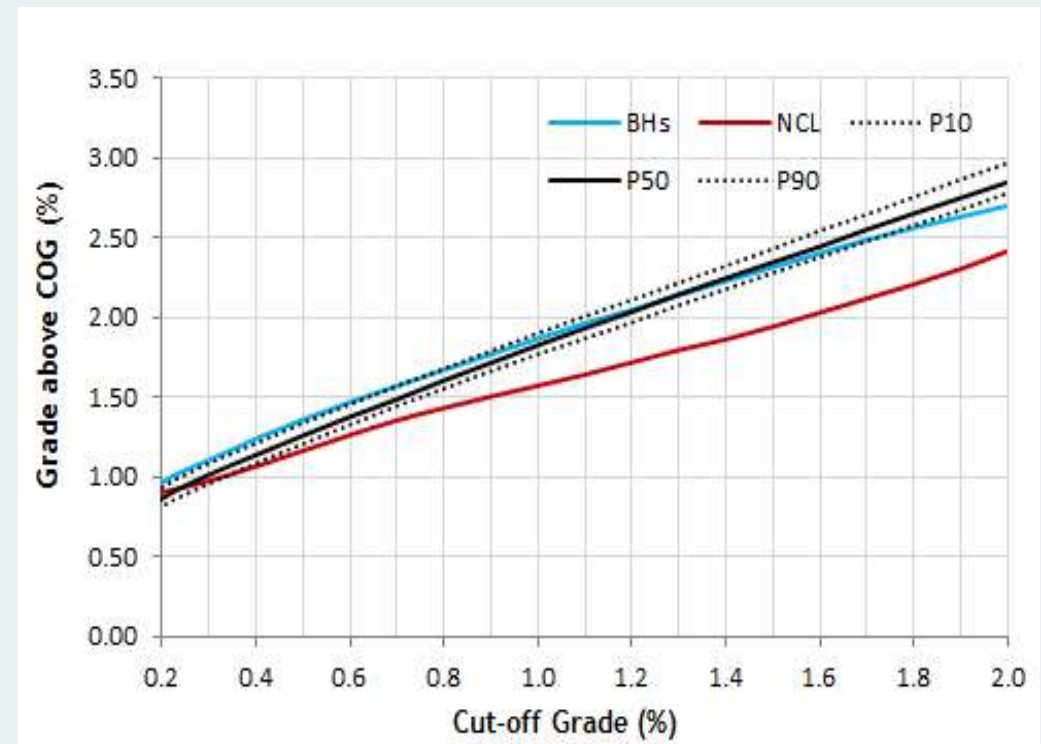
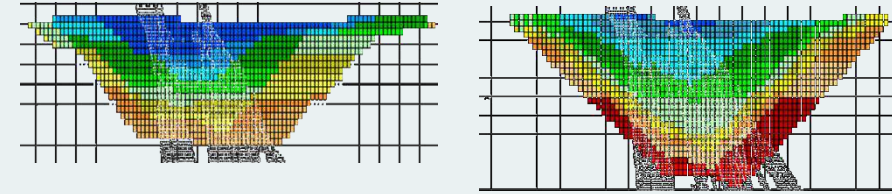
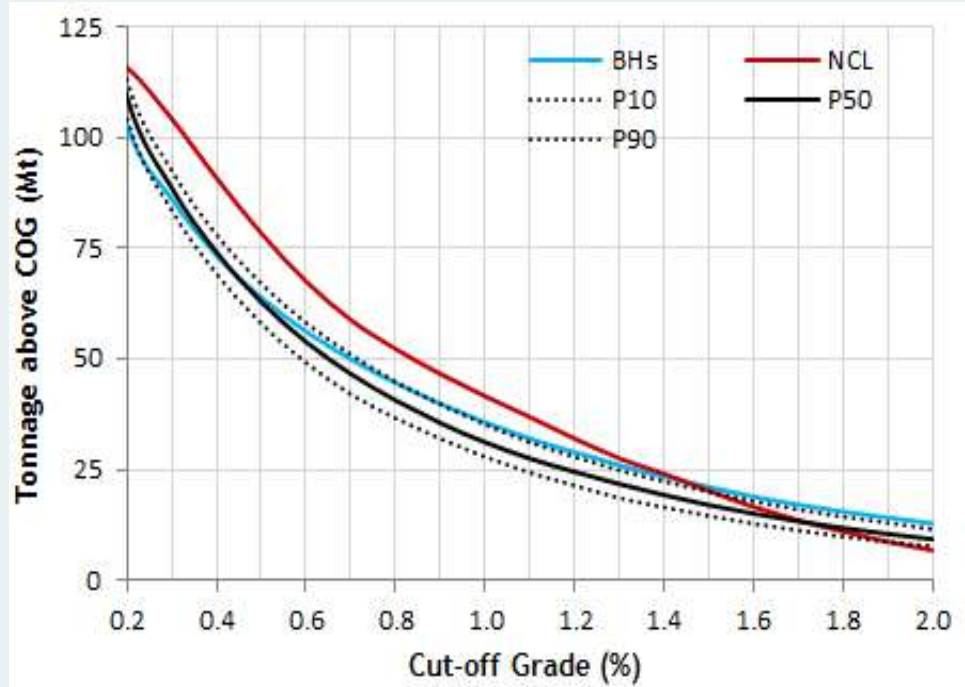
Stochastic



Meaning: If this approach was applied from the start, ie several years earlier, there would be more gold produced from the same assets.

More Comparisons with Reality?

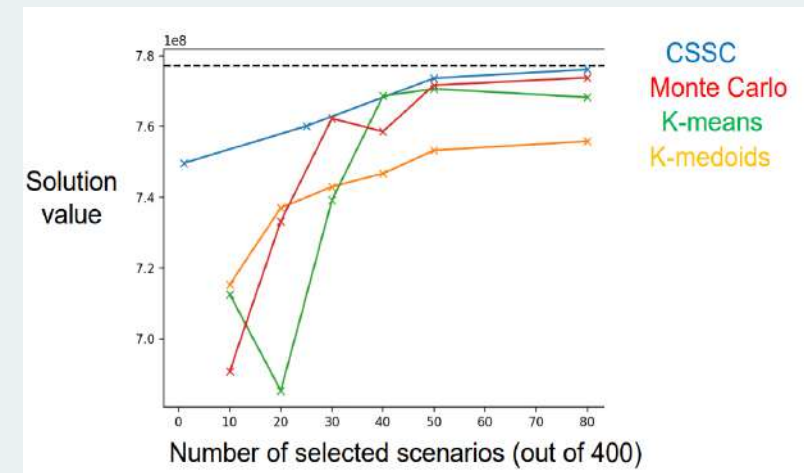
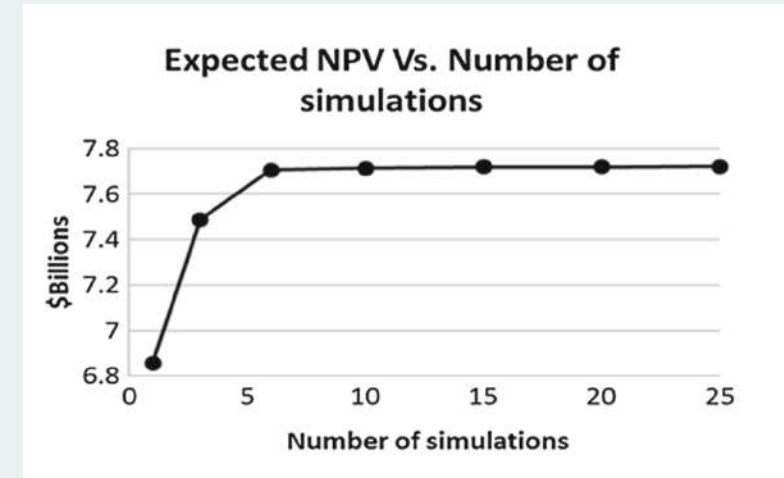
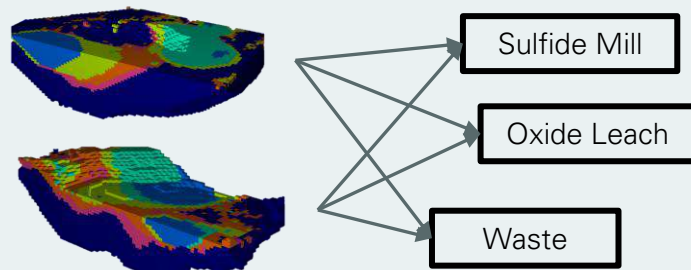
Reconciliation Study, Schedules vs Blast Holes



P50: Stochastic Schedule
BHs: Blast Holes
NCL: Conventional Schedule

How Many Simulations?

- Stable LOM plans and forecasts after 10-15 simulations
- *Support - scale effect*: the variability of a schedule (grouping thousands of blocks) is substantially lower than that of individual blocks

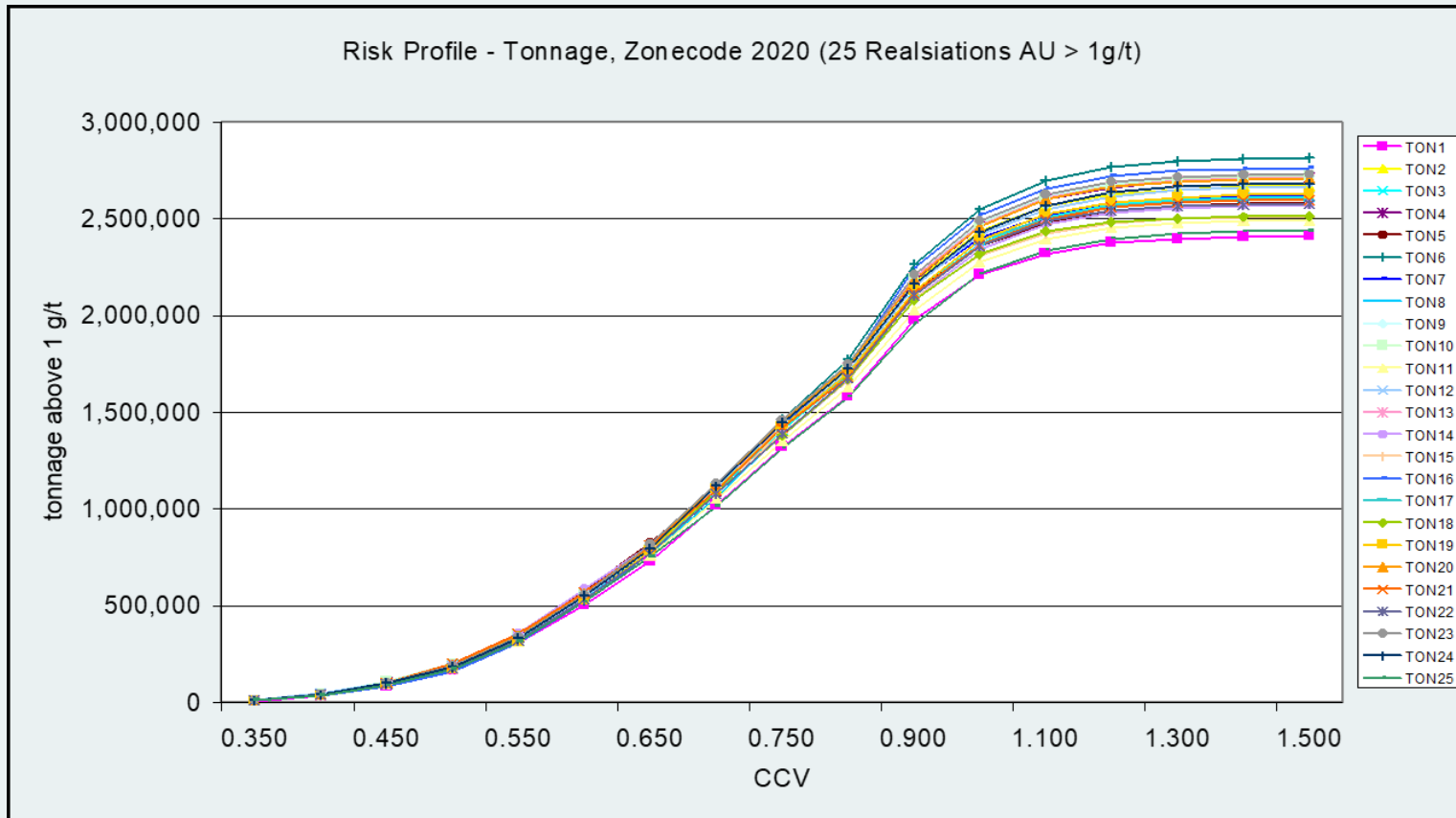


2 mines, 400 scenarios: ~ 70 simulations provide stable results

All-inclusive Simultaneous Stochastic Optimization

A Reserve Classification Related Issue

- Tonnage above the 1g/t cut-off (left) versus the CCV for 25 realizations of a gold deposit

