Exploring the Dark

Mario Alvarez Grima, Senior R&D Specialist of IHC Merwede

presents

Decision Making on the Ocean Floor

A simulation framework to assess variability and uncertainty in deep sea mining

14 March 2013

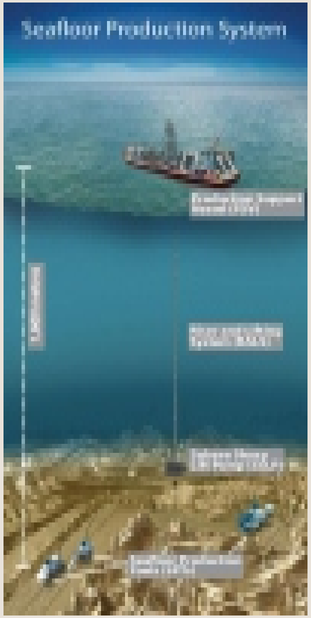
The technology innovator.

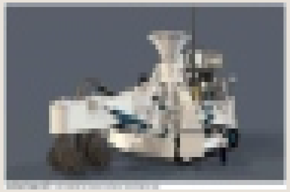
Content

1. Relevance of Deep Sea Mining
2. Existing Challenges
3. Motivation/Urgency of the Topic
4. Research Approach
5. Risk Based Decision Making
6. Examples (case-studies)
7. Conclusions

1. Relevance of Deep Sea Mining

- **DEMAND**: growing world population and raw material scarcity
- **STRATEGY EU + NL**: world leader in new technologies to remain competitive with other growing economies and markets, free access to raw materials
- **STRATEGY IHC**: opportunity to approach new markets – wet to deep sea mining – develop to be a world leader





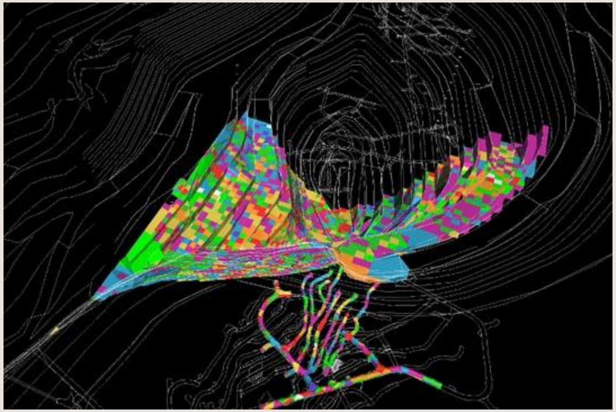
2. Existing Challenges

1. Environmental Assessment
   - Understanding of deep sea ecosystems
   - impact of mining operation
2. Exploration
   - Exploration methods, gathering information
   - Transformation from resource to reserve
3. Mining
   - Excavation under hyberbaric pressure
   - Navigation through hars unknown environment
4. Transporation (vertical riser)
   - Dynamic behavior
   - plug formation, clogging, fluid flow
5. Processing
   - Different metal concentrations

3. Motivation/Urgency of the Topic (1)

GEOSTATISTICS →

Estimation/Simulation



Develop framework for:

Strategic exploration,

Resource/reserve definition and quantifying level of confidence/risk,

Support in equipment selection, mine design and scheduling optimization,

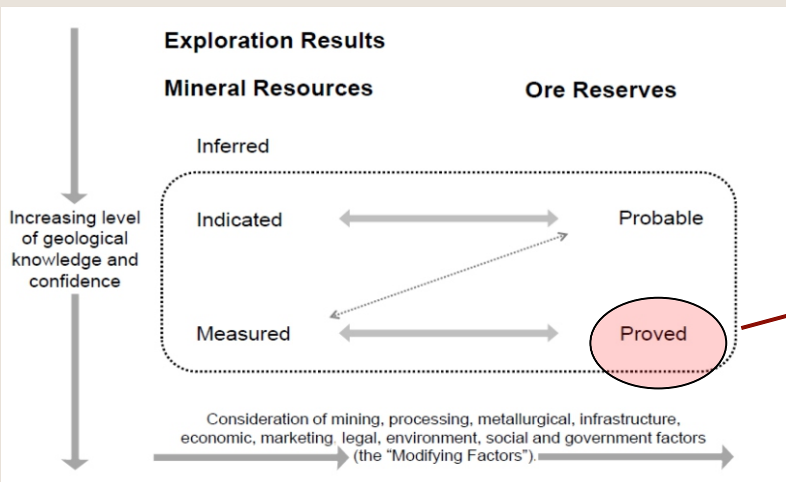
Improved deep sea mine design (through in-situ pre-sorting)

3. Motivation/Urgency of the Topic (2)

STRATEGIC ISSUE!

