Communicating Uncertainty in Geometallurgical Models

SAIMM Geometallurgy 2025

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Communicating Risk is Important

Good Risk Communication

- **Medical: This surgery succeeds in 8/10 patients - two face serious complications or death.**
- Aviation: Commercial flights crash once every three million departures - still safer than driving to airport
- Polling:
  - Leading by 52 to 48%
  - Margin of error is +/-3%

Mining Industry Examples

- **Resource Estimation: Measured, Indicated and Inferred categories**
- Capital Cost Estimation: Class One through Five estimates with accuracy ranges from ±5 to ±50 percent
- Safety: Lost time injury frequency ranges from 0.5 to 3 incidents per million hours


IT IS COMPLEX, SO
KEEP IT SIMPLE

The River

The Orebody and Its Uncertainties

- Risk Amplifiers:
    - Complexity
    - Lack of data
    - Wrong data recorded
    - Poor quality data
- Risk Reducers:
    - Thorough mapping and modeling
    - Fit for purpose data
    - Useful, and understandable models

The Crew

Your People and Communication

- Risk Amplifiers:
  - Siloed teams not talking
  - Overconfidence in others
  - Inexperience or lack of training
- Risk Reducers:
  - Integrated, well-trained teams
  - Transparent, actionable communication
  - Continuous learning and adaptation

The Boat

Your Process Plant Design

- Risk Amplifiers:
  - Bad scale-up algorithm
  - Under-designed
  - Lack of flexibility
  - Poor maintenance
- Risk Reducers:
  - Flexible, robust design
  - Adaptive process controls
  - Built-in redundancy

Planning

Geomet Sampling and Testwork

- Risk Amplifiers:
    - Missing key drivers
    - Non-representative samples
    - Sparse data
- Risk Reducers:
    - Several phases of work
    - Variability vs model calibration
    - Learn, adapt, reassess
    - Communicate limitations

Why Is Geometallurgy Confusing?

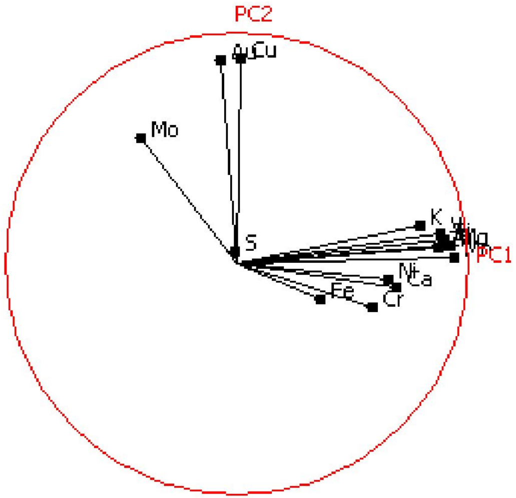
Implausible Mathematics

Relentless drive for a single value per block.

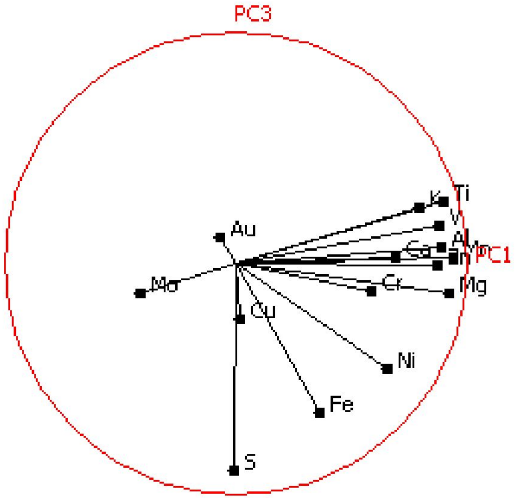
$$CEE\left(\frac{kwh}{t}\right) = 0.9 * F80^{0.446} - 54 * DWi^{-0.003} + 28 * BWi^{0.14} + 1679 * P80^{-0.853} + 6 * SG^{-0.273}$$

$$\begin{aligned} &Total\ Flotable\ Zinc \\ &\quad = 93.9 - 50.6 * max(0{,}1.02 - zinc) - 0.15 * max(0, elevation - 4901) - 5.4 \\ &\quad * max(0, pyrite - 1.9) - 11.2 * max(0{,}1.9 - Pyrite) + 104.1 \\ &\quad * max(0, copper - 0.03) + 1620.2 * max(0{,}0.03 - copper) \end{aligned}$$