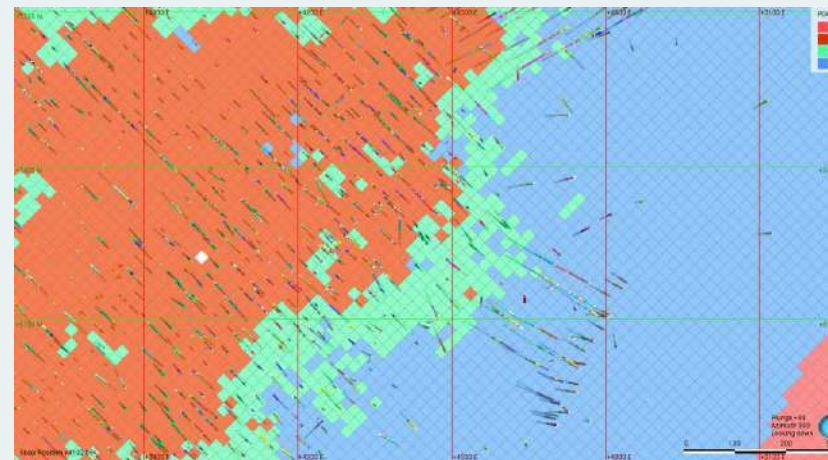


A Comparison

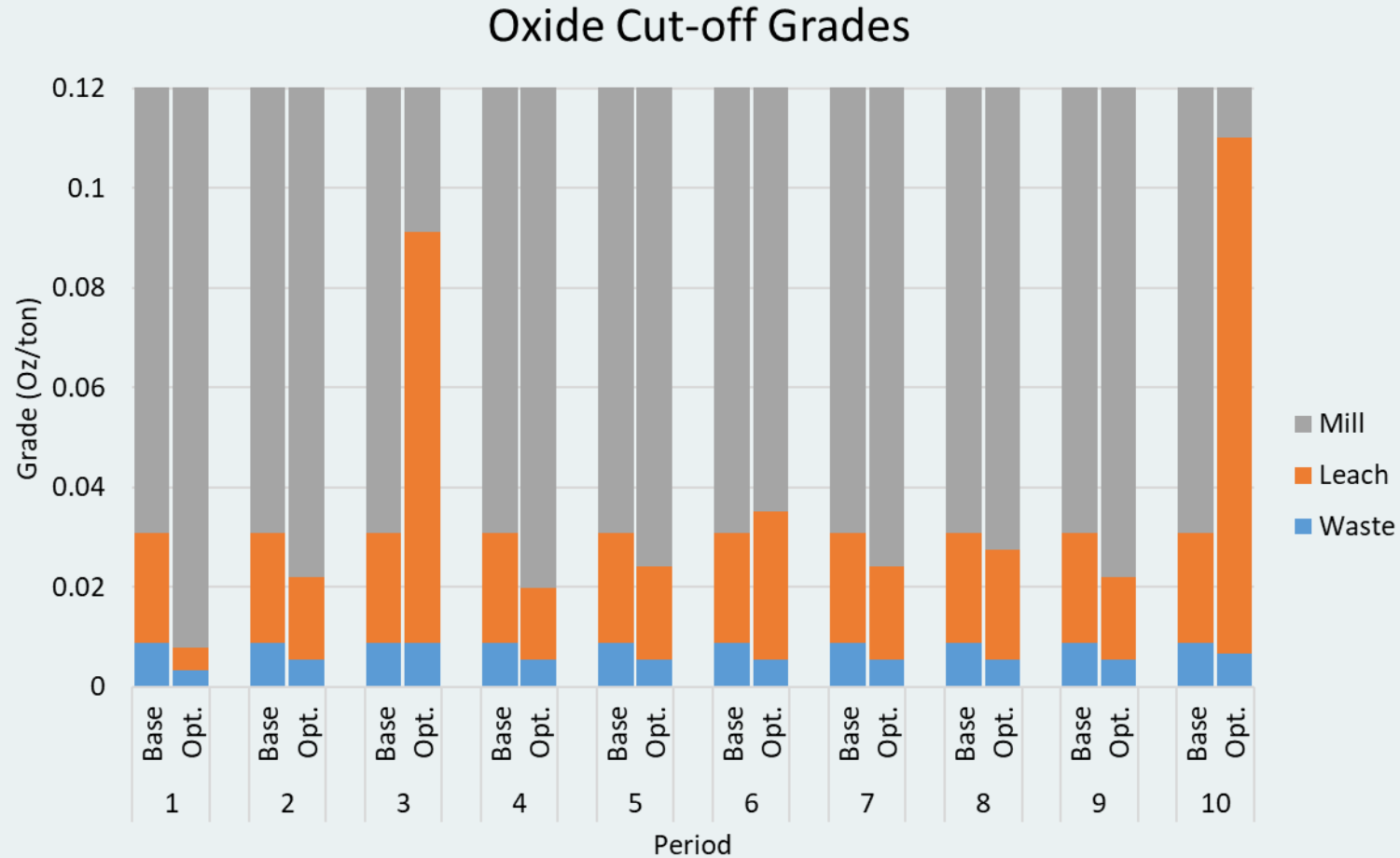
Deterministic Classification



Probabilistic Classification

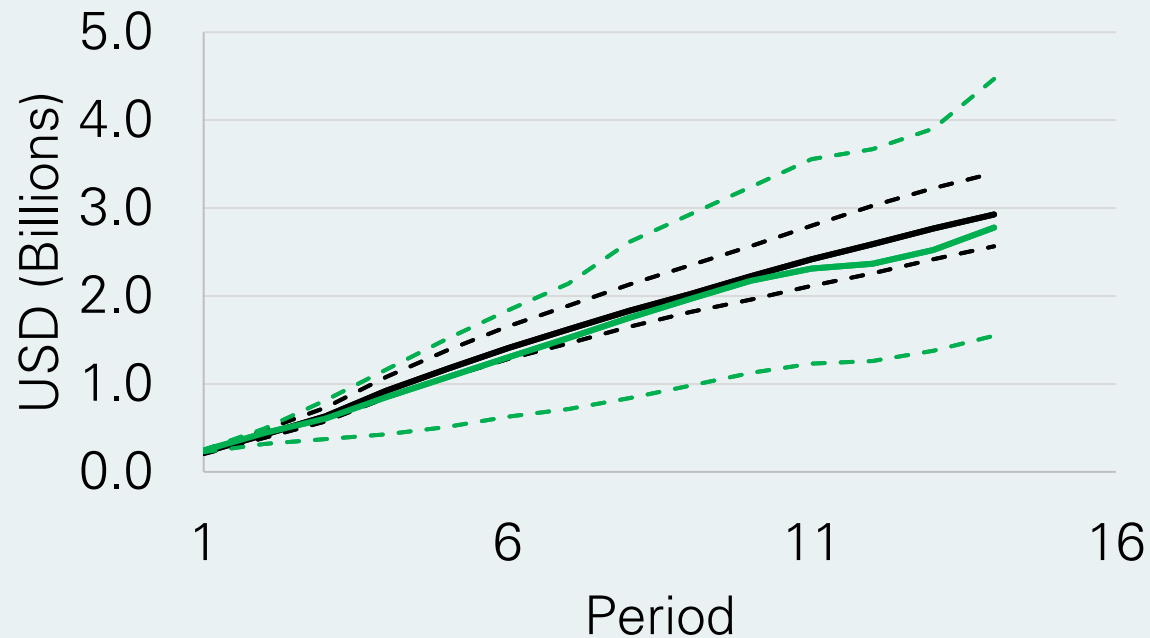


An **Output**: Cut-off Grade Optimization



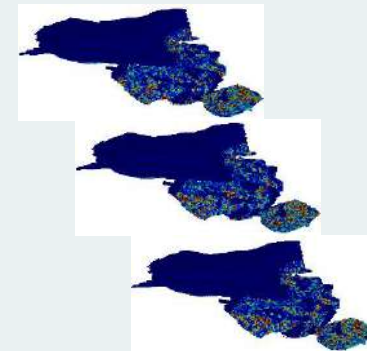
Joint Supply and Market Uncertainty

Net Present Value

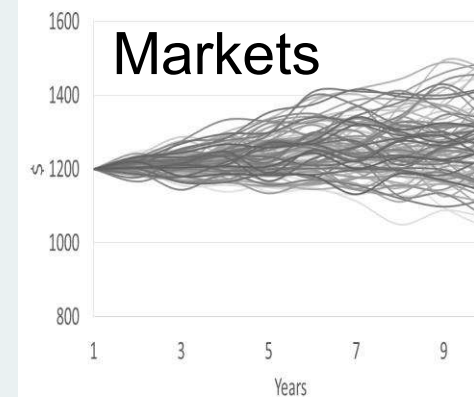


P10/P90 - - - P50 — Bounds —
 Joint Supply and Market Uncertainty Supply Uncertainty

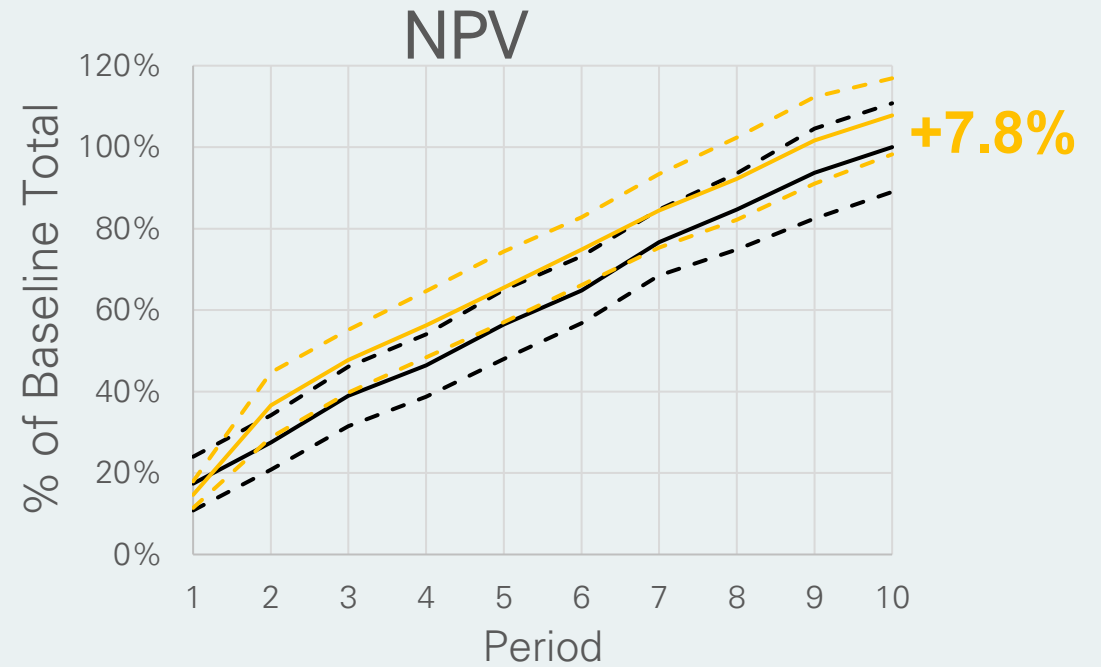
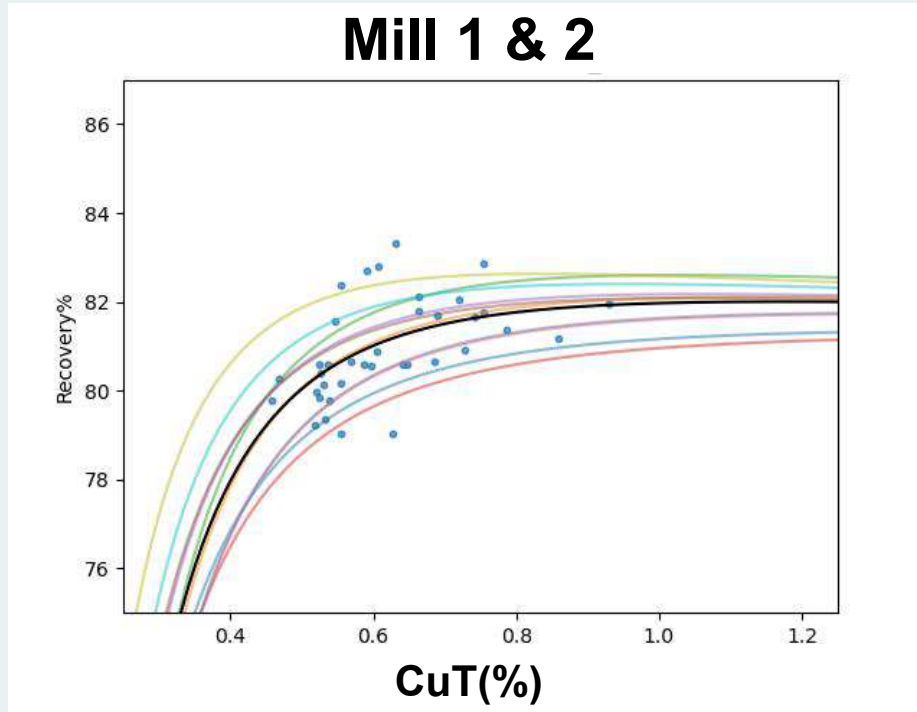
Mineral Deposits