Investors in Mineral Resource exploitation require project information in terms of **resources/reserves** linked to the level of **confidence**

For deep sea deposits, the level of **information is scarce** and data gathering is difficult and **expensive**



JORC code - http://www.jorc.org

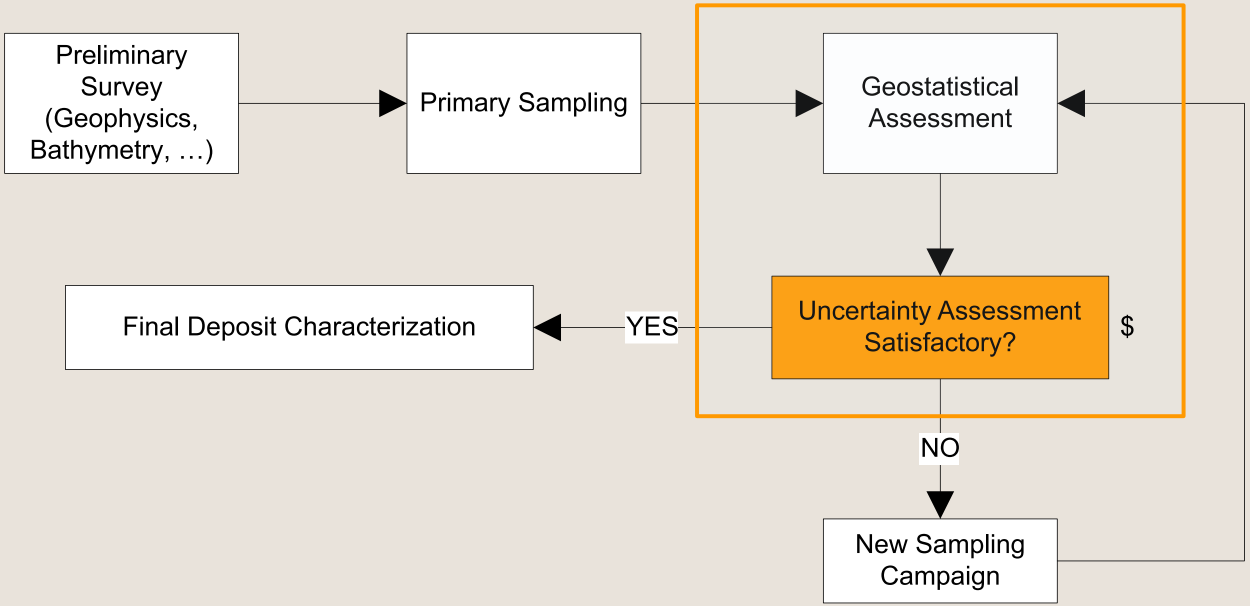
3. Motivation/Urgency of the Topic (3)

AID CLIENTS TO ANSWER THE FOLLOWING QUESTIONS:

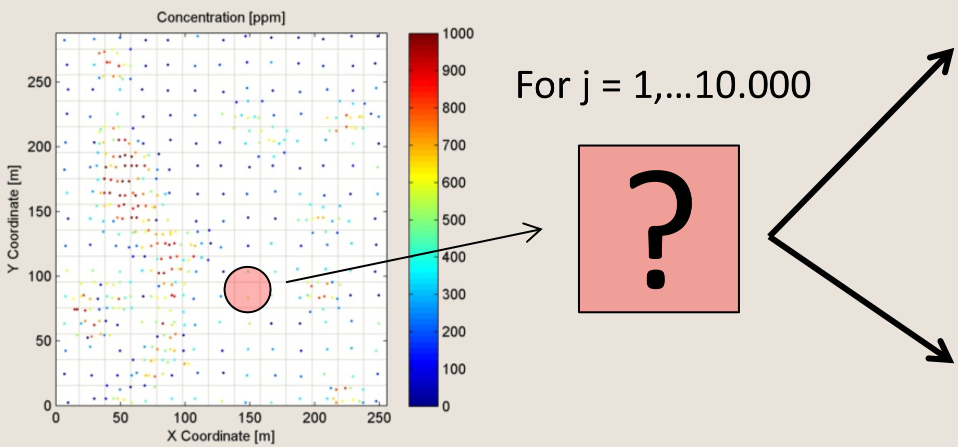
- What financial risk is associated with investing in deep sea exploration and mining technology?
- How can we determine/quantify the risk (level of confidence of extractable reserves)?
- Which information needs to be available to make ``informed'' investment decisions?
- How to obtain these very expensive data in strategic stages to mitigate risk?
- How to transform mineral resources to extractable reserves at 2000m depth?
- How to maximize recovery and minimize extraction costs (in-situ presorting)?

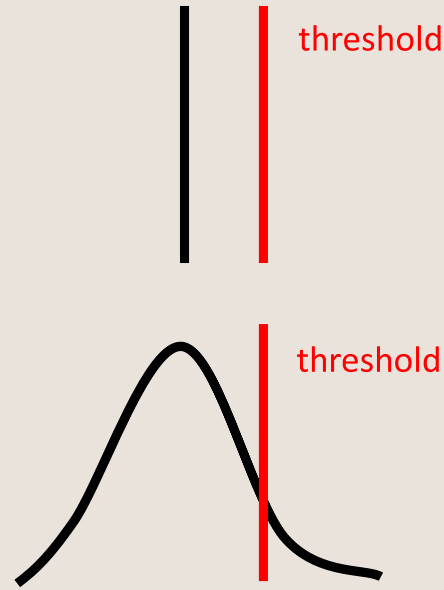
3. Motivation/Urgency of the Topic (4)

… in the first year of production after start-up 60% of mines surveyed had an ***average rate of production less than 70% of the designed capacity****…*
(Vallee, 2000)