Complexity Over Transparency



Scaled Coordinates PC1 - PC2 (60.4%)



Scaled Coordinates PC1 - PC3 (58.3%)

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"PCR2" function="0.6260178 * ((CU_PCT ^ 0.17079 - 1) / 0.17079 - -1.8867503) / 0.9494263 + 0.6232933 * ((AU_PPM ^ 0.0240075 - 1) / 0.0240075 - -3.503793) / 1.1240964 + 0.052337337 * ((AL_PCT ^ 0.365281 - 1) / 0.365281 - 0.35954705) / 0.6727541 + -0.075004235 * ((CA_PCT ^ 0.0514041 - 1) / 0.0514041 - -1.6613916) / 1.1202357 + -0.1333647 * ((CR_PPM ^ -0.215607 - 1) / -0.215607 - 1.0756882) / 1.0235586 + -0.11035635 * ((FE_PCT ^ 0.171158 - 1) / 0.171158 - 1.460721) / 0.4694653 + 0.11411636 * ((K_PCT ^ 0.186848 - 1) / 0.186848 - -0.82110727) / 0.66965467 + 0.052681424 * ((MG_PCT ^ 0.473771 - 1) / 0.473771 - -0.14681832) / 0.86333716 + 0.016059373 * ((MN_PPM ^ 0.334229 - 1) / 0.334229 - 15.753773) / 6.5327168 + 0.3813904 * ((MO_PPM ^ 0.0511836 - 1) / 0.0511836 - 2.1576629) / 1.6299096 + -0.04724609 * ((NI_PPM ^ -0.131013 - 1) / -0.131013 - 1.2285755) / 1.0064163 + 0.039379828 * ((S_PCT ^ 0.376339 - 1) / 0.376339 - 0.5374394) / 1.3739445 + 0.07536386 * ((TI_PPM ^ 0.185334 - 1) / 0.185334 - -2.4221225) / 0.6740798 + 0.08872348 * ((V_PPM ^ 0.301341 - 1) / 0.301341 - 6.7636704) / 2.9318895 + 0.04928204 * ((ZN_PPM ^ 0.14443 - 1) / 0.14443 - 4.0517087) / 1.6078268" comment="13.3901005%"/>

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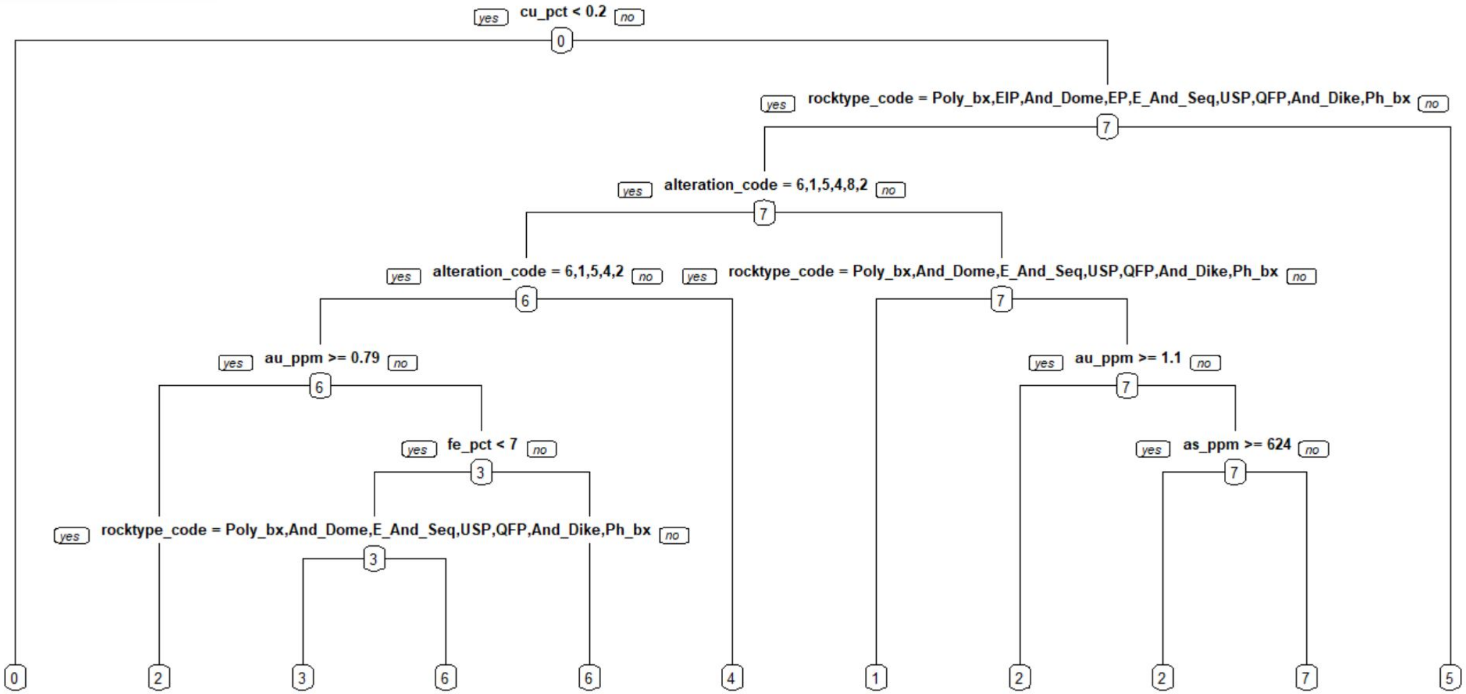
Ignores Natural Variability