Commodity Price



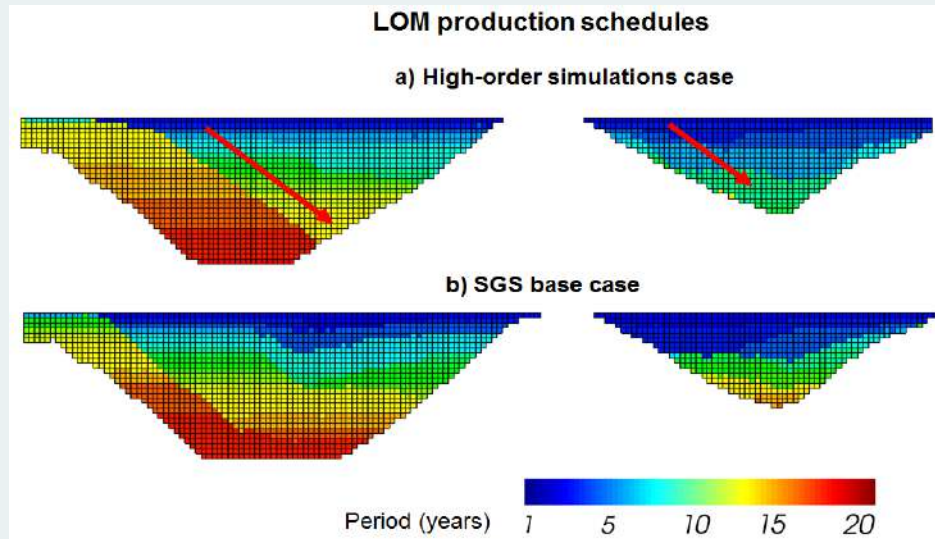
Recovery Uncertainty



**Baseline
(Supply Uncertainty)**

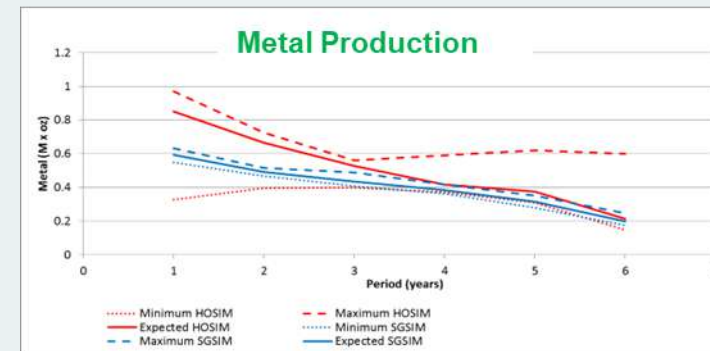
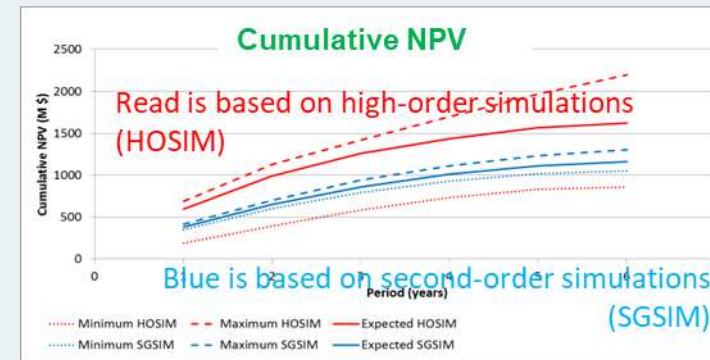
**Supply &
Recovery
Uncertainty**

Do methods of modelling uncertainty matter to mine production scheduling ?



Comments:

- Both schedules above are stochastic
- Schedules are physically different (and pit limits)
- High-order simulations lead to 40% higher NPV
- More ore for less waste



ALL IMPROVEMENTS ARE DUE TO:

Managing Technical Risk from
materials mined

and at the same time

Capitalizing from the Synergies
between all parts of the mining complex

Where to from here?

New Research

The Self-learning Mining Complex

and

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

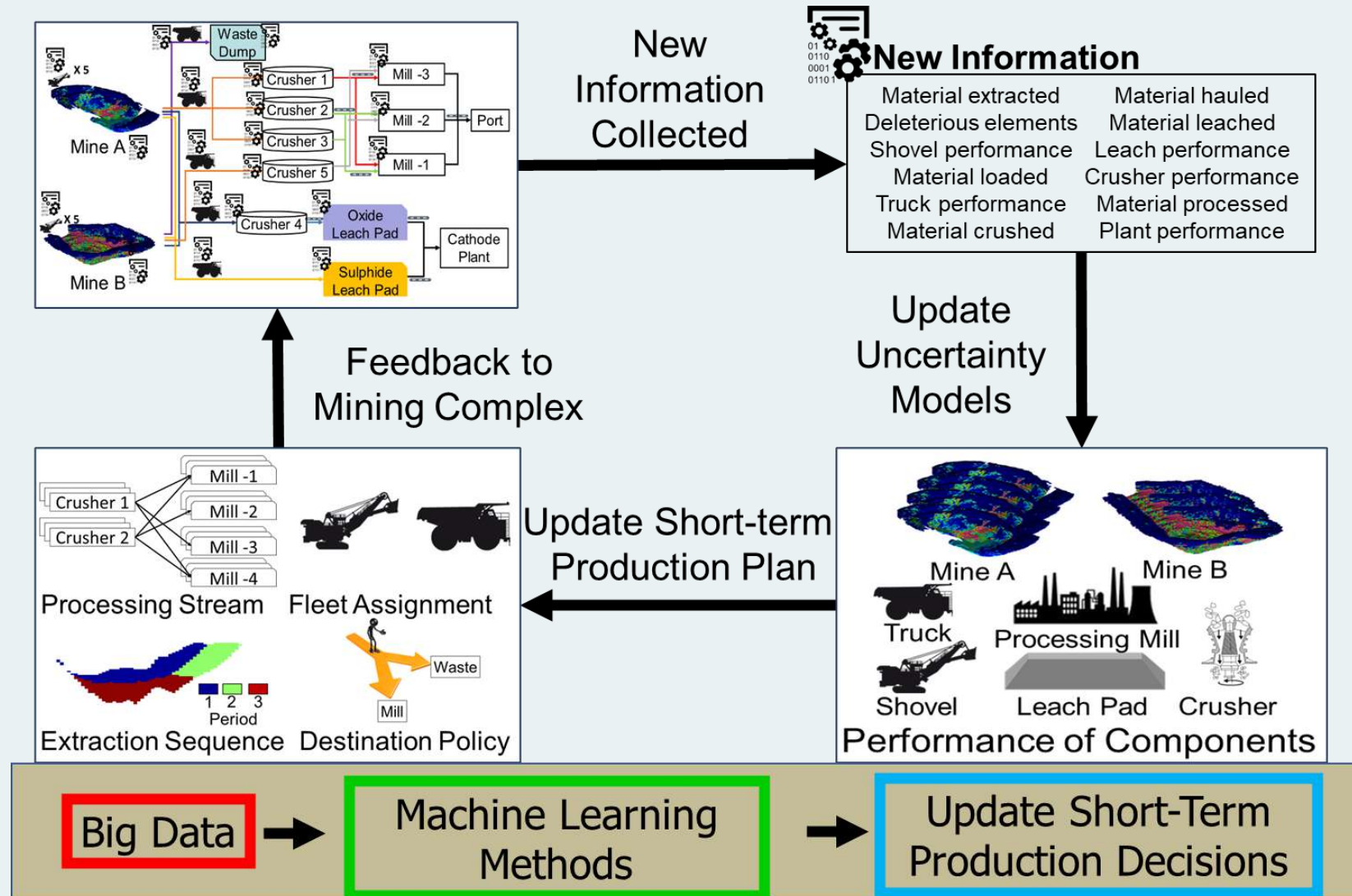


Exploration



Blasthole

New Information: Workflow



COSMO Industry Members



Funding Agencies



Canada Research
Chairs

Chaires de recherche
du Canada











PROBABILISTIC METHODS IN SUPPORT OF RESOURCE AND RESERVE DISCLOSURES

Marcelo Godoy
Chief Technology Officer
AngloGold Ashanti

PRESENTATION OUTLINE

-  The facts: Estimation vs. Simulation
-  Methodologies for Mineral Resource Classification
-  Parker's Rule
-  Orebody Simulations in support of Resource & Reserve Classification
-  Two Approaches to Solve the Open Pit Scheduling Problem
-  Conclusions

Estimation vs. Simulation

Estimation

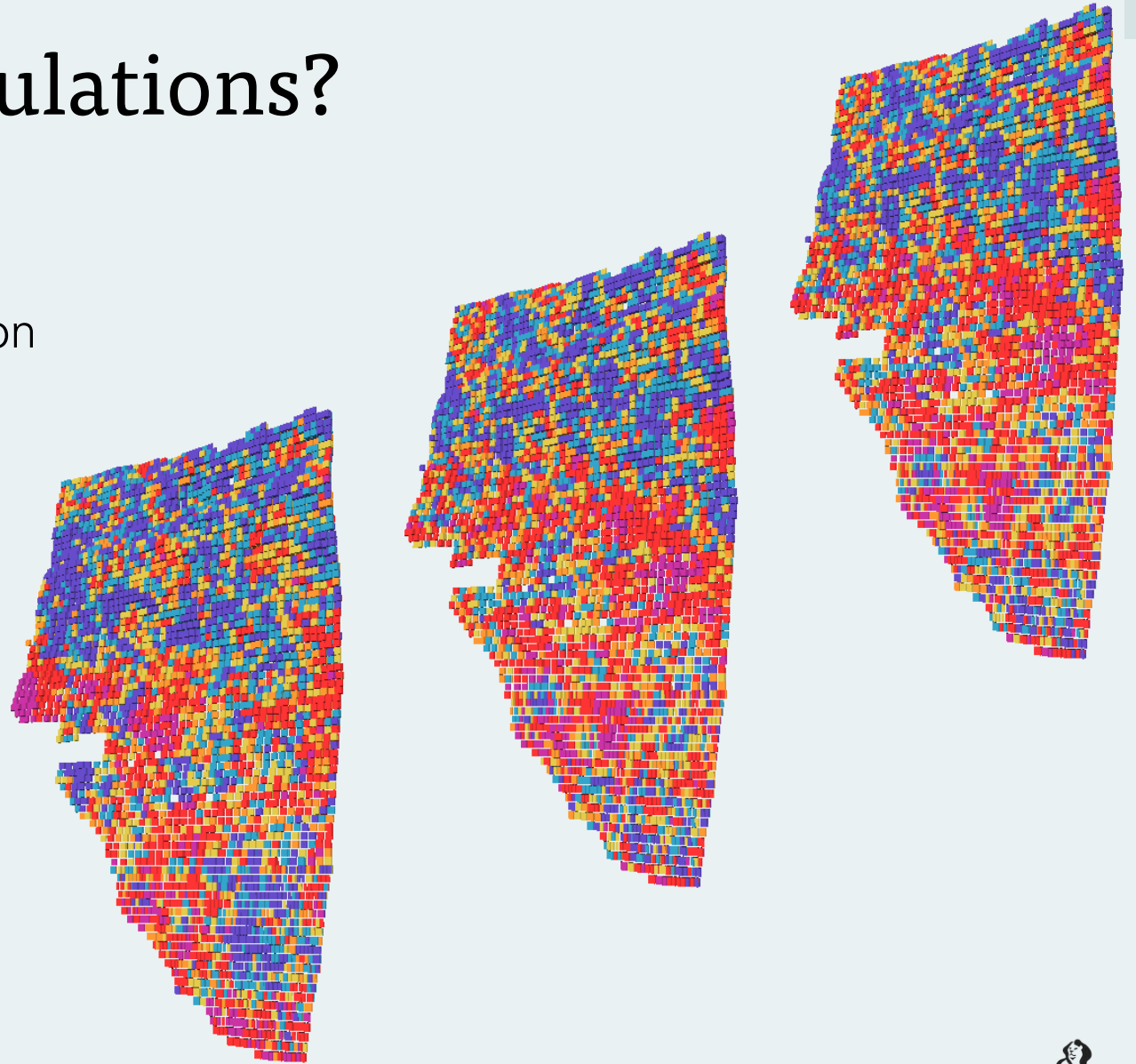
- Provides a single map representing a smooth view of the underlying mineralization
- Globally unbiased
- May be conditionally biased
- Does not reproduce data histogram
- Does not reproduce the input variogram
- Honors local data
- Locally accurate
- Assessment of local averages