4. Research Approach (1)





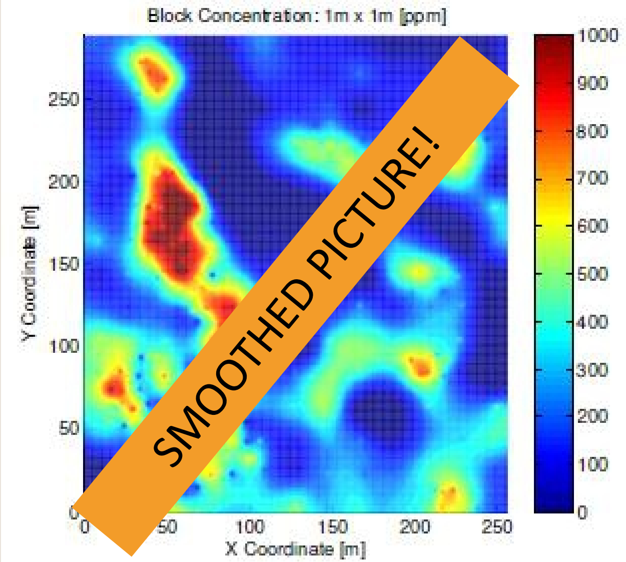
Applications:

- Exploration
- Resource/Reserve Estimation
- Equipment Selection & Design
- Mine Planning
- Processing Logistics

4. Research Approach (2)

Estimation:

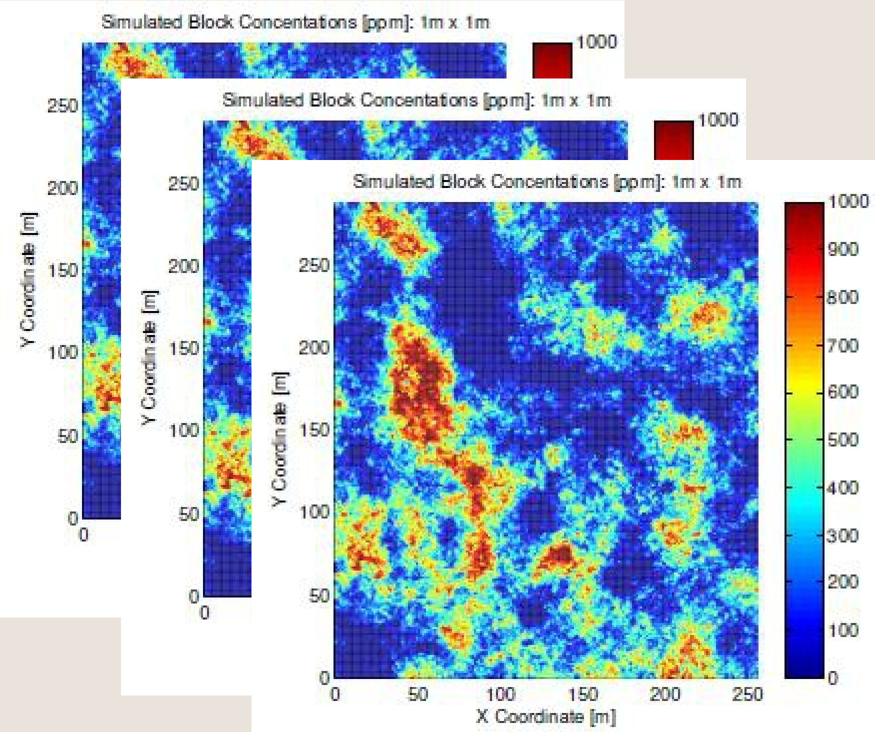
Designed to compute the ``best'' estimate at a single location



(b) Block Kriging

Simulation:

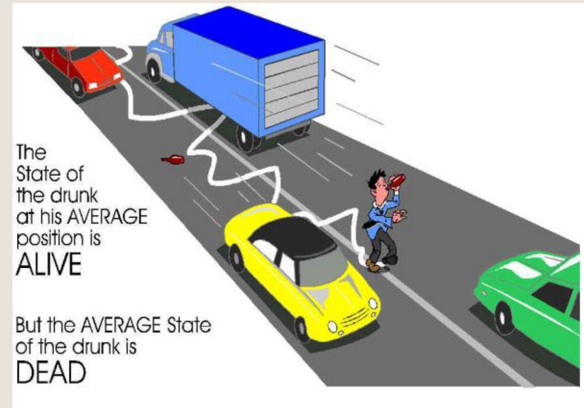
Equally-probable realizations provide a measure of quantifying the uncertainty