How can we do better?

Quantifying Risk

The Power of Useful Models

- **Explainable**
  - The model must align with geological/metallurgical understanding.
- **Significant**
  - The model must demonstrate a statistically sound correlation with the data.
- **Parsimonious**
  - Choose the simplest model consistent with the data.
- **Projectable**
  - The model must be useful to mine planners and applicable across the deposit.
- **Contrast**
  - The selected model must prove it makes a material difference compared to simple alternatives.

Back-up the Narrative with Data

Now that we understand the risks, how do we navigate them?

Calm Waters

- The orebody is simple and homogeneous—grade, mineralogy, and hardness are consistent across the deposit.
- The plant is well-designed, proven, and easily handles the expected feed with margin to spare.
- Any operational bottlenecks are not in the plant
- Minimal geometallurgical effort required:
  - Basic, representative sampling is sufficient
  - No need for complex modeling
- Direct attention and resources to the true bottlenecks

Chaotic Disorder

- Ore variability is chaotic; no spatial correlation with no geological driver
- Strategy: Build a bulletproof plant and team
- Conservatism in predictions
- Use simple models that do not mislead understanding of low accuracy
- Use stochastic predictions to communicate the range of risk
- Broad-domain sampling; avoid over-investing in futile precision

Mapped Drivers

- Clear drivers identified
- Strategy: Precision mapping and modelling
- Design proactively for changes in duty
- Targeted blending or campaigning
- Pre-planned process tweaks

Fatal Flaws Detected

- No need for quantification of the risk.
- Simply could result in total loss.
- Rarely comes to pass.
- Usually the project stalls at the project financing and approvals stage.
- Either change technology, or look for a better focus case

Risk Calculations

Risk = Probability x Impact

- + Geology Error
- + Sampling Error
- + Metallurgy Error
- + Modelling Error

Total Error = Probability

Note, errors are not linear they multiply!

