

Financial Regimes for Polymetallic Nodule Mining: A Comparison of Four Economic Models

Randolph Kirchain, Frank R Field, and Richard Roth

Materials Systems Laboratory, Massachusetts Institute of Technology

Study Objective

- Review information about four financial payment system models that have been submitted to the ISA or presented in other public venues
- Attempt to identify the most likely cause of difference among reported results
- Example difference
 - the AG report states that a mining entity operating under an ad-valorem royalty of 2% of net metal value for the first eight years of production and 4% thereafter would be expected to earn an internal rate of return (IRR) of **27%**.
 - CSU report says that, given a constant ad-valorem rate of 2% for the life of the mining operation, a mining entity would only be expected to earn an IRR of **17%**.

The four models being compared here are :

- the African Group Model (AG)
 - Available information: Report “Request for consideration by the Council of the African Group’s proposal on the Economic Model/Payment ...” that was submitted to the ISA on September 7, 2018.
 - Questions answered by AG representatives
 - Model available: No
- the China Southern University Model (CSU)
 - Available information: presentation “Financial model and economic evaluation of polymetallic nodules development in the Area” by Prof. Shaojun Liu from CSU that was submitted to the ISA on September 7, 2018.
 - Questions answered by CSU representatives
 - Model available: No
- the German Federal Ministry for Economic Affairs and Energy Model (BMWi)
 - Available information: document “Analysis of the Economic Benefits of Developing Commercial Deep Sea Mining Operations ...” a report for the Federal Ministry for Economic Affairs and Energy (BMWi) issued on September 30, 2016.
 - Questions answered by CSU representatives
 - Model available: No
- the Massachusetts Institute of Technology model (MIT)
 - Model available: YES

Review Process

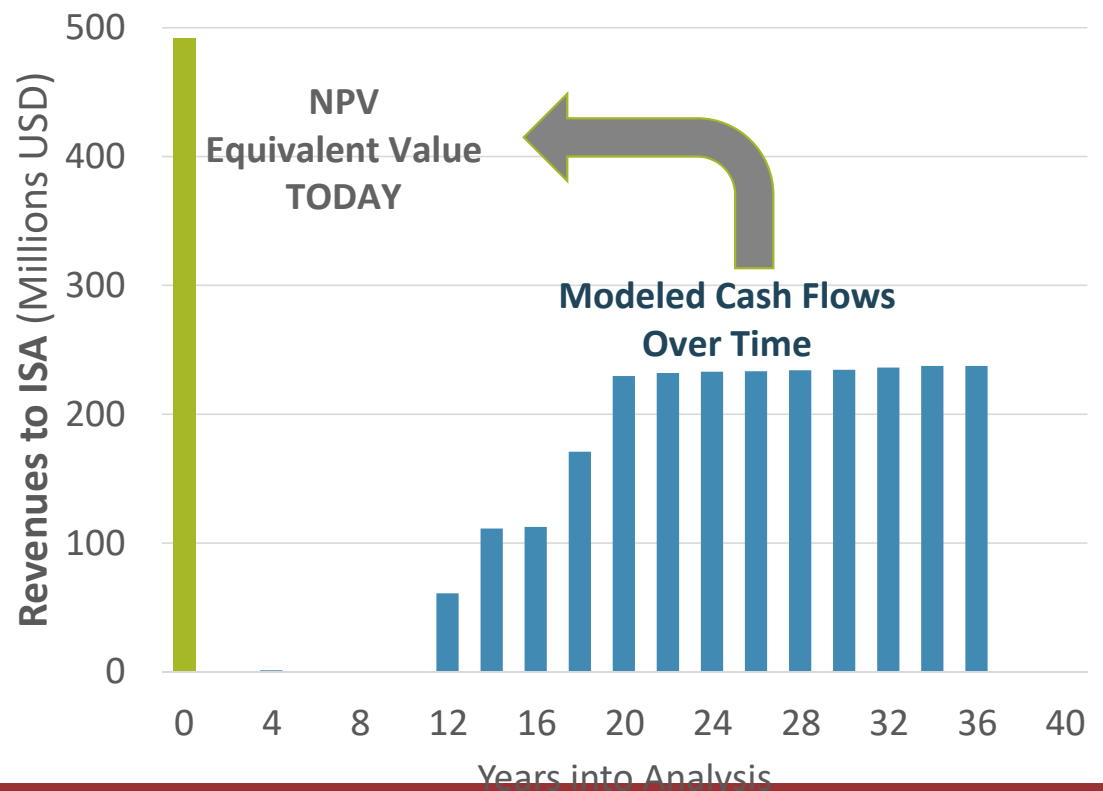
1. The authors reviewed publically available information about each of the review models and developed questions for each modeling team.
2. Each team was interviewed by phone and/or email.
3. The authors created models that used those data to replicate the results reported for each model.
 - These proxy models were then used to explore the key drivers of the differences among the results previously reported.

