Optimisation of Long-term Mining Schedule

Maximising NPV

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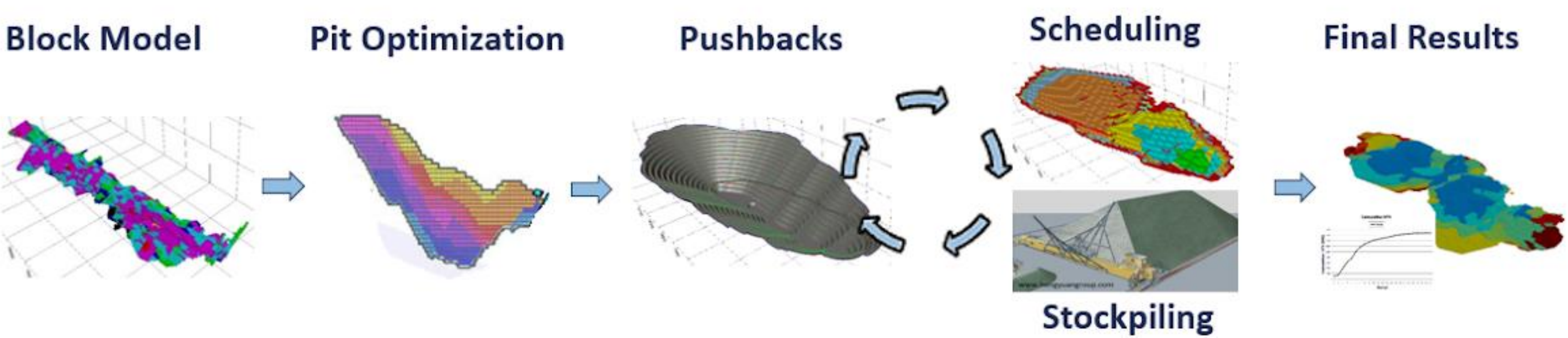
Agenda

- How we optimise
  - Unconstrained system approach
- How we should optimise
  - Mining is ALWAYS constrained
- A couple of examples

Industry Standard Practices

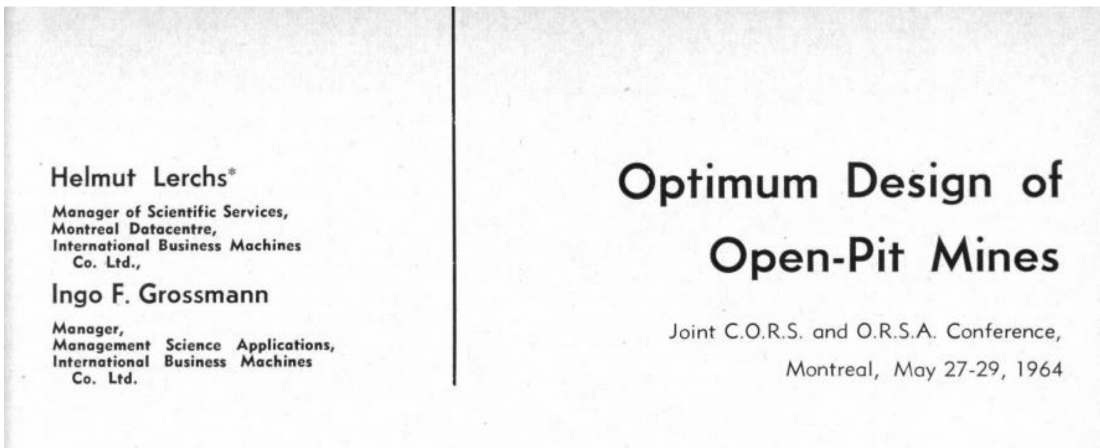
Non-Constrained Mining

- De-facto industry standard is Lerchs-Grossman algorithm implemented in various software packages
- In the process we also define cut-off grade – a measure that allows us to separate economic ore from waste