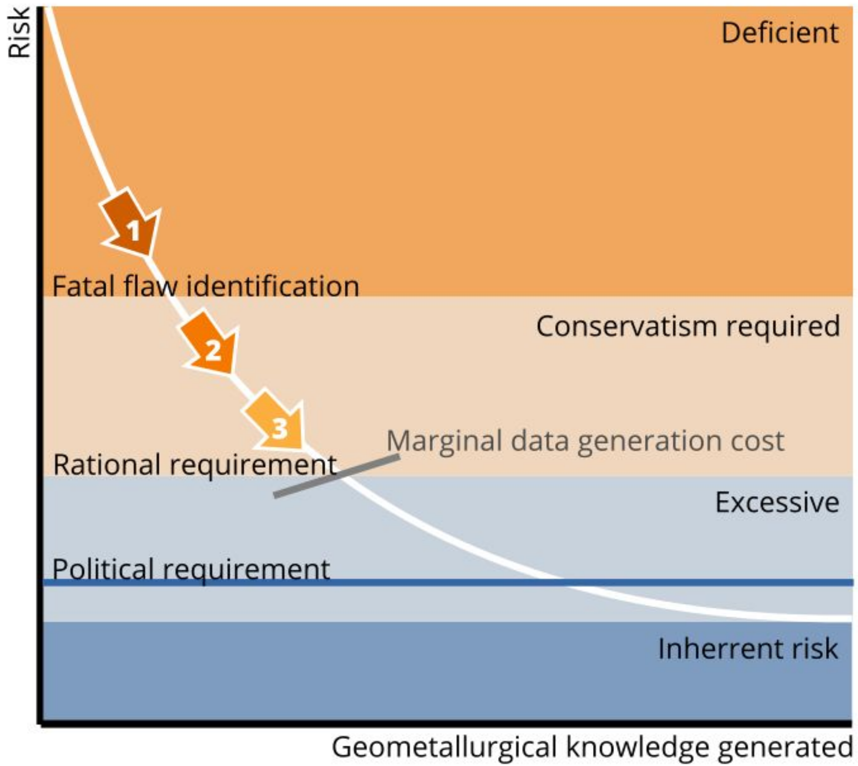
For example…

87 ± 5% Cu recovery

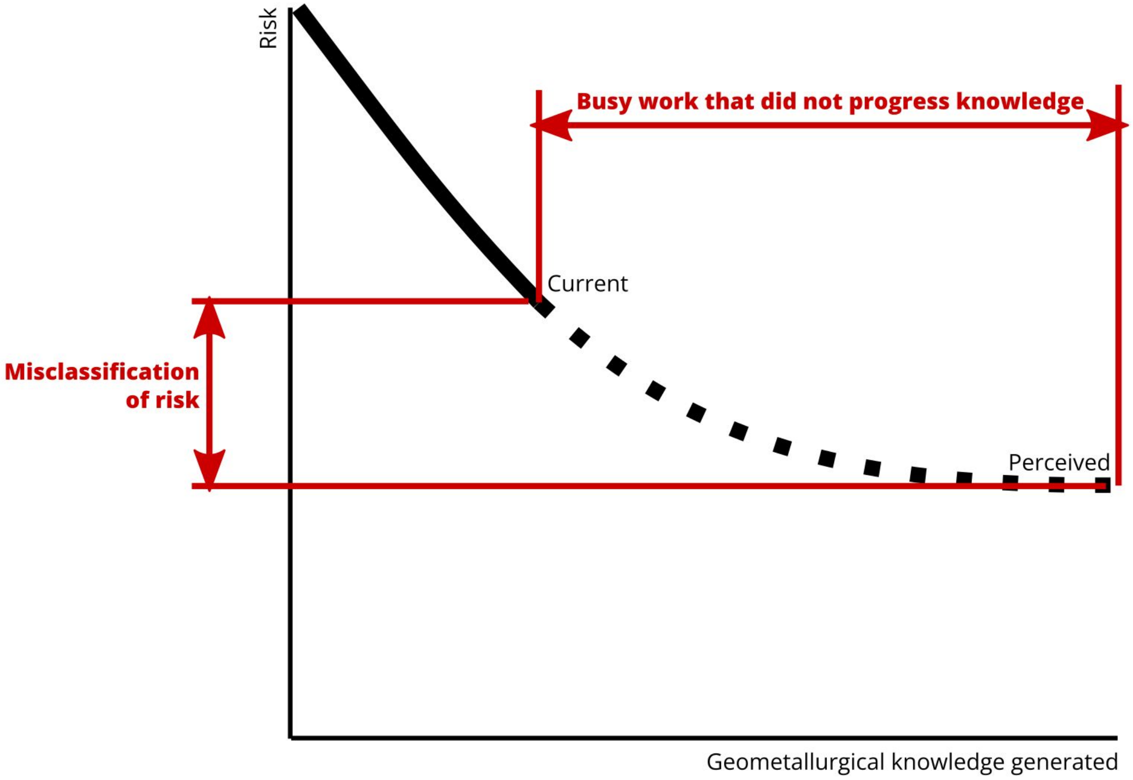
NPV of 1% Cu recovery = USD$100M

Risk = 5 x 100 = USD$500M

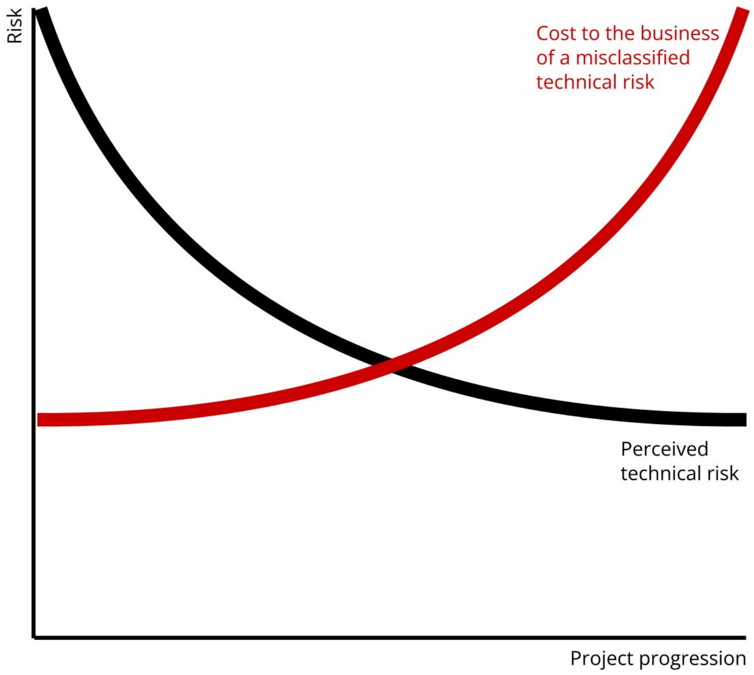
Risk Reduction



Risk Misestimation



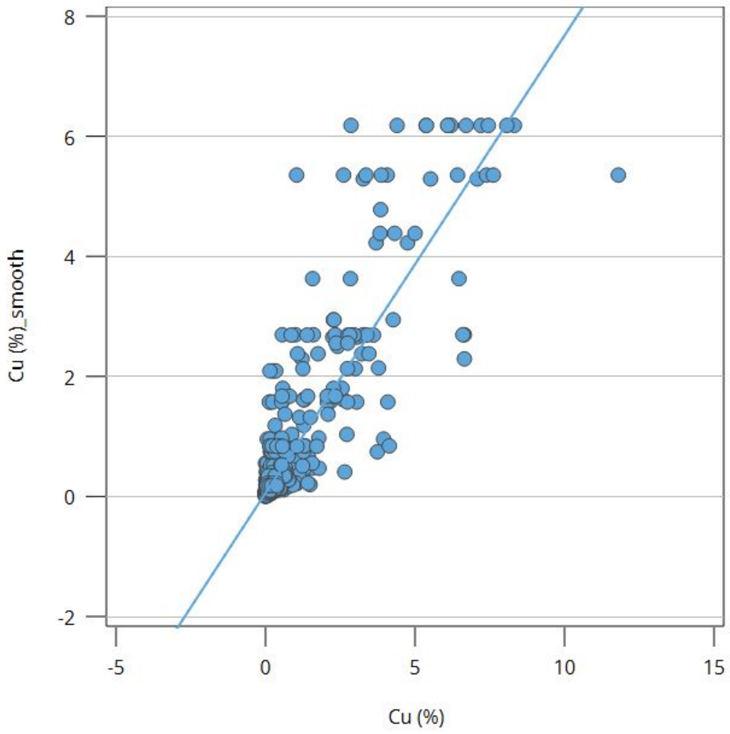
Risk Misclassification



Validating and Communicating Risk

Statistical & Mathematical Methods

- Confidence Intervals
- Probability Distributions
- Bootstrap Resampling
- Cross-Validation
- Bayesian Inference
- Information Theory Metrics
- **R-squared Values**
- Model Validation Statistics
- Prediction Intervals
- Credible Intervals
- Percentile Reporting