Simulation

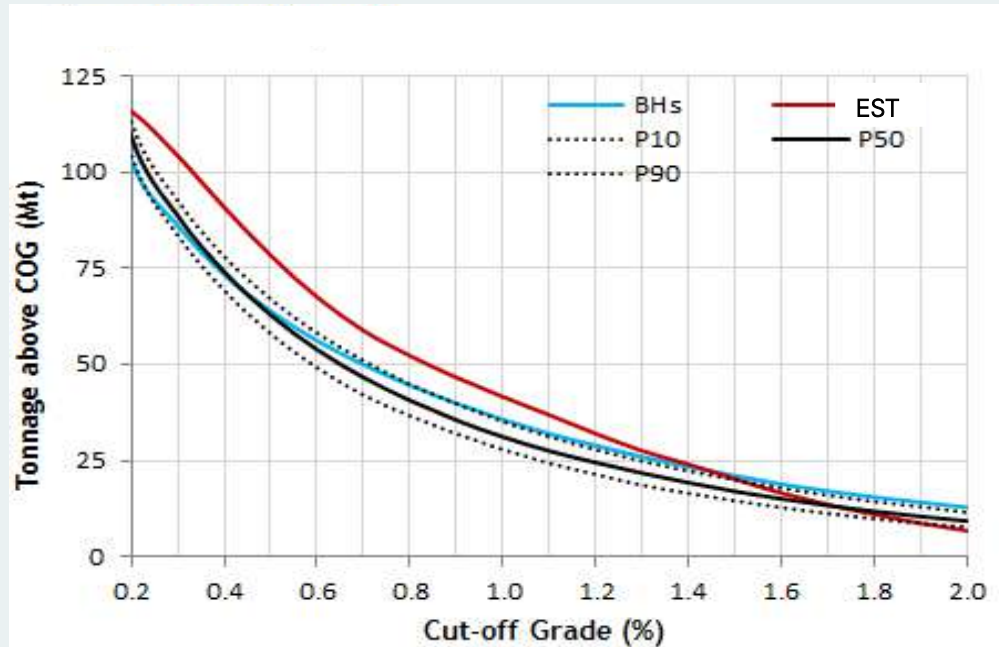
- Provides several equally probable alternative versions of the underlying mineralization
- Globally unbiased
- Conditionally unbiased
- Reproduces data histogram
- Reproduces the input variogram
- Honors local data
- Locally inaccurate
- Assessment of local uncertainty

Why do I trust simulations?

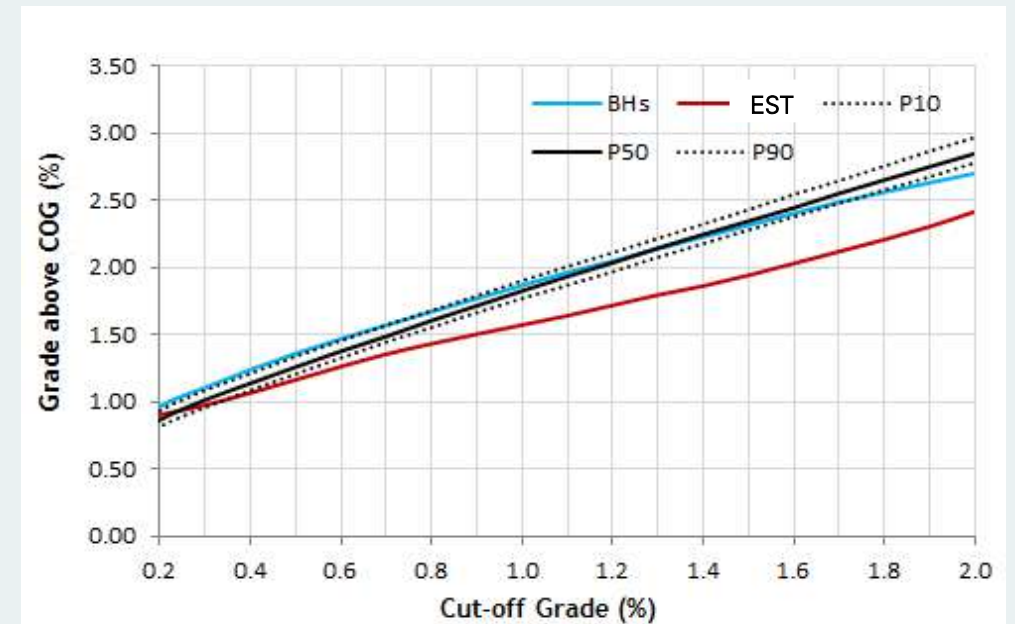
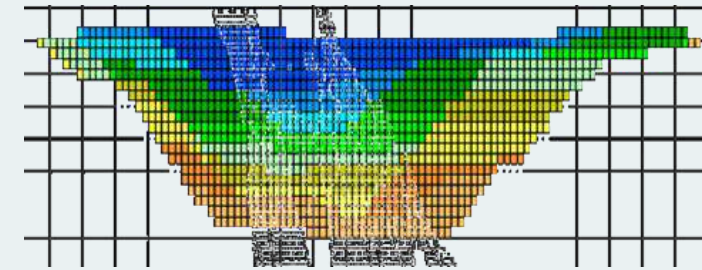
1. Honour samples at their location
2. Reproduce sample histogram
3. Reproduce variogram model



REAL LIFE EXAMPLE: Estimated Model vs. Simulated models vs. Grade Control



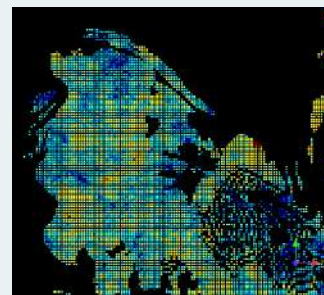
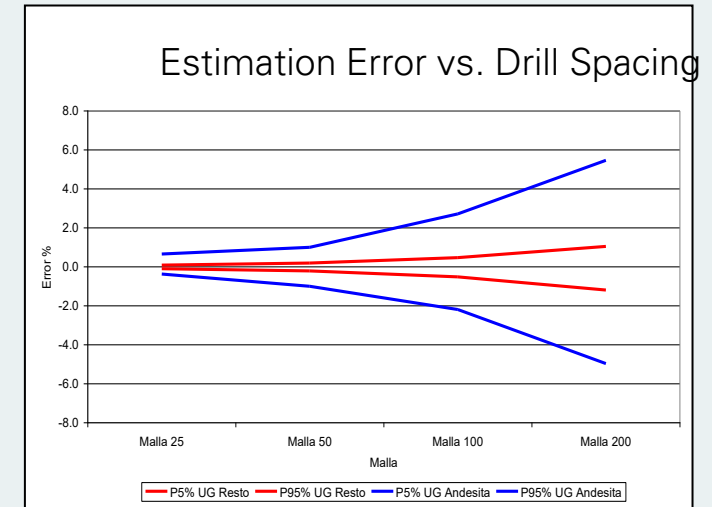
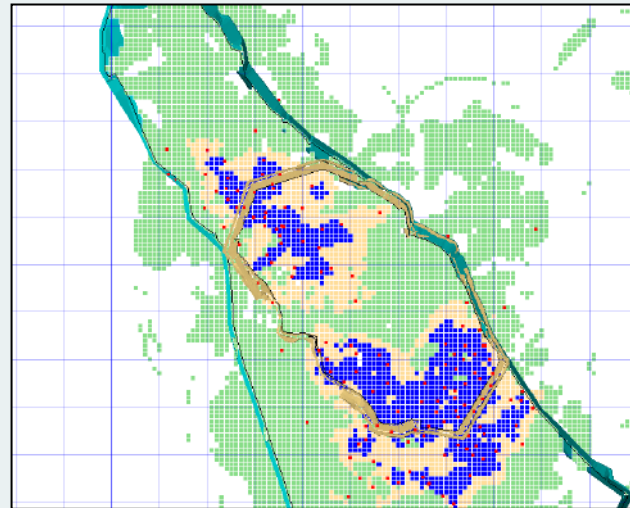
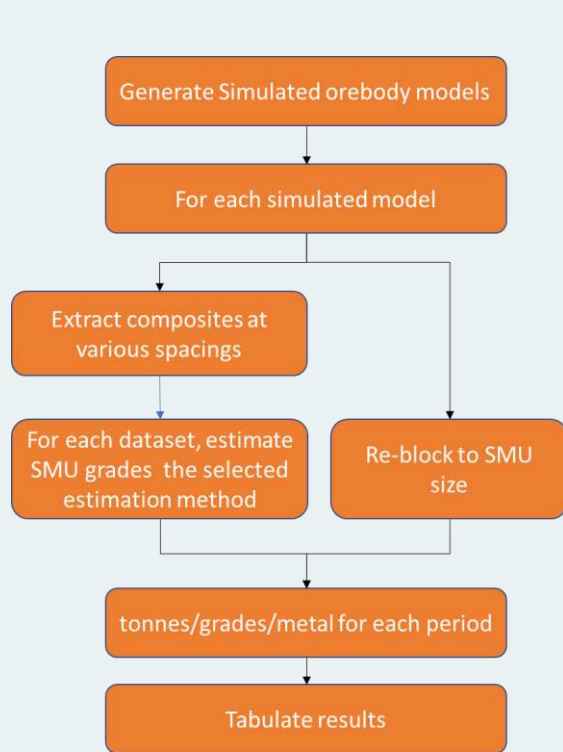
P10, P50, P90: Simulations
BHs: **Grade Control Model**
EST: **Estimated Model (Kriging)**



Methodologies for Mineral Resource classification

<p>Geometrical criteria</p>	<p>Based on drilling density and widely used for Resource classification</p>	<ul style="list-style-type: none"> • Nominal drill hole spacing • Distance to neighbouring drill holes and • Spatial coverage (i.e., interpolation vs. extrapolation, number of octants, number of samples per drill hole)
<p>Geometrical-geostatistical criteria</p>	<p>Based on geostatistical as well as geometrical parameters</p>	<ul style="list-style-type: none"> • The Kriging variance is the most used - allows for the mapping of equivalent drilling patterns in three dimensions • Variogram ranges are also frequently used to justify minimum drilling spacing requirements
<p>Probabilistic techniques</p>	<p>Based on the real assessment of uncertainty associated to tonnage and grade estimates over time periods</p>	<ul style="list-style-type: none"> • Using conditional simulation models • Allow for the direct inference of quantitative uncertainty measures

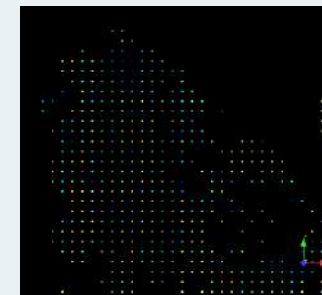
Geometrical-geostatistical criteria – Cond. Simulations



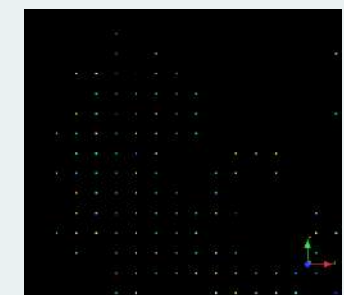
25 x 25



50 x 50



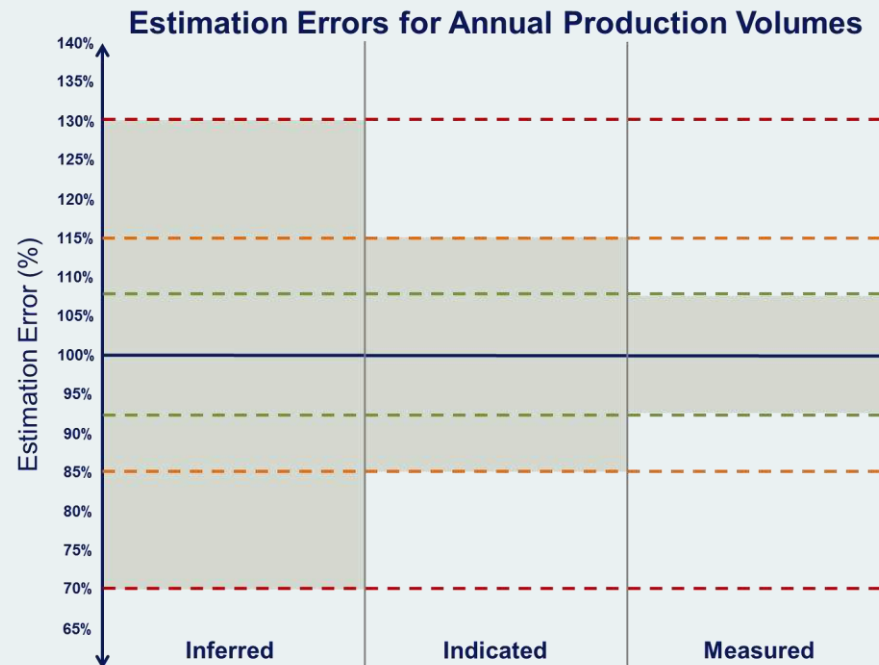
100 x 100



200 x 200

Parker's Rule

- **Measured Resource:** estimation error within +/-15% at 90% over a quarterly mining period.
- **Indicated Resource:** estimation error within +/-15% at 90% confidence over an annual mining period.
- **Inferred Resource:** has a lower level of confidence than that applied to Indicated Resource; it is reasonably expected that the majority of Inferred material could be upgraded to Indicated with continued exploration.

