Optimization and Simulation Model for a Coal Mine

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The problem

Description

• The studied system encompasses two open pits mines located in Moatize/Mozambique and managed by Vale S.A.

• Each mine contains mining fronts from where many varieties of coal (named plys) can be retrieved. Moreover, those sites also contain waste, a material that, regardless of having no financial value for the company, still needs to be moved from the mining fronts.

• All material is transported by trucks: the plys are sent to the primary crusher or to the ROM pad (a buffer site) while the waste is sent to an appropriate destination.

• After the crusher, the plys are processed in the coal plants which generates a subproduct called tailings, which are stored in silos that also need to be emptied by trucks and moved to a dam.

• The final products from processing plys are thermal and metallurgical coal which are shipped from the plant by conveyors and are not part of this scope.

• Trucks and loading equipment operators work in shifts.

• Trucks, loading equipment and crusher are subjected to maintenance and failures.
The problem

Frontiers

Scope for this presentation

Mineral fronts

- ROM pad
- Crusher
- Waste deposit

Project frontier

- Tailings dam
- Tailings silo
- Dispatch yards
- Plant
- Ship
Complexity

- The model considers two mining sites, each containing approximately:
  - 8 mining fronts operating simultaneously
  - One loading equipment per mining front
  - 80 trucks of different models (fleets)
  - A dozen of different plys
  - One ROM pad, one crusher and one tailings silo each
our solution
Our approach

- The optimization and simulation model aims to represent the two mines located in Moatize/Mozambique and managed by Vale S.A.

- The optimization model was implemented using the COIN-OR CLP solver embedded in the AnyLogic simulation model and aims to maximize the transportation capacity in the mine by:
  - Sizing the truck fleet for each mining campaign
  - Allocating the volumes of coal, tailings and waste to be transported by each fleet

- The simulation model was developed using AnyLogic and allows the graphical and temporal visualization of the results provided by the optimizer. Moreover, it allows the following analysis:
  - Uncertainties like equipment failure (trucks, loading equipment and crusher)
  - Cycle times of trucks: travel, queue before loading, loading time, queue before unloading and unloading time
  - Utilization levels for trucks, loading equipment and crusher
  - Input rate on crusher (mine throughput)
  - Operators shift planning
  - Maintenance planning
Mathematical formulation

• Objective function: maximize the transported material:

$$\max \sum_{k \in K} \sum_{i \in I} \sum_{j \in J} x_{ij}^k$$

• Constraints:
  - Meet the crusher demand:
    $$\sum_{i \in I} x_{ib}^k + x_{rb}^k \leq V_{bk}, \forall b \in B, k \in K, r_k = \text{ply k from ROM pad}$$
  - ROM pad mass balance:
    $$\sum_{b \in B} x_{rb}^k \leq V_{rk} + \sum_{i \in I} x_{ir}^k, \forall k \in K, r_k = \text{ply k from ROM pad}$$
  - Meet the required volume of coal and waste to be taken from mining fronts:
    $$V_{pk}^+ \geq \sum_{j \in J} x_{pj}^k \geq V_{pk}^-, \forall k \in K, p \in P$$
    $$V_{pe}^+ \geq x_{pe}^e \geq V_{pe}^-, \forall p \in P, e=\text{waste}$$

• Time availability of the trucks:

$$\sum_{i \in I} \sum_{j \in J} \sum_{k \in K} y_{ijc}^k (t_{ijc} + e_{ijc}) \leq n_c T, \forall c \in C$$

• Capacity of trucks per fleet:

$$\sum_{c \in C} y_{ijc}^k S_c \geq x_{ij}^k, \forall i \in I, j \in J$$

• Mass balance in the nodes:

$$\sum_{k \in K} \sum_{i \in I} y_{ijc}^k = \sum_{k \in K} \sum_{i \in I} y_{jic}^k, \forall j \in J, c \in C$$
Why AnyLogic?

• The conceptual model has an underlying optimization problem that needs to be solved by linear programming packages. Thanks to the AnyLogic capability for importing external Java libraries we can import and use the CLP optimization package.

• The trucks behavior while traveling through the mine include movement between sites, failures and operational blocks, which can be easily modeled via statecharts.
Why AnyLogic?

• When the trucks arrive in loading or unloading points, they need to wait in a queue, seize a resource (loading equipment or crusher), which is a typical discrete event simulation process:
results
AnyLogic Model
Trucks travelling through mine
AnyLogic Model

Crusher
AnyLogic Model

Mining front
Results
Optimizer output

```
x[0][10][1] = 380000
x[0][10][2] = 280000
x[1][10][1] = 200000
x[3][10][2] = 200000
x[3][10][1] = 180000
x[2][10][2] = 50000
x[3][11][8] = 546238
x[4][11][4] = 300000
x[4][11][8] = 283761
x[6][10][1] = 600000
x[7][10][2] = 700000
x[8][11][4] = 1000000
x[9][11][8] = 500000
x[13][15][12] = 1425199
x[14][15][12] = 1528500
```

Status: OPTIMAL

função objetivo: 1.04E7
Results

Crusher KPIs
Results

Mining fronts KPIs

Estoques & Carregamento (t)

- Estendi (demas): 0
- Estendi (demas): 0
- SP: 372.480
- WC: 100.000
- TC: 0
- UC: 0
- LC: 0
- THHC: 0
- THCT: 0
Results

Trucks time line
Results

Loading equipment time line
Conclusion

• An optimization and simulation model was developed to be used by VALE S.A. in a coal mine located in Moatize/Mozambique.

• The optimization model aims to size the truck fleets to be used and maximize the amount of coal to be transported, respecting constraints regarding the transportation of waste and tailings.

• The simulation model allows temporal visualization of the mining operation and includes uncertainties such as failures.

• The model can be used to compare the mine throughput in different scenarios, as well as:
  • Analyze the mine behavior with different truck and loading equipment fleet
  • Simulate different shift and maintenance policies

• In a future project, the following aspects could be improved:
  • Use of CPLEX or GUROBI instead of the CLP solver, possibly using Python pipeline
  • Implement mines as a population, so the number of mines to be simulated would be flexible
  • Model trucks movement in detail, possibly using AnyLogic Road Library
Teams

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Na terminologia náutica, a "Vela de Genoa" ou "Genoa" é a vela situada à proa da embarcação, frente ao mastro vertical. A contribuição da Vela de Genoa para um veleiro é uma metáfora do nosso papel como consultores: a Genoa interage com a Vela Grande, melhorando o escoamento de ar entre as duas velas, permitindo que o veleiro atinja velocidades cada vez maiores. É assim que queremos a Genoa: acelerando o seu negócio!

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THANK YOU!