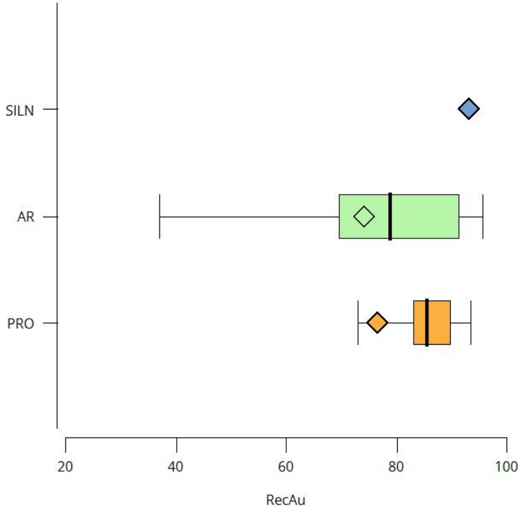
Visualization & Graphical Tools

- Tornado Diagrams
- Heat Maps
- **Box Plots**
- Error Bars
- Traffic Light Systems
- Risk Matrices
- Uncertainty Bands
- Grade Tonnage Curves
- Decision Tree

Target RecAu by Alteration domains

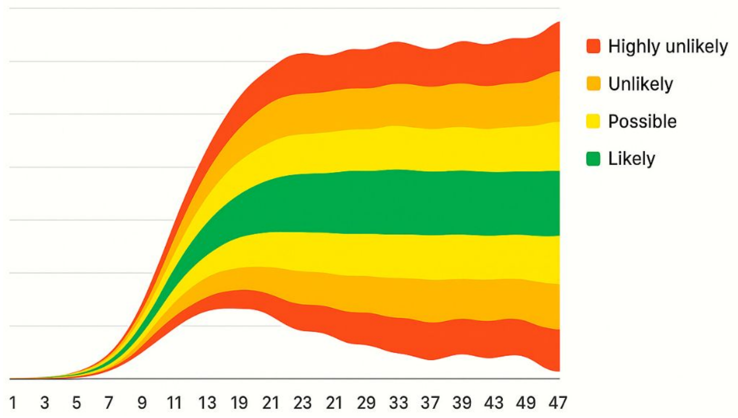
RecAu by domains

Alteration	n	Min	Max	Mean	σ(SD)	Lower	Upper
PRO	10	16.4	93.3	76.7	24.6	60.3	93
AR	9	16.3	95.7	74.2	24.5	57	91.5
SILN	1	93.2	93.2	93.2	0	41.4	145
	20						



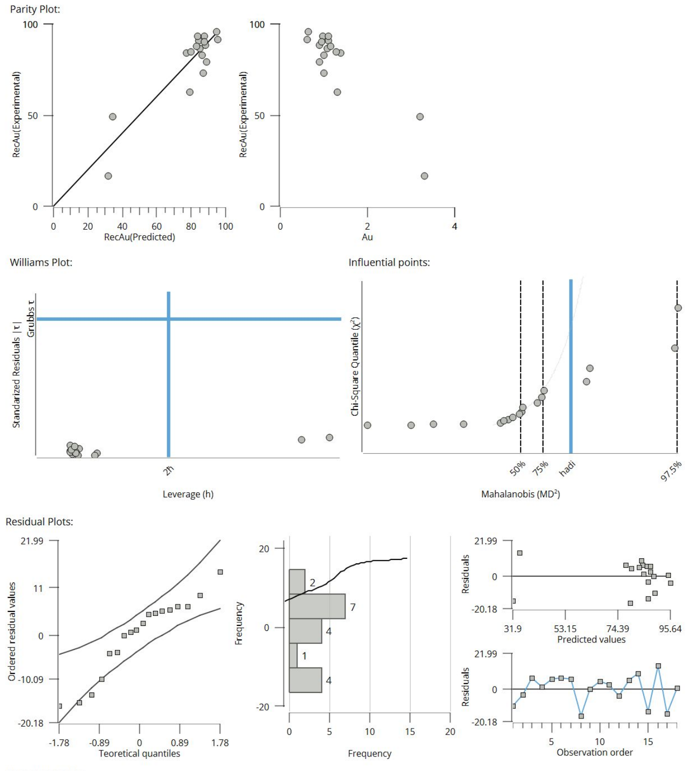
Simulation & Modeling Techniques

- **Monte Carlo Simulation**
- Geostatistical Simulation
- Conditional Simulation
- Sequential Gaussian Simulation
- Multiple-Point Statistics
- Ensemble Modeling
- Multi-Model Inference
- Model Averaging
- Fuzzy Logic Modeling