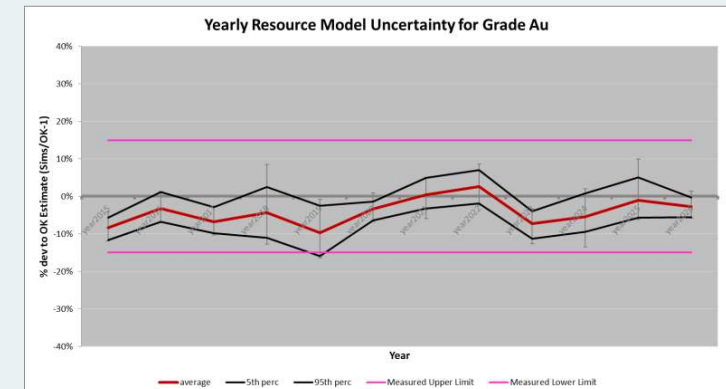
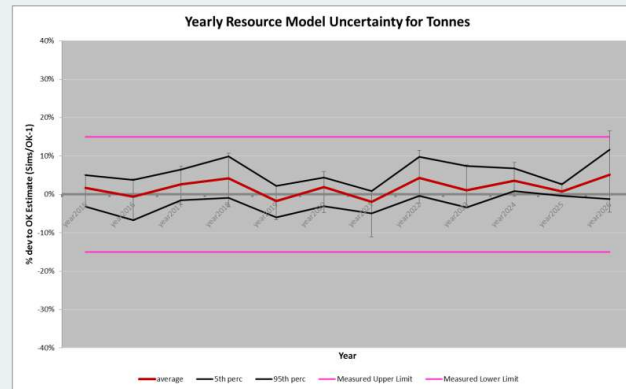
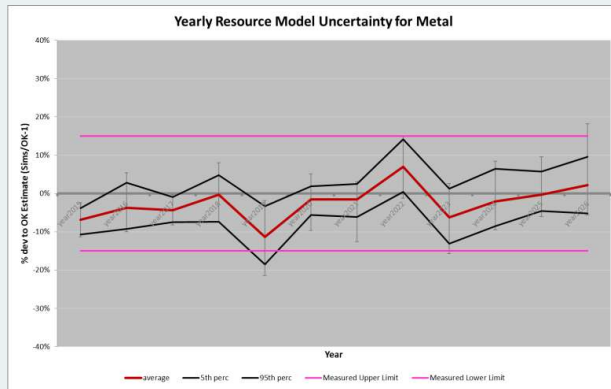
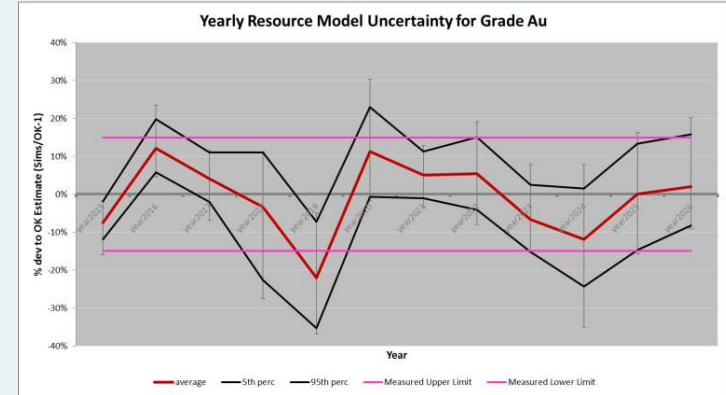
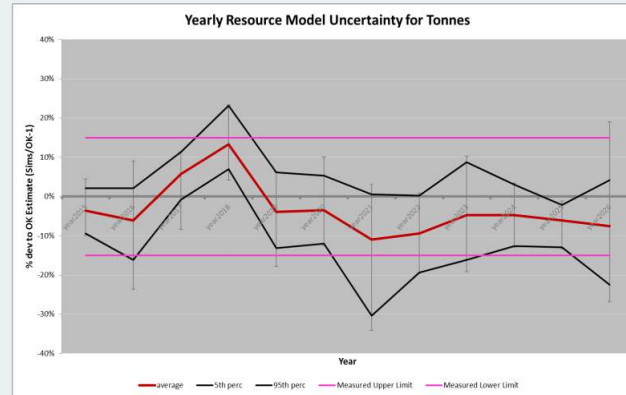
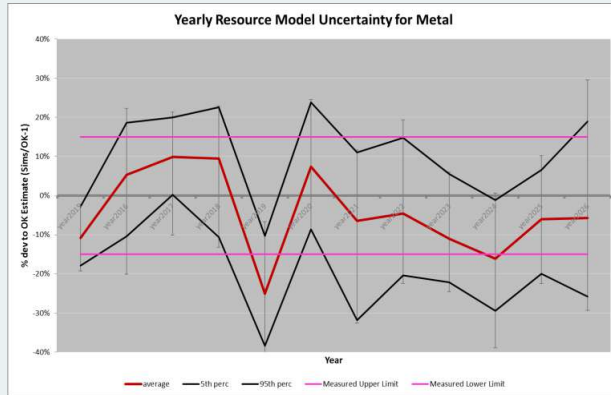


$$\text{Estimation Error} = \frac{(\text{Predicted} - \text{True})}{\text{True}}$$

Components:

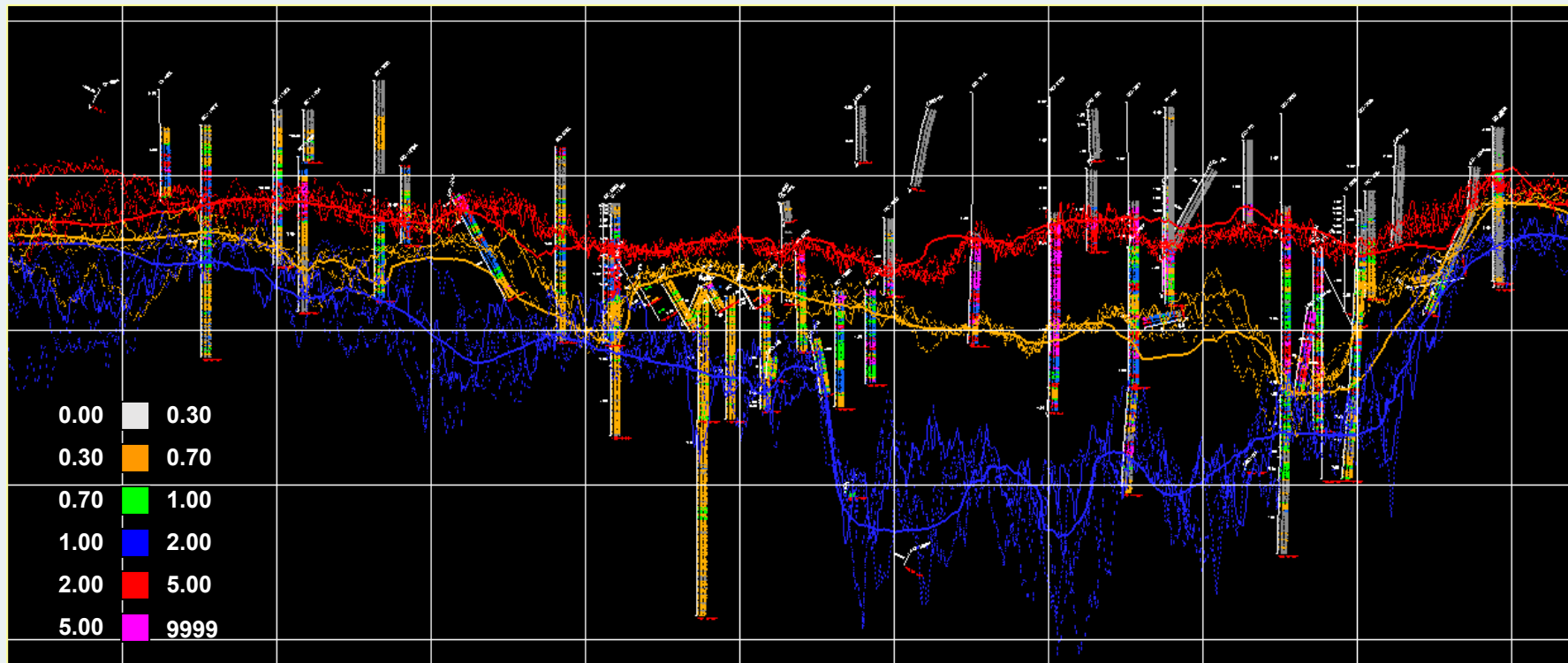
- Time period or production increment
- Magnitude: \pm %
- Confidence Interval: probability within range

Validation of Resource Classification with Conditional Simulations



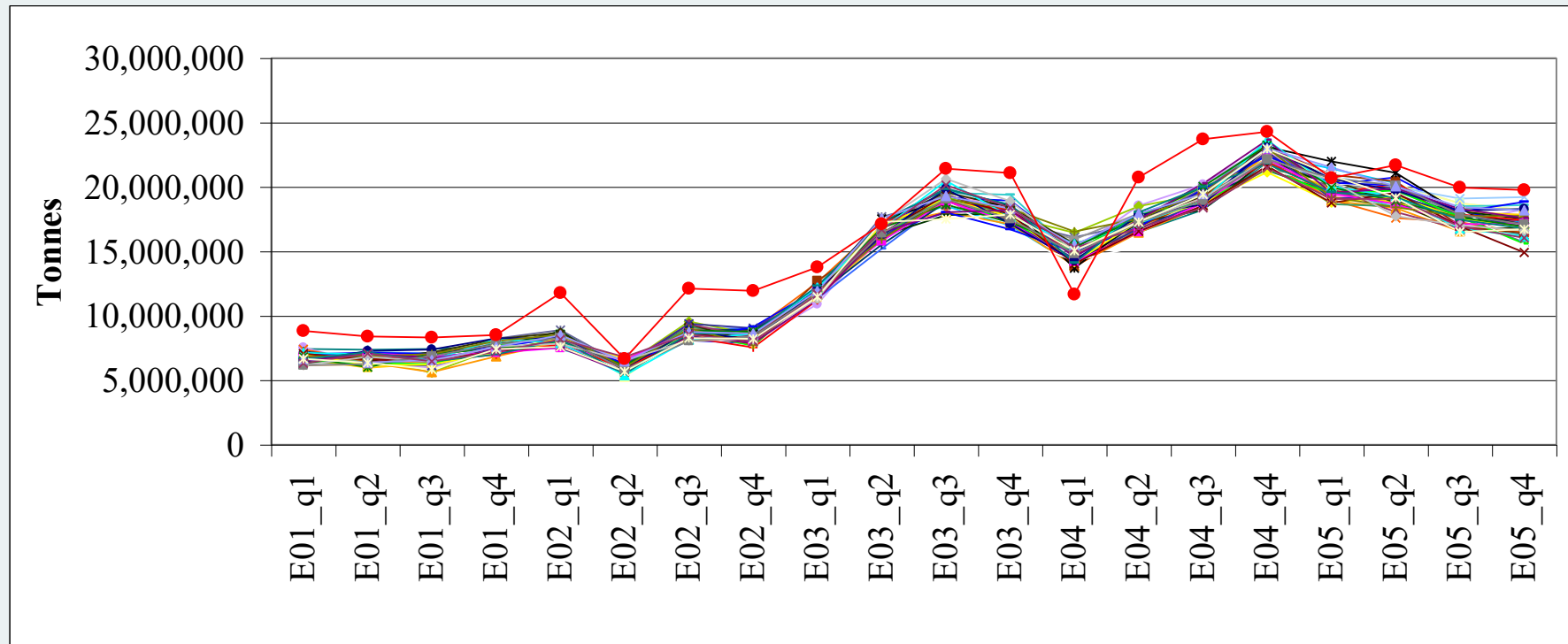
Validating Geological Models with Simulated Geologic Contacts