(a) Simulation

4. Research Approach (3)

after S. Savage

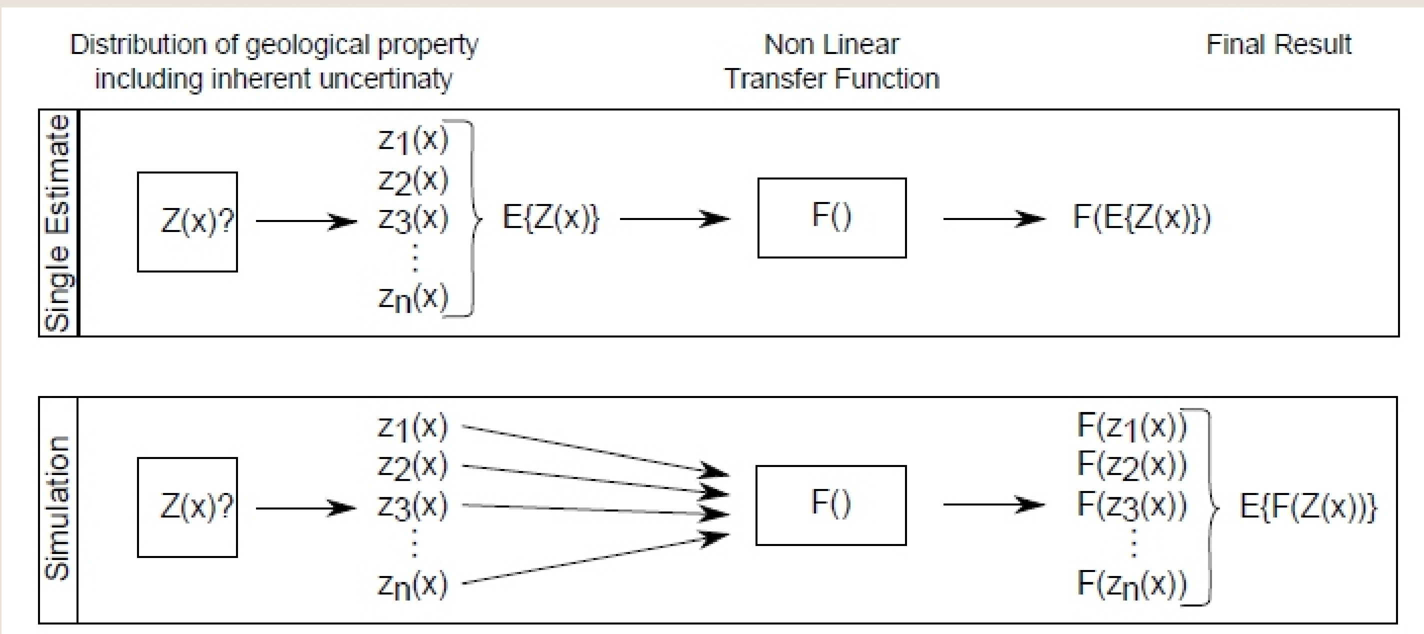


DO NOT SUBSTITUTE ENTIRE DISTRIBUTIONS FOR SINGLE ESTIMATES WHEN DEALING WITH:

Uncertainty

Non-Linear Transfer Functions

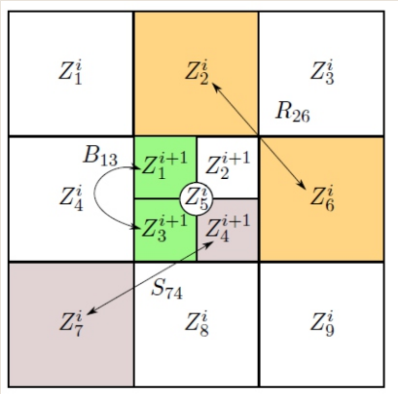
THE FLAW OF AVERAGES



4. Research Approach (4)

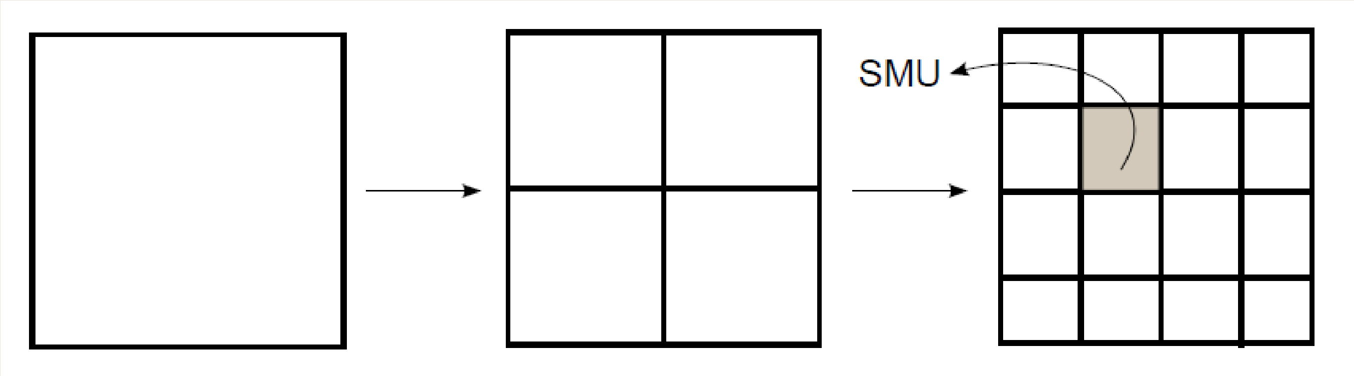
LOCAL AVERAGE SUBDIVISION (LAS)

The coarse resolution of an intially generated random field is further improved through a sequence of calculation stages.



All four local child variables must satisfy:

1. Average to the parent value
2. Show a correct variance according to the local average theory
3. Properly correlated with one another
4. Properly correlated with the neighboring child values across the parent boundaries.

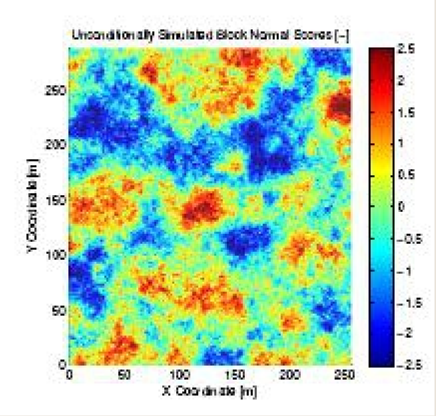


4. Research Approach (5)

Simulation = two step approach using LAS

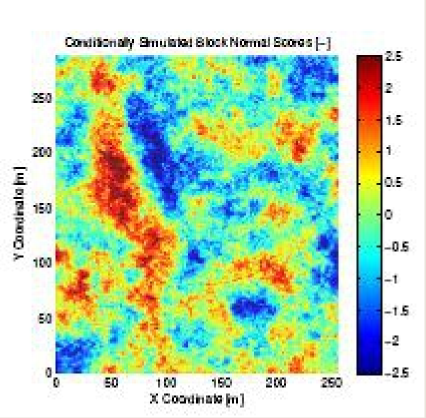
1. Unconditional random field simulation (LAS)

$$f(\mathrm{x}_1,\ldots,\mathrm{x}_k;b_1,\ldots,b_k)=\frac{1}{(2\pi)^{k/2}\,|C|^{1/2}}\exp\{-\frac{1}{2}(\mathrm{b}-\mu)^T C^{-1}(\mathrm{b}-\mu)\},$$