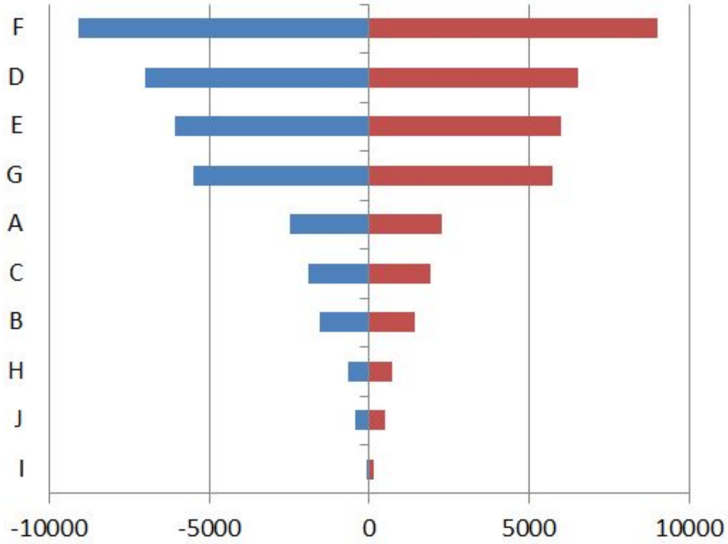
Data Quality & Validation

- Parity Plot
- Williams Plot
- Data Quality Indicators
- Confidence Categories
- Model Validation Statistics
- Cross-Validation
- Sample Representivity Metrics



Risk Assessment Frameworks

- Scenario Analysis
- **NPV Sensitivity Analysis**
- Risk Registers
- SWOT Analysis
- Uncertainty Cascading



Experience vs Sophistication

		STAKEHOLDER SOPHISTICATION	
		Low	High
TEAM EXPERIENCE	Low	KEEP IT SIMPLE ● Confidence ranges ● Box plots ● Basic scenarios	LEARN TOGETHER ● Standard methods ● Clear documentation ● External expertise
	High	TRANSLATE DOWN ● Visual summaries ● Traffic lights ● Economic scenarios	FULL TOOLKIT ● Advanced stats ● Simulations ● Technical detail

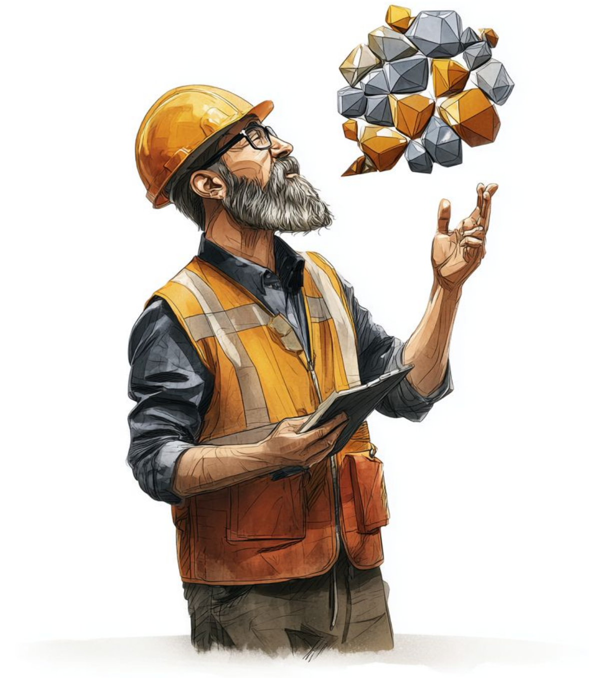
Explainable Models

Narrative First, Statistics Second

Why narrative beats numbers:

- **Trust** - easier to test simple relationships
- **Transferability** - Simple models survive new data; complex ones don't
- **Troubleshooting** - When things go wrong, you need to know why
- **Teamwork** - activate the internal locus of control for each discipline

"All models are wrong, but explainable models stay useful longer."



The Bottom Line

- Uncertainty isn't the enemy - poor communication of uncertainty is
- Match your tools to your audience, not your comfort zone
- Simple, honest communication beats complex false precision
- Your geometallurgical model is only as good as the decisions it enables

What You Can Do Monday Morning

- Add confidence intervals to your next metallurgical prediction
- Ask "What are the key drivers?" in your next project meeting
- Get all of your data into Cancha:
  - Clean, consistent data
  - Visualize
  - Document
  - Communicate
- Start conversations, not just deliver reports

Questions

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