How We Optimise

- Block model, processing parameters, cost parameters are subjected to Lerchs Grossman algorithm

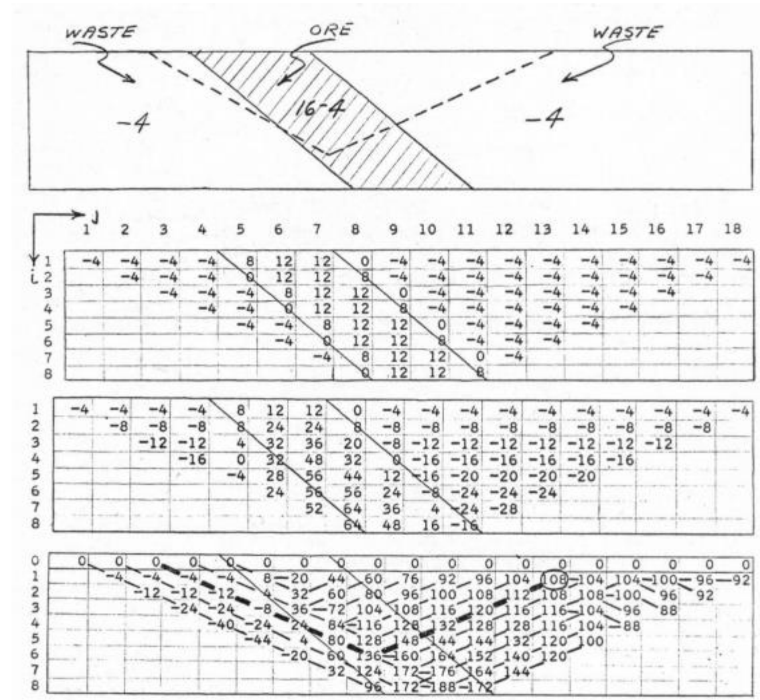


Helmut Lerchs*
Manager of Scientific Services,
Montreal Datacentre,
International Business Machines
Co. Ltd.,

Ingo F. Grossmann
Manager,
Management Science Applications,
International Business Machines
Co. Ltd.

Optimum Design of Open-Pit Mines

Joint C.O.R.S. and O.R.S.A. Conference,
Montreal, May 27-29, 1964



Source: The Canadian Mining and Metallurgical Bulletin for January, 1965, Montreal

Cut-Off Grades - Unconstrained

- Cut-off grade is representation of relative economic value of sending a block with grade x to one process or another
- And you can have as many cut-off grades as you want
  - Breakeven cut-off

    $x = [(M_o + P_o + O_o) - (M_w + P_w + O_w)] / r(V - R)$
  - Mill cut-off

    $x = [P_o + O_o] / [r(V - R)]$
  - Mine cut-off with no waste stripping

    $x = (M_o + P_o + O_o) / [r(V - R)]$
  - Mine cut-off with waste stripping

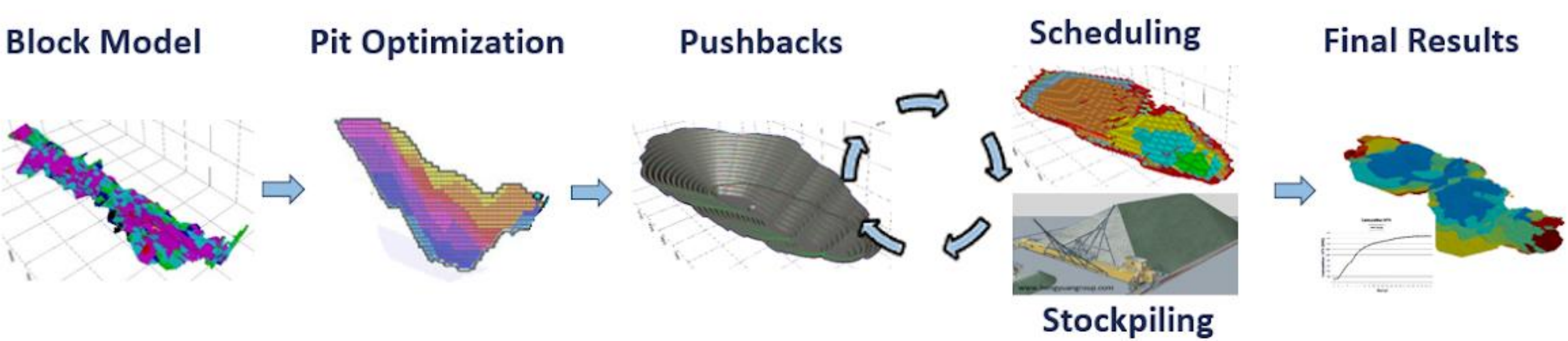
    $x = [(M_o + P_o + O_o) + s(M_w + P_w + O_w)] / r(V - R)$