Looking North



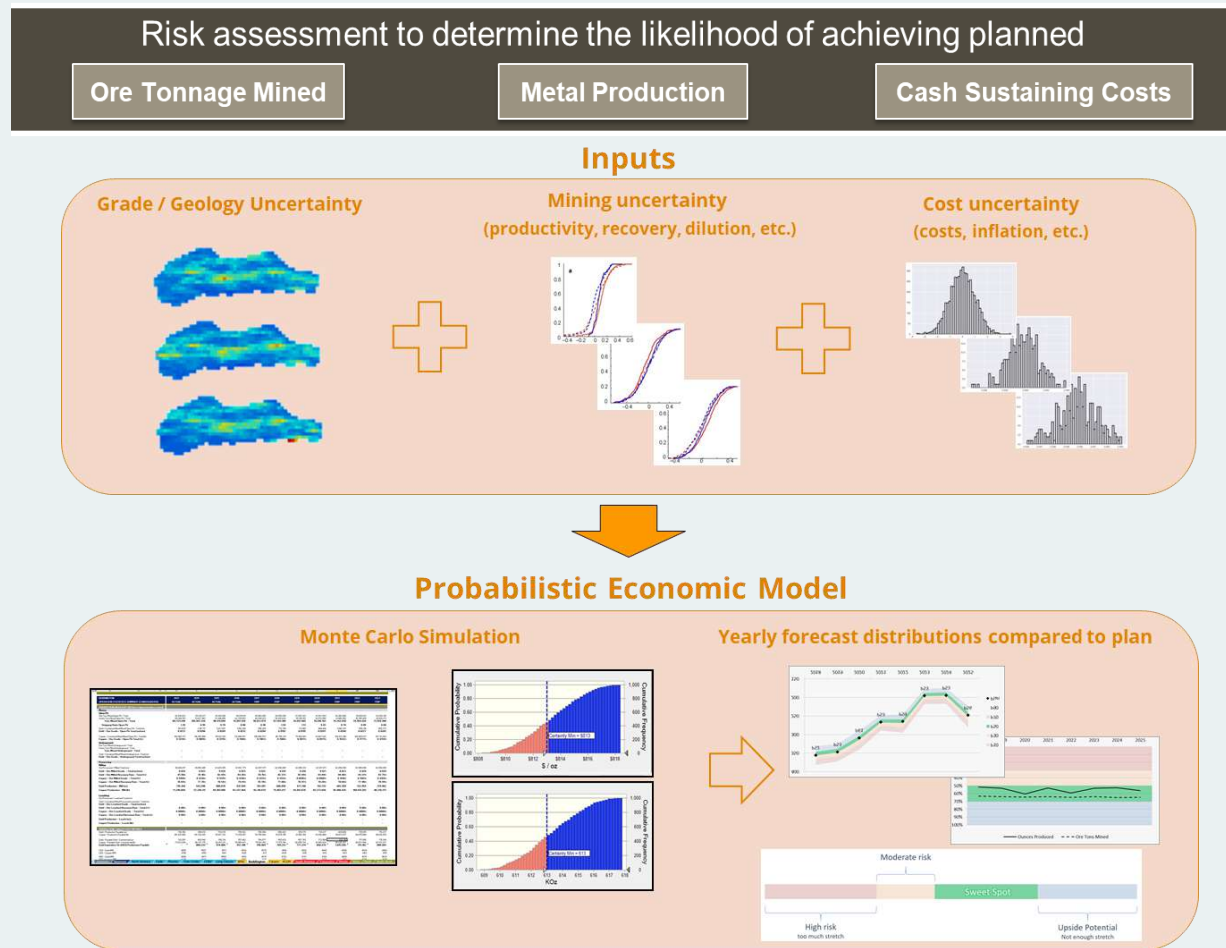
Simulated HE, LE and PR surfaces with drill holes displaying Total Copper values.

Validating Production Forecasts

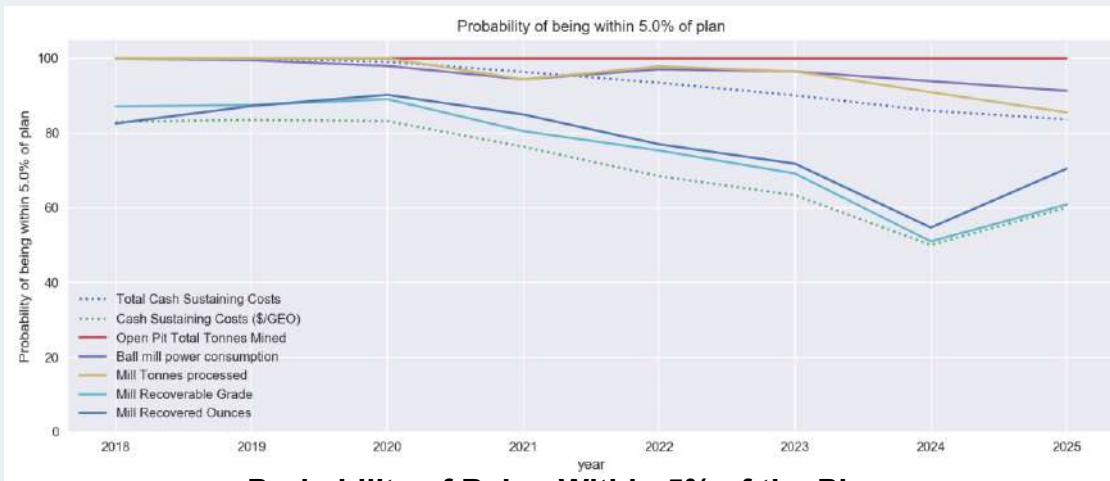
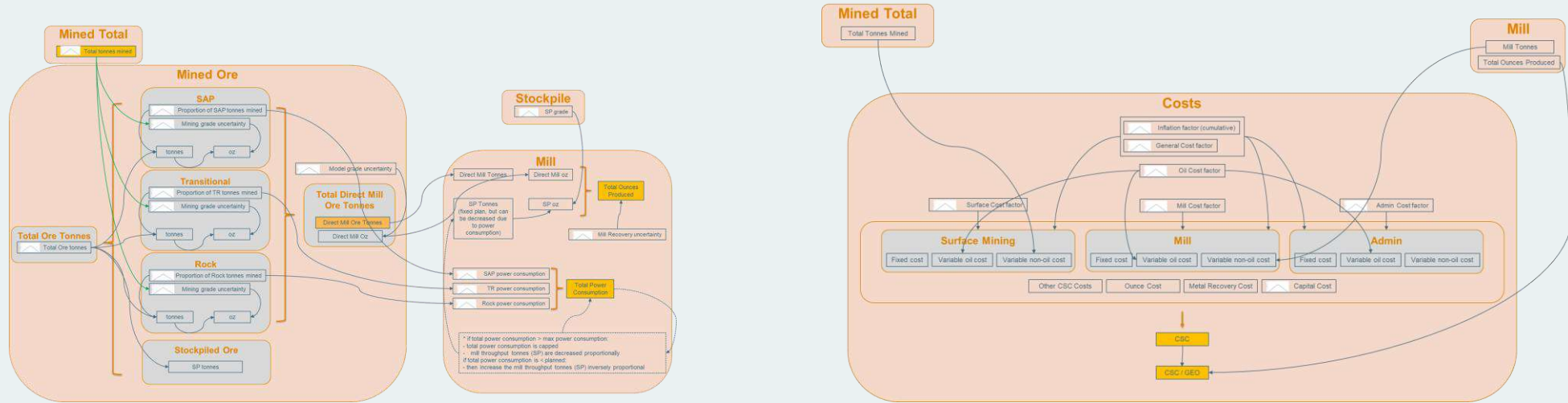


Analysis of risk
for Tonnes by
Quarters for
five-year plan

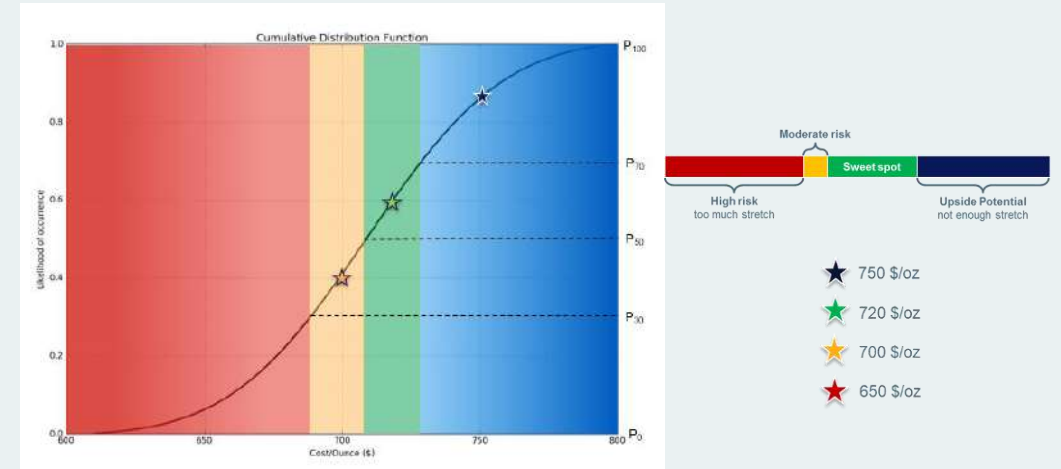
Probabilistic Assessment of Modifying Factors



Risk Model – Mining, Processing and Cash Cost*



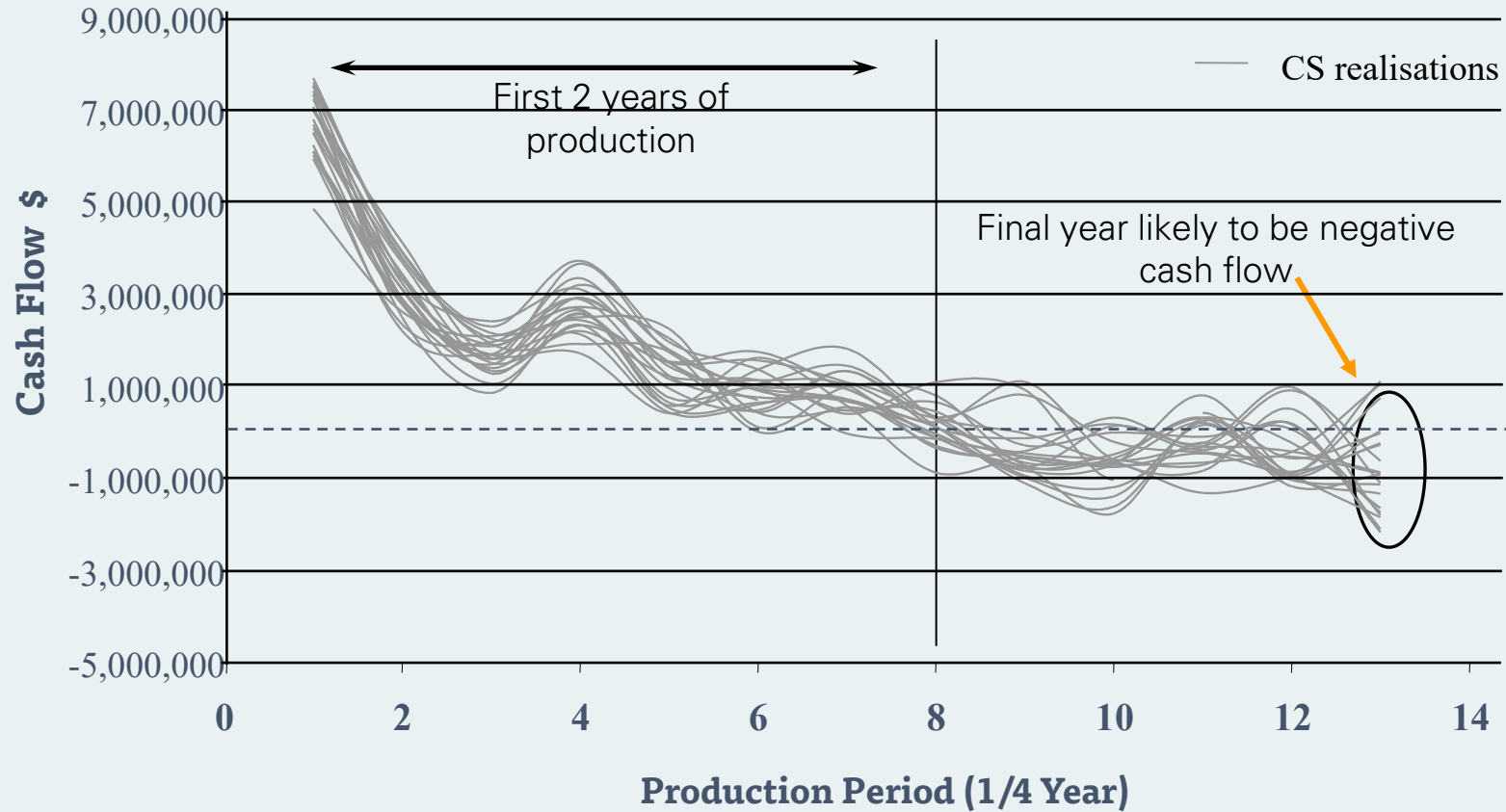
Probability of Being Within 5% of the Plan