Overall All Four of the Models are Analytically Similar

- ALL models are very similar
 - ALL carry out discounted cash flow analysis
- All four models explored a collection operation of 3 million dry tons of nodules per year

Discounted Cash Flow Model is Standard Tool for Assessment Economic Viability of Any Activity

- Estimate magnitude & timing of future cash flows
 - Operating expenses
 - Investments (capital expenses)
 - Royalties, taxes, and fees
 - Revenues
- Compute various financial metrics
 - Discount all CFs to present = Net Present Value (NPV)
 - Solve for discount rate where $NPV = 0 \rightarrow$ Internal rate of return (IRR)



Overall All Four of the Models are Analytically Similar

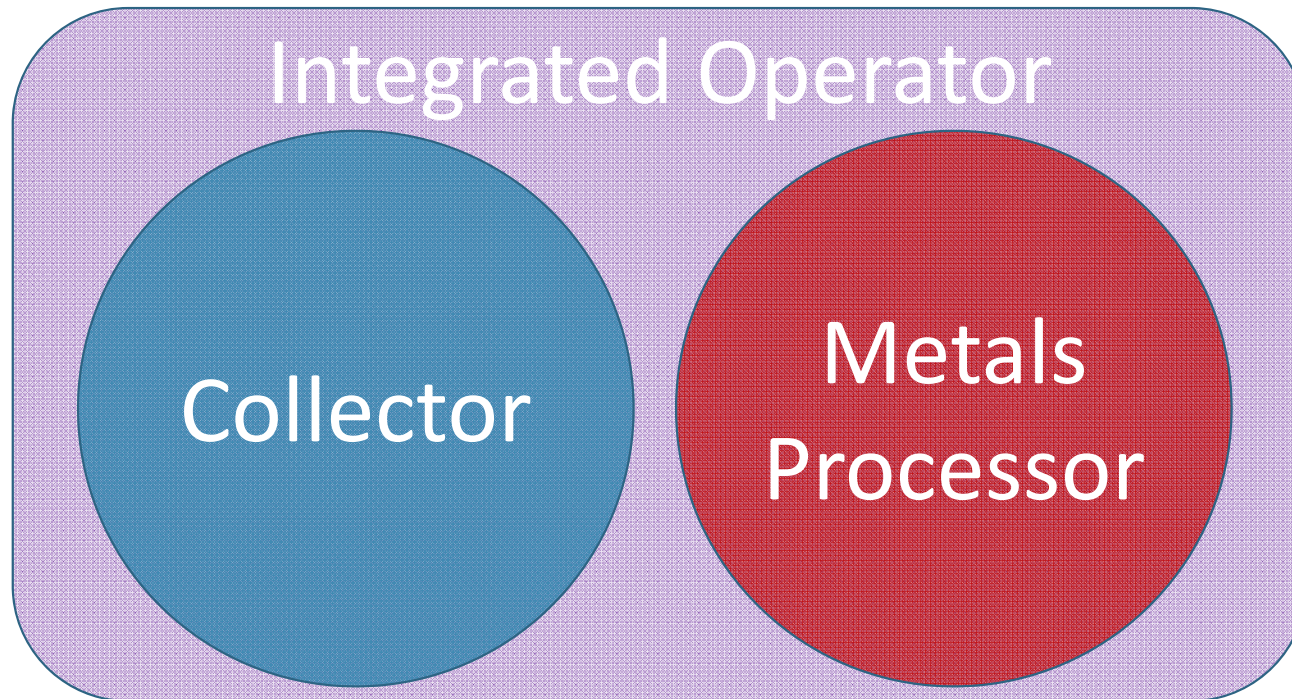
- ALL models are very similar
 - ALL carry out discounted cash flow analysis
- All four models explored a collection operation of 3 million dry tons of nodules per year
- Most commonly reported metrics were
 - IRR (3 of 4)
 - NPV (3 of 4)