    ……………………………………………………………………

Source: J.-M. Rendu. An introduction to cut-off grade estimation. Second edition. 2014. Society for Mining, Metallurgy & Exploration Inc.

Non-Constrained Mining – Conclusions

- Algorithms used have no concept of constraint
- No variable discussed is time related
  - Opportunity cost is not considered
  - No time value of money is involved
- **SO THE APPROACH CANNOT BE NPV MAXIMISING**



Mining Is ALWAYS Constrained

- As mining is constrained *

1. **IDENTIFY the system's constraint**
2. **Decide how to EXPLOIT the system's constraint**
3. **SUBORDINATE everything else to the above decisions**
4. **ELEVATE the system's constraint**
5. **If in the previous steps a constraint has been broken Go back to step 1, but do not allow inertia to cause a system constraint**

* – Source : E.M. Goldratt, J. Cox. The Goal. A process of Ongoing Improvement. Third Revised Edition. 2004. North River Press

Role Of Cut-Off

Constrained System

- Cut-off may serve as tool to EXPLOIT the system constraint and SUBORDINATE other parts of the system
  - By ensuring maximum economic value flow through the constraint
- When system constraint is not in the most CAPEX intensive part (i.e. not in the mill or shaft) the constraint should be ELEVATED so that system constraint shifts to appropriate place

Cut-Off Grades – Constrained

- Now cut off grade allows to maximise economic value flow through the constraint by introducing opportunity costs to calculations
  - Mine cut-off with capacity constraint in
    - Mill: $x = [M_o + P_o + O_o + (i\ t\ NPV_i)] / [r(V - R)]$
    - Mine: $x = [M_o + P_o + O_o + (i\ t\ NPV_i)] / [r(V - R)]$
    - Refinery: $x = [M_o + P_o + O_o] / [r(V - R - (i\ t\ NPV_i))]$
  - Mill cut-off with capacity constraint in
    - Mill: $x = [M_o + P_o + O_o + (i\ t\ NPV_i) - (M_w + P_w + O_w)] / [r(V - R)]$
    - Mine: $x = [(M_o + (i\ t\ NPV_i) + P_o + O_o) - (M_w + (i\ t\ NPV_i) + P_w + O_w)] / [r(V - R)]$
    - Refinery: $x = [(M_o + P_o + O_o) - (M_w + P_w + O_w)] / [r(V - R - (i\ t\ NPV_i))]$
- Cut-off grade now depends on discount factor, NPV and throughput capacity of system components (constraints)
- Let’s introduce a second processing option……

Source: J.-M. Rendu. An introduction to cut-off grade estimation. Second edition. 2014. Society for Mining, Metallurgy & Exploration Inc.