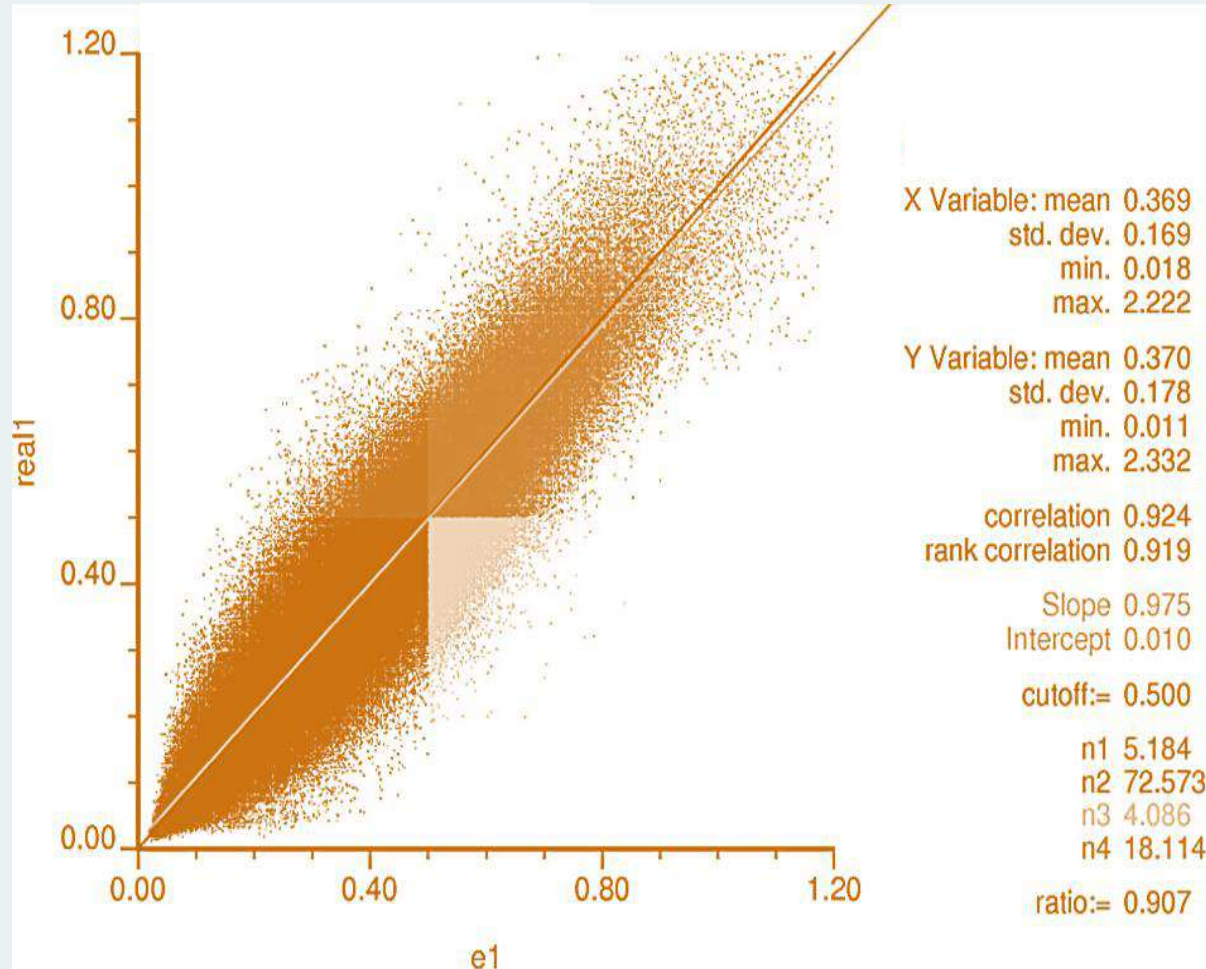
Probability Distribution for Cash Cost

* Godoy, M., Casper, M., Paradis, J., Desarrollo Estratégico de Recursos Mineros Bajo Condiciones de Incerteza, IIISPM, 2021.

Assessing mine plan cashflow risk

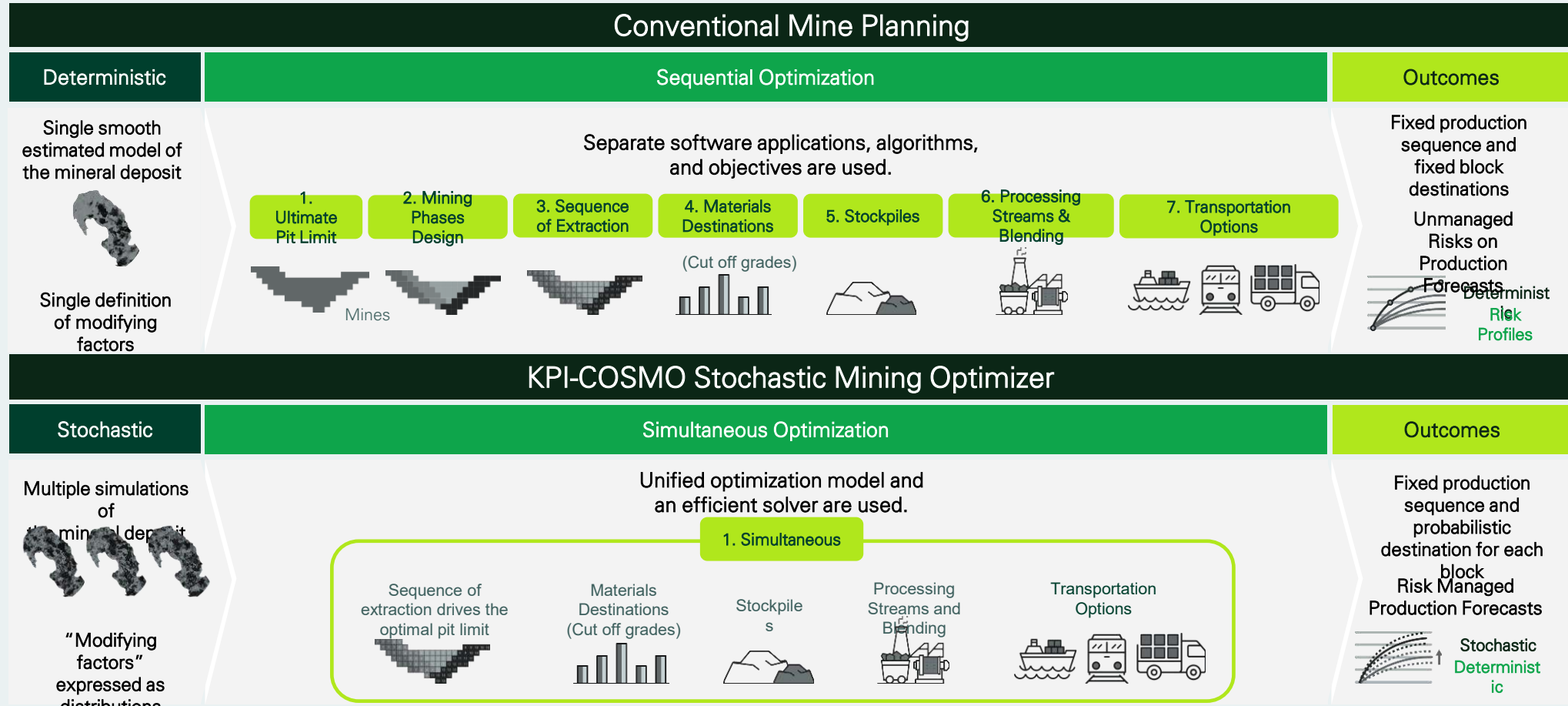


Mine planning based on estimated models = misleading results

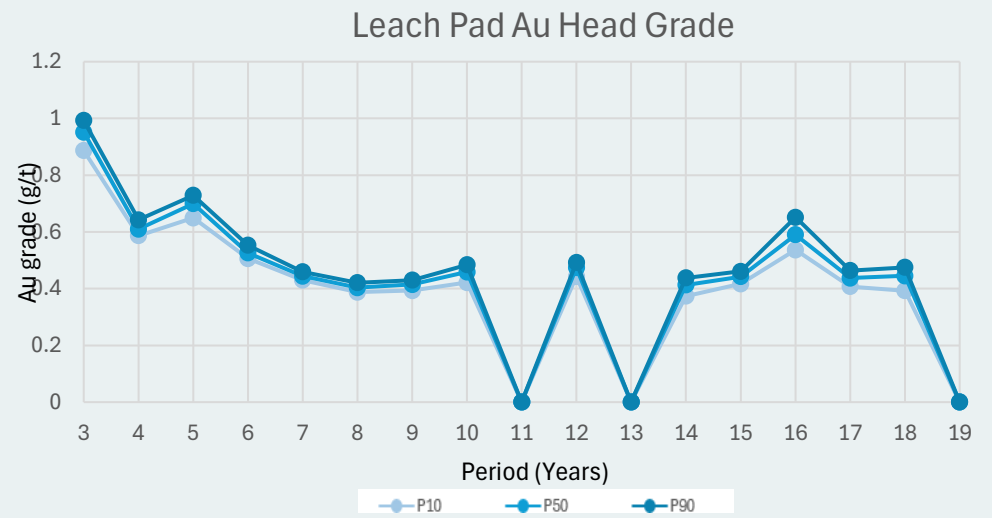
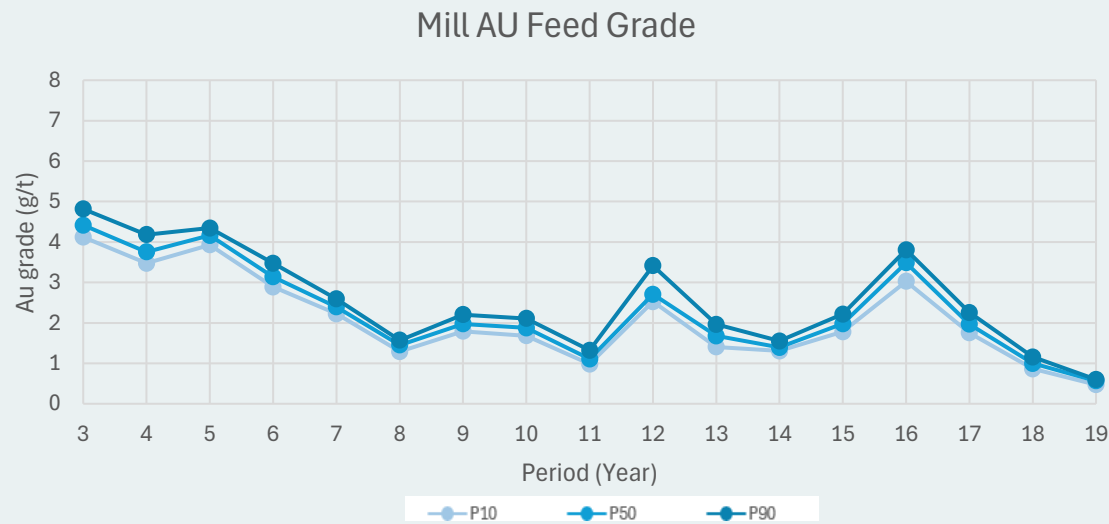
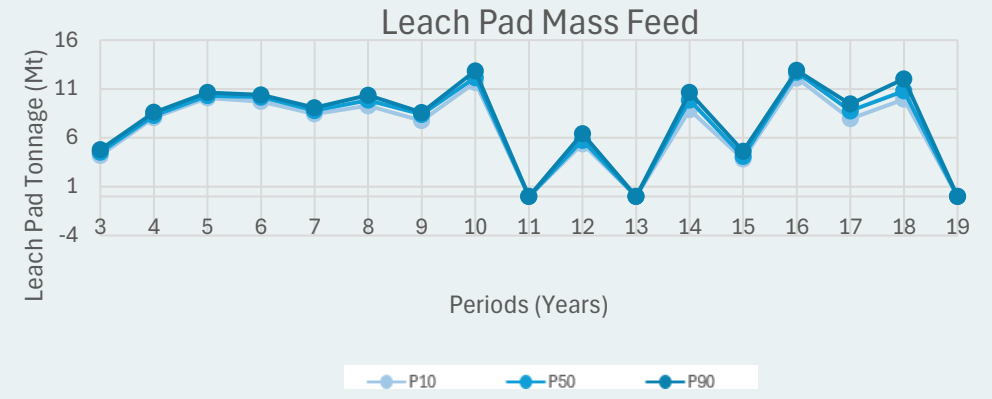
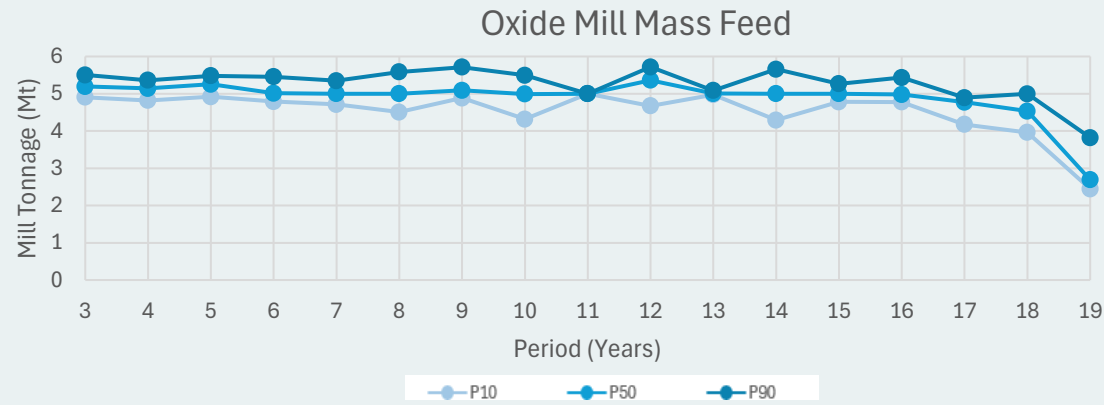