	AG	BMWi	CSU	MIT
Metrics Reported				
IRR	✓	✗	✓	✓
NPV	✗	✓	✓	✓
Revenues to ISA	✓	✗	✗	✓
Revenues to Sponsoring State	✓	✗	✗	✗
ISA share of profit	✓	✗	✗	✗
Sponsoring state share of profit	✓	✗	✗	✗
Other			Break-even time and grade, payback period	

Identified 21 Significant Characteristics that Vary Across the Models

- Analytical framing
 - Reported evaluation metric
 - Operational scope
 - Analysis Period
- Production characteristics
 - Scale
 - Ramp up period
 - Metallurgical processing
 - Metals recovered
 - Metals Content of Nodules
 - Metallic yield
- Magnitude of estimated future prices
 - Cobalt
 - Copper
 - Manganese
 - Nickel
 - Gross Metal Value of Nodule (USD / tonne nodule)
 - Net Metal Value of Nodule (USD / tonne nodule)
- Magnitude of estimated operations-related cost cash flows
 - CAPEX
 - OPEX
 - Salvage value
 - Site remediation
- Magnitude of estimated financial regime-related cash flows
 - Sponsoring State Tax rate
 - Royalties
 - ISA Fees

Operational Scope: Three models assume integrated operator; MIT model assesses separate operators



Key Issues:

Analysis period and timing

Analysis period comprises both Before production (feasibility activities and operation design and build (D&B)) and During production and possibly AFTER production

	AG	BMW _i	CSU	MIT
Analysis Period	35 years	16	28	37
Exploitation period analyzed	28 years incl. 3 years D&B	16 years incl. 4 years D&B	28 years incl. 3 years D&B	30 years incl. 3 years D&B

Key Issues:

Ramp up

- Ramp up is the period where operations are not a full capacity.
- Later analysis shows this to be very influential

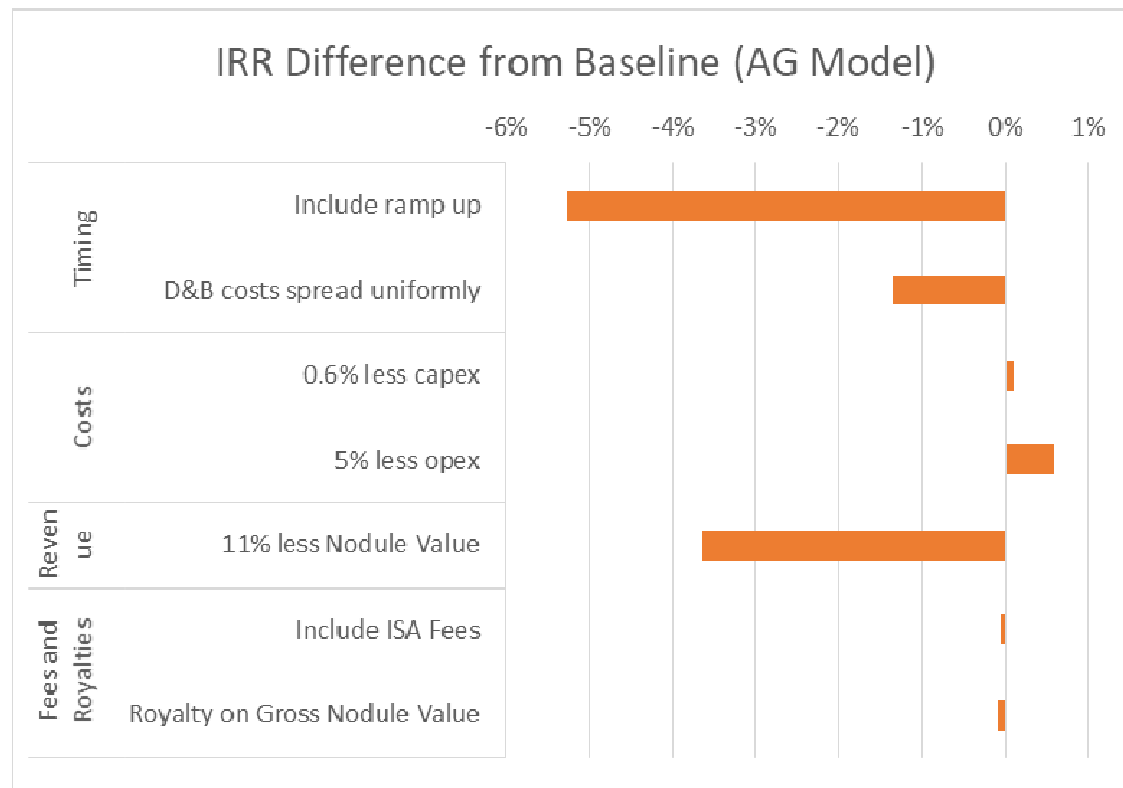
	AG	BMWi	CSU	MIT
Ramp up period (years not at full production)	0 years	2	0	2