Optimising Economic Value

Let's simplify

- We can use economic values direct (and not via proxy such as cut-off)
    - Build deposit economic block model with available information for each block
        - Ore properties, Processing parameters, Geotechnical parameters, Mining and Processing Economics
    - Circumvent difficulties associated with identification of THE bottleneck/constraint
        - Define constraints for system – all potential limitations in mining, comminution, enrichment, refining, environmental, logistics and market
- Use mixed integer linear programming solutions to optimise schedule direct with several constraints in the system and variability in values
- **Maximise NPV**

Output

Mining schedule focused on maximising NPV that takes into account

- Several processing streams
- Variable costs
  - Change in mining costs
  - Change in cost structure for the processing circuit
  - Change in cost of transportation in time
- Various constraints
  - Limitations in mining
  - Limitations in crushing capacity of the plant
  - Limitations in ore feed properties to the plant
- Other constraints and cost and revenue factors

Limitations of the approach

Strategic by nature

- Resulting schedule is long term strategic schedule
  - The schedule is a guideline for better mining and processing sequencing to achieve maximum NPV
- Resulting schedule requires further validation and design work in conventional mining software packages
  - For detailed planning
  - For public reporting

Examples

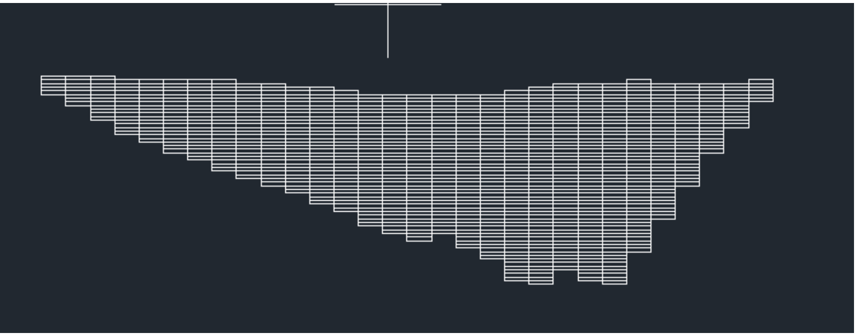
Projects at various stages with different complexities

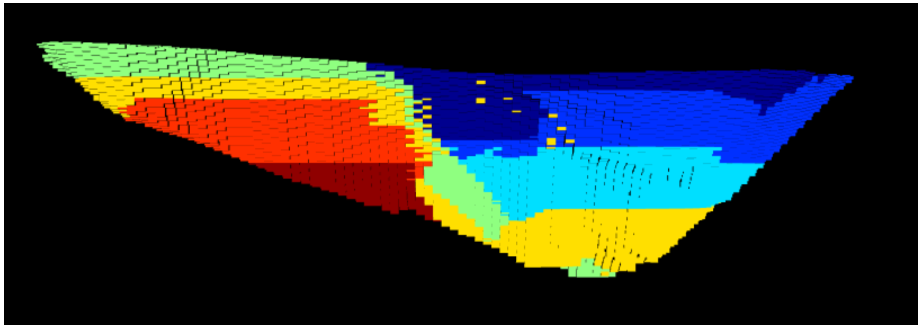
- Early stage Sb project with conceptual grade/tonnage estimate
  - Preliminary definition of economics
  - Modelling of various throughput options
- Cu deposit with Mineral Resources defined. Two processes for oxide and fresh ore with different economics (see next slide)
  - Direct economic schedule optimisation increased NPV estimation by 50% with similar tonnage within LOM
- Producing Au company with several pits and stockpiles, various ore hardness (BWi) levels, and oxide ore in some of the deposits feeding a single plant
  - Scheduling for the whole system is done is 2 weeks
  - The optimisation identified priorities for mining and processing that took into account all the geometallurgical parameters

Examples (Cu)

Right pit returns NPV that is 50% higher

- The pits have similar volume but different sequencing
- The biggest difference is achieved via informed choices of where to send individual block





- The pit shell was created using Lerchs Grossman algorithm
- Scheduling was done using push backs with different revenue factors

- Each block was assigned with economic parameters based on mining, comminution and enrichment details
- Pit optimisation and scheduling were done simultaneously using constraints in each process
- Result is a schedule with mining sequence optimised for maximum NPV

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Thank You