2. Conditioning (BLUE)

$$Z_c(\mathrm{x})=Z_u(\mathrm{x})+[Z_k(\mathrm{x})-Z_s(\mathrm{x})],$$



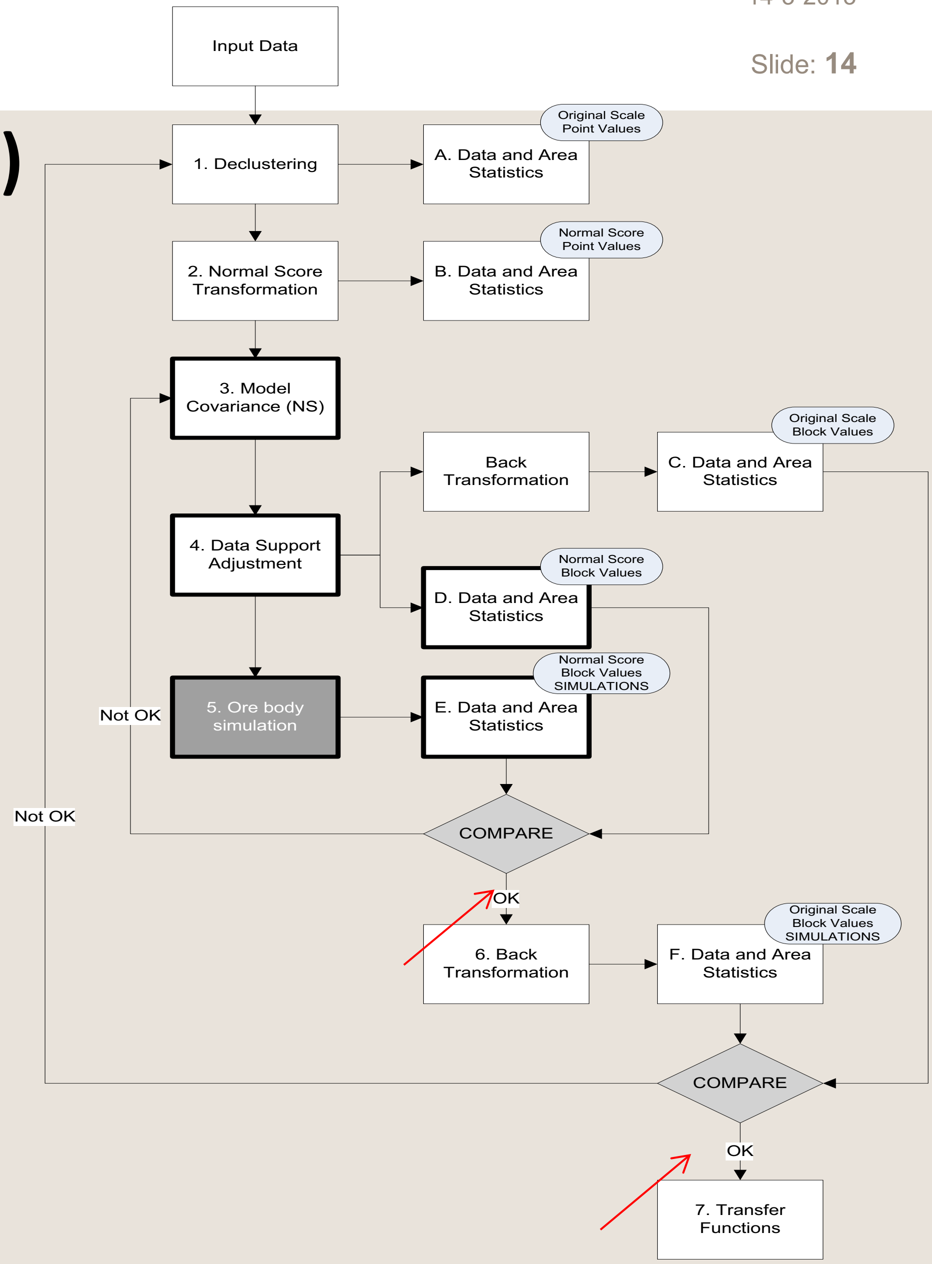
- C: desired conditional simulation
- U: unconditional LAS simulation
- K: BLUE based on known measurements
- S: BLUE based on simulated values at sampling locations

4. Research Approach (6)

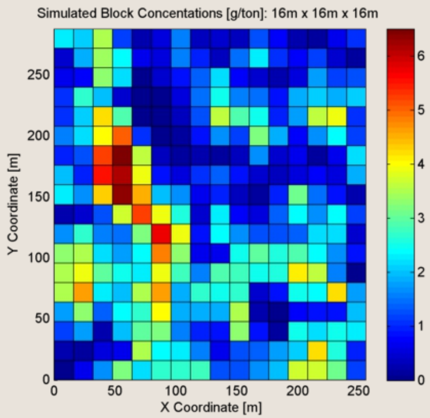
EXTENSIONS OF LAS:

Preferentially sampled data
Not normally distr. data
Point measurements

FRAMEWORK = systematic, easy to follow and robust



5. Probability Risk Based Decision Making



Rock

For each Block in the field

Decision

WASTE

ORE

return vs. costs

$$p.r.z = C_m + C_p$$

$$\mathrm{E}[Pr_{ore}] = -C_m + P_o \cdot [p \cdot r \cdot m^+ - C_p] + P_w \cdot [p \cdot r \cdot m^- - C_p],$$

WASTE

- Mining Cost
- Transportation to deep sea waste dump

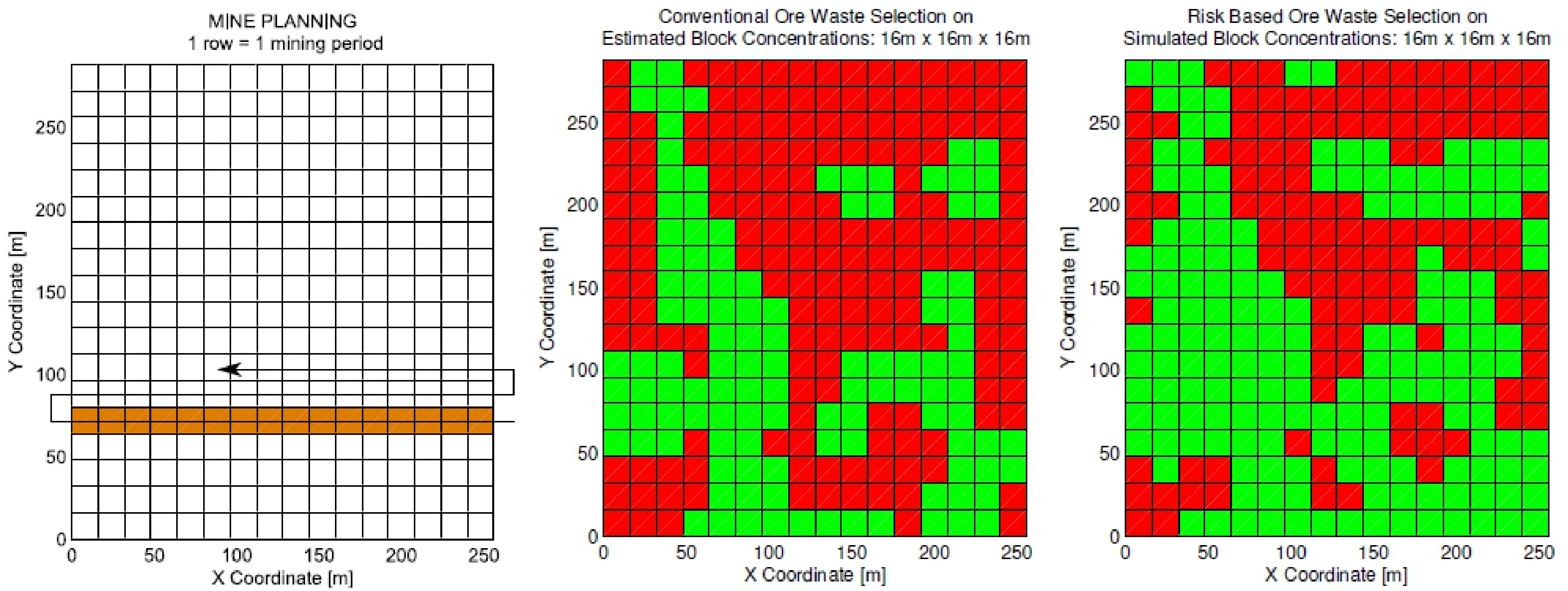
ORE

- Mining Cost
- Processing Cost: vertical riser, barges, processing plant

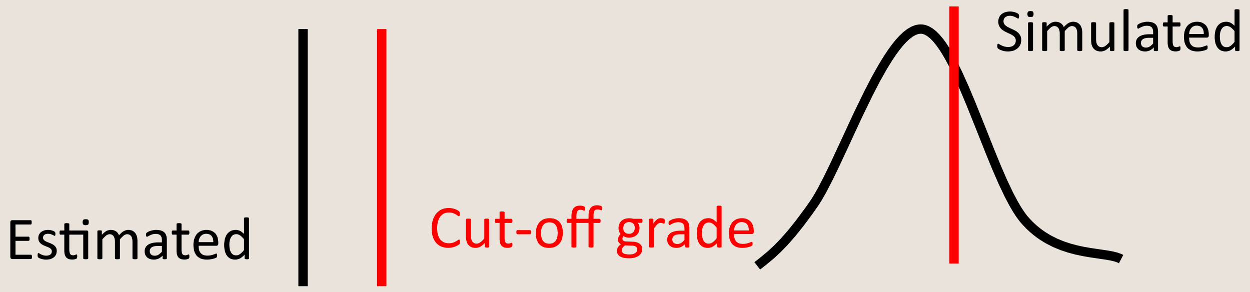
$$\mathrm{E}[Pr_{waste}] = -C_m - P_o \cdot [p \cdot r \cdot m^+ - C_p],$$

IF $\mathrm{E}[\mathrm{Pr}_{ore}] > \mathrm{E}[\mathrm{Pr}_{waste}]$ then ORE ELSE WASTE