Key Issues: Metallurgical process & Metals recovered

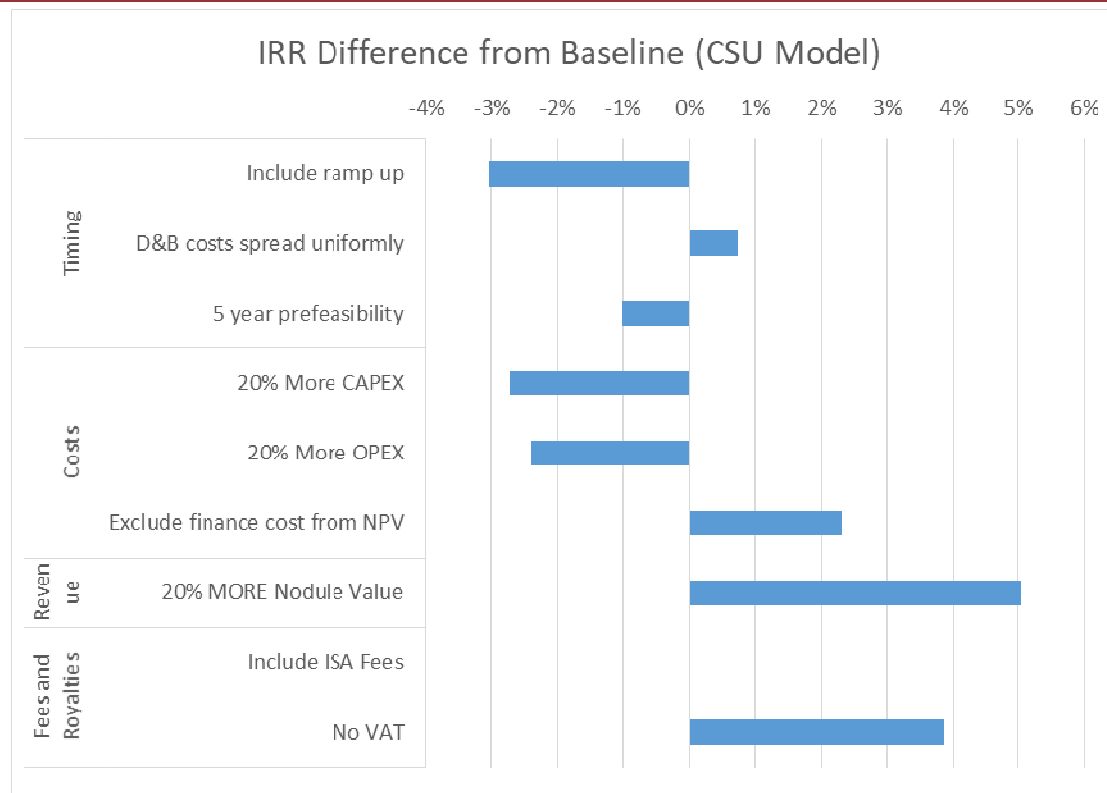
Three of the four models assumed metallurgical processing to recover Mn metal, the BMWi model assumed only three metals were recovered