- A known property: $E\{f(x)\} \neq f(E\{x\})$
- This becomes even more significant in the context of a mining complex with compound non-linearities.
- Any framework that considers uncertainty is better than one that ignores it.

Two approaches to solve the mine scheduling problem



Case Study – Stochastic Solution



CONCLUSIONS

- While we cannot control gold price, we can narrow the gap in estimated and actual tonnages and grades, metallurgical recoveries, costs and productivity. Probabilistic methods help closing this gap and drive more reliable Resource and Reserve Estimates.
- A comprehensive risk assessment process was discussed that extends the orebody risk assessment to include mining, processing and cost parameters to allow for assessment of uncertainty related to modifying factors that are critical to Reserve estimation.
- Using estimated models as inputs to a production scheduling optimizer will produce misleading results. This becomes even more significant in the context of a mining complex with compound non-linearities.
- Annual forecasts derived from stochastic scheduling can support Resource Classification efforts. The Parker's rule provides key criteria for indicated resources with +/-15% estimation confidence over annual production periods.

Towards Probabilistic Mineral Resources and Reserves - Technical Presentation and Discussion, PDAC 2026

1. Probabilistic Methods in Resource Estimation (Edson Ribeiro, Representative with CRIRSCO)

Current Adoption in Industry

Only about **20% of mining companies use conditional simulations** to report mineral resources.

Some of the main reasons for this low adoption include:

- Lack of training in probabilistic methods
- Limited availability of appropriate software and technology
- Perception that **regulations are unclear** regarding the use of probabilistic approaches

However, it is increasingly recognized that the **mining industry must communicate geological uncertainty in a clear and understandable way.**

The Role of CRIRSCO

Edson introduced the role of the **Committee for Mineral Reserves International Reporting Standards.**

CRIRSCO should be understood as **more than a reporting template**, it represents a **governance system** that gather the representatives for developing mineral reporting codes and guidelines in different countries.

Its role includes:

- Providing guidance to **national and regional reporting organizations**
 - Facilitating **translation and adaptation into different national languages**
 - Promoting consistency in mineral resource reporting worldwide
 - Ensure that the fundamental Principles of Transparency, Competence and Materiality are observed by all Competent Persons reporting Exploration Results, Mineral Resources and Mineral Reserves
-

Responsibilities of the Competent Person (CP)

A key element of the CRIRSCO system is the role of the **Competent Person (CP)**. Observing the three fundamental Principals, the CP must exercise professional judgment when selecting appropriate methodologies for resource estimation and classification.

A well structured Competency Framework for CPs is presented by Jacqui Coombes on her book “*Cracking the Competency Code*”, that considers four dimensions equally important

- **Applied reasoning**
 - **Governance and compliance**
 - **Stakeholder leadership**
 - **Core technical skills**
-

Resource Classification and Uncertainty

Mineral resource categories exist primarily to **communicate the level of uncertainty associated with geological models**.

However:

- Resource classifications are **not permanent labels**
 - They should be **reviewed and updated over time**
 - As additional information becomes available, **uncertainty and risk may change**
-

Regulatory Perspective

Edson highlighted that **probabilistic reporting is not prohibited by any current reporting regulations**. On the contrary, **quantification of risks is recommended by major reporting codes and industry guidelines**.

Examples include:

Canada

- Best practice guidelines from the **Canadian Institute of Mining, Metallurgy and Petroleum (CIM)**
- Reporting requirements under **National Instrument 43-101**

These guidelines and regulations **explicitly recognize conditional simulations and other non-linear estimation methods as best practices**.

United States

- U.S. regulations largely incorporate definitions from CRIRSCO.
 - While wording may vary slightly between jurisdictions, the **conceptual basis remains the same**: mineral resource classification is fundamentally linked to **uncertainty**.
-

Final Message

Edson concluded that the choice of **mapping and communicating uncertainty through probabilistic approaches is ultimately the responsibility of the Competent Person**.

He closed with the statement:

“If not the CP, then who?”

2. Simulation and Stochastic Mine Planning: Fundamentals, Advantages and Challenges (Prof. Roussos Dimitrakopoulos, Professor at McGill University and Canada Research Chair - Tier I)

Prof. Roussos Dimitrakopoulos began his presentation by highlighting that the **mining industry often operates in a highly compartmentalized way**. Different professionals and technical disciplines tend to work **in silos**, limiting the integration of knowledge across the mining value chain.

Why Mining Projects Underperform

According to Prof. Dimitrakopoulos, many mining projects **fail to achieve their planned production targets** because of an incomplete understanding of what is actually in the ground.

A key issue is that **conventional deterministic models do not properly account for geological uncertainty**. When uncertainty is ignored, decisions may rely on an overly simplified or misleading representation of the orebody.

Evidence from Real-World Examples

He presented **real-world case studies** demonstrating that:

- Even deposits with **dense drilling information** still contain significant geological uncertainty.
- This uncertainty **propagates through the entire mining value chain**, affecting:
 - Resource/reserve estimation and classification
 - Mine planning
 - Production scheduling
 - Operational performance

Importantly, uncertainty can vary **across different time horizons**, from exploration to production.

Limitations of Deterministic Models

Prof. Dimitrakopoulos illustrated that **different estimation methods produce different representations of the same orebody**.

However:

- None of these models can **perfectly represent the true geology**.
- Choosing a single deterministic model may lead to **false confidence** about what exists underground.

In contrast, **conditional simulations** provide a more appropriate framework for representing uncertainty.

Rather than producing **one potentially wrong model**, conditional simulations generate:

- **Multiple equiprobable realizations**
- Each representing a **possible version of the geological reality**
- Together they capture the **range of uncertainty in the deposit**

Application to Resource Classification

In the context of **resource classification**, Prof. Dimitrakopoulos presented an example using:

- **CCV (Conditional Coefficient of Variation)**
- **25 conditional simulations**
- Analysis of the resulting **uncertainty thresholds**

These metrics were used to **support the classification of mineral resources** in a more quantitative and uncertainty-aware framework.

Final Message

Prof. Dimitrakopoulos concluded that **geological uncertainty must be explicitly mapped and managed across the entire life of mine**.

Rather than ignoring uncertainty, it should be:

- Integrated into **resource estimation and classification**
- Incorporated into **mine planning**
- Used to support **more consistent decisions and operational strategies**

Managing uncertainty across different planning horizons ultimately leads to **more robust mine plans and more reliable operations**.

3. Probabilistic methods in support of resource and reserve disclosures (Marcelo Godoy, CTO of AngloGold Ashanti)

The presentation emphasized that the main purpose of working with **probabilistic methods** in mining is to **create value and reduce risk across the mining value chain**.

Decision-Making Under Uncertainty

At AngloGold Ashanti (AGA), key financial metrics such as **costs and capital guidance are reported as ranges of values**, rather than single deterministic numbers.

This reflects a fundamental reality: **exact values are rarely known with certainty**.

Despite this, the speaker argued that the mining industry still operates in a **very rudimentary and conservative way**, with significant resistance to change. Probabilistic thinking and **stochastic mine planning** are not yet standard practice, although they should be.

Benefits of Conditional Simulations

A case study was presented demonstrating that **simulated orebodies provide estimates closer to reality** when compared with **grade-control data**.

This reinforces the idea that:

- Deterministic models provide **one simplified representation** of the orebody.
 - Conditional simulations generate **multiple plausible representations**, better capturing geological variability and uncertainty.
-

Practical Experience with Parker's Method

The speaker noted that he has worked with **Harry Parker's resource classification method** for more than ten years.

Key observations from this experience include:

- The commonly used **15% probability threshold** for defining resource classification categories should **not always be rigidly applied**.
- **Professional judgment and experience** are required to determine the

appropriate threshold for each deposit.

By adjusting this threshold, he observed that:

- Resource classifications aligned **more closely with reserve definitions**
- Production volumes became **more consistent with expected outcomes**

This adjustment reflects the **support volume effect**, which influences how uncertainty manifests at different scales of mining.

According to the speaker, this practical flexibility is **one of the main strengths of Parker's method**.

Incorporating Uncertainty into Modifying Factors

When moving from **resources to reserves**, several **modifying factors** must be considered, including:

- Commodity price
- Metallurgical recovery
- Operating costs
- Capital costs

These parameters are also **subject to uncertainty**, yet they are often treated deterministically.

At AGA, the recommendation is to use **Monte Carlo simulation** to model cost uncertainty and report results using the **P80 value**.

Role of Risk Analysis in Investment Decisions

Risk analysis was highlighted as a **critical tool for investment decision-making**, especially when companies are committing **billions of dollars to mining projects**.

When a single number must be reported, one possible approach is to use the **average value of the risk distribution**, while still understanding the broader uncertainty profile behind that number.

Technology Enabling Probabilistic Mine Planning

The presentation concluded by highlighting the importance of new

technological tools that support probabilistic workflows.

In this context, the speaker cited **KPI COSMO** as one of the most significant technological advancements in recent years for integrating uncertainty into **mine planning and decision-making**.

4. Opened discussions and Q&A

The final part of the session focused on **questions and open discussion** about the practical implementation of probabilistic approaches in the mining industry.

Quality and Validation of Simulations

One of the main topics discussed was **how to evaluate the quality of conditional simulations**.

Participants highlighted that conditional simulation methods have **evolved significantly over the years**, particularly due to:

- Increased availability of specialized software
- Major advances in **computational power**

These developments now allow practitioners to generate **more robust and reliable simulation models** than in the past.

Beyond Grade Uncertainty

Another important point raised during the discussion was that **uncertainty analysis should not be limited to grades**.

Participants emphasized the need to also simulate **volume uncertainty**, which can have a **major impact on mining projects**, affecting:

- Resource estimates
- Production forecasts
- Economic evaluations

Addressing both **grade and volume uncertainty** provides a more complete representation of geological risk.

Implications for Greenfield Projects

For **greenfield exploration projects**, probabilistic reporting was highlighted as particularly valuable.

Reporting results as **probabilistic ranges** can:

- Provide a clearer understanding of project risk
- Better support investment decisions

- Help guide **future exploration campaigns**

In particular, probabilistic models can identify **high-potential areas that still contain significant uncertainty**, helping prioritize additional drilling.

Perspective from Auditors

From the auditors' perspective, it was acknowledged that **reports based on conditional simulations can be approved**, provided that:

- The methodology is **clearly described**
- The workflow is **well documented**
- The assumptions and results are **transparent and traceable**

Proper documentation and communication are therefore essential for gaining regulatory and audit acceptance.

Perspective from CIM

Representatives from the **Canadian Institute of Mining, Metallurgy and Petroleum** noted that existing guidelines **do not prevent the use of conditional simulations**. In fact, the **CIM best practice guidelines recognize and support these methods**.

However, there is still a need to develop **more specific best-practice guidance** to:

- Facilitate wider adoption
- Standardize workflows
- Improve the consistency of probabilistic reporting across the industry

Contact us.

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