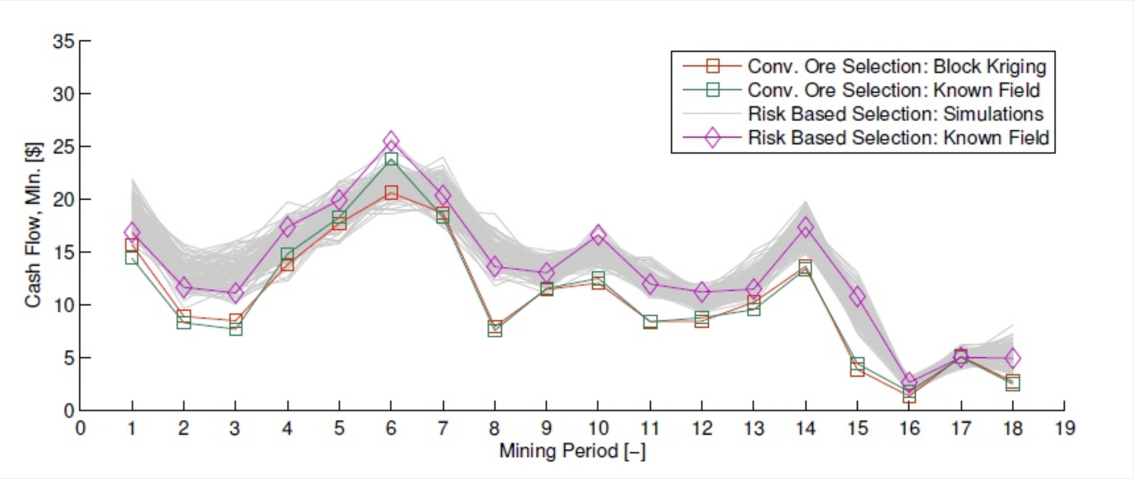
6. Example (1) Ore Selection

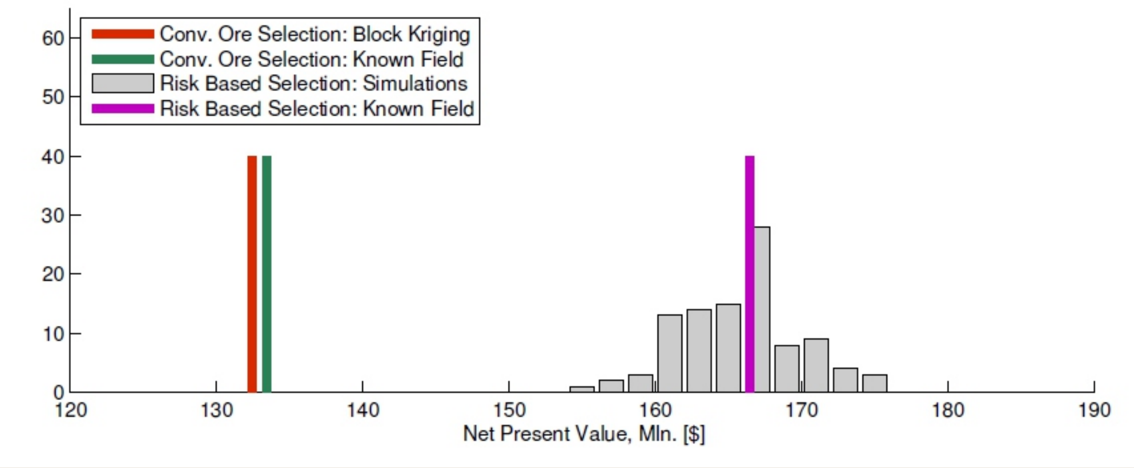


(a) Mining Sequence (b) Conventional Selection (c) Risk Based Selection

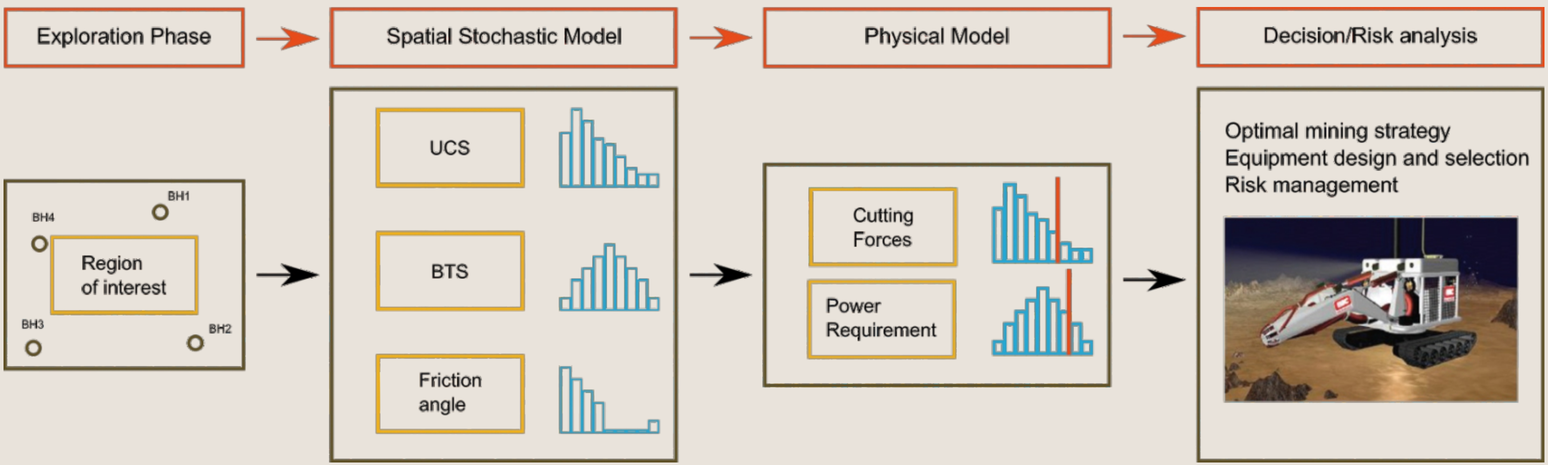


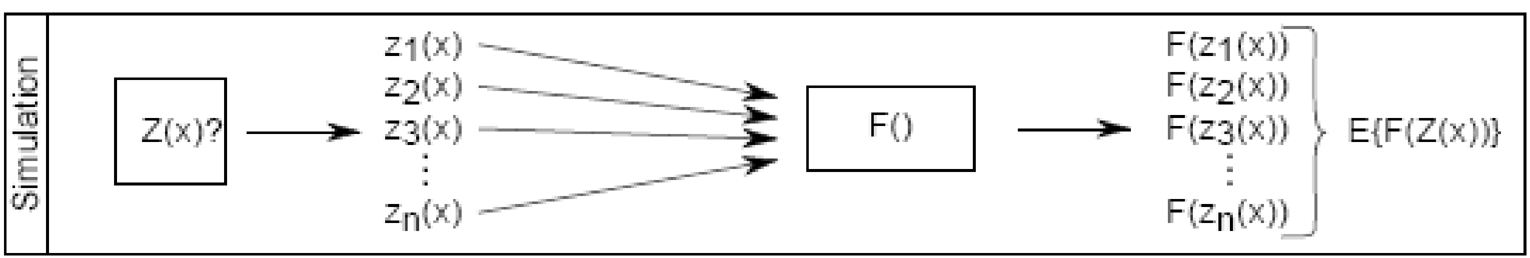
6. Example (2) Cash Flow Analysis



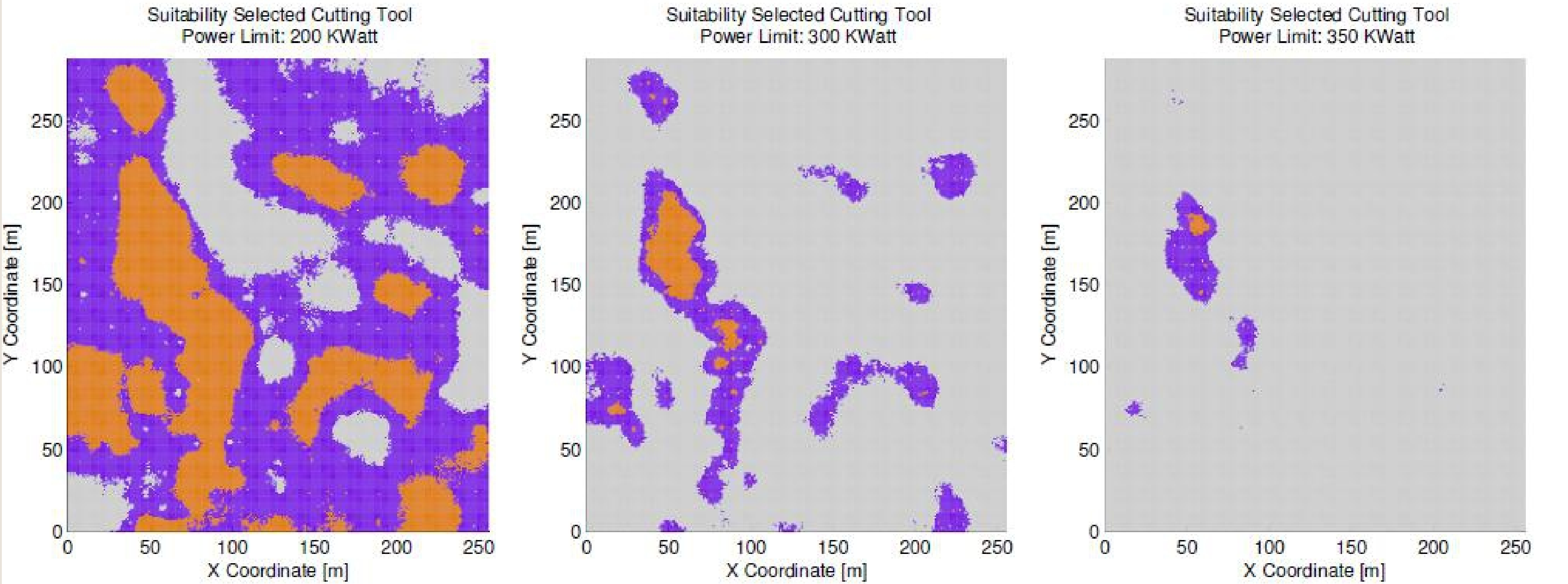


6. Example (3) Support Equipment Selection





6. Example (3) Support Equipment Selection



(a) 200 $kWatt$ (b) 300 $kWatt$ (c) 350 $kWatt$

7 Conclusions

- The developed probability simulation framework copes with geological and geotechnical uncertainties and allows propagating them through the whole project chain.
- The proposed method improves the decision making process and the quantification of uncertainties and risks.
- Further investigations in this field will be carried out in the coming years in close cooperation between Delft University of Technology and IHC Merwede (PhD research: 2013 - 2017).

Thanks for your attention