	AG	BMWi	CSU	MIT
Metallurgical processing	Mn recovered to EMM	High-pressure/high-temperature leaching using sulphuric acid	Mn recovered to EMM	Mn recovered to EMM
Metals recovered	(✓ = included)			
Cobalt	✓	✓	✓	✓
Copper	✓	✓	✓	✓
Manganese	✓	✗	✓	✓
Nickel	✓	✓	✓	✓

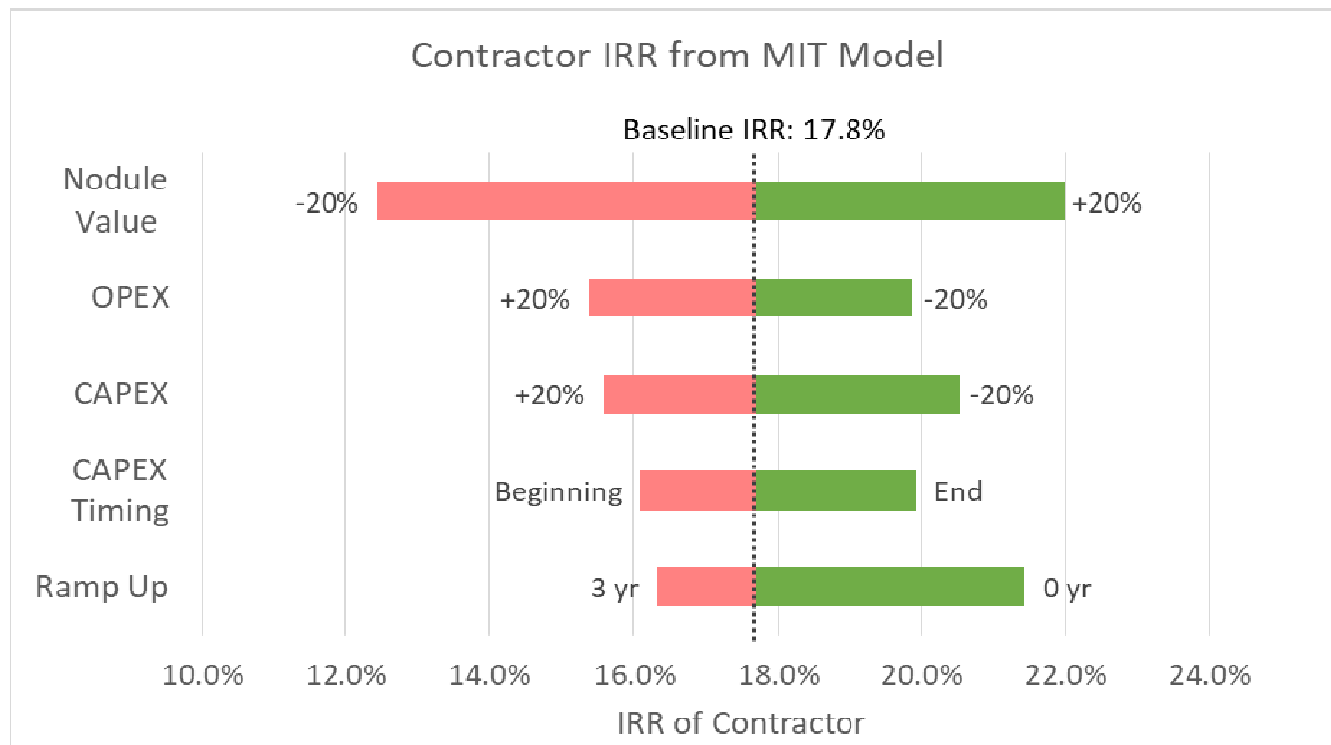
Influential Assumptions in the AG model



Influential Assumptions in the CSU Model



Impact of assumptions on the MIT model



Key Assumptions that Should be Considered by the WG based On the Model Comparison

- **Scope of analysis**
 - Integrated vs separate
 - Salable Mn ore or Mn metal
- **Value of the nodules**
 - Conservative historic prices
 - Aggressive price forecasts
- the magnitude of OPEX costs;
- the magnitude of CAPEX costs;
- **the duration of the production ramp up; and**
- **the timing of capital expenditures**