Optimization and Simulation Model for a Coal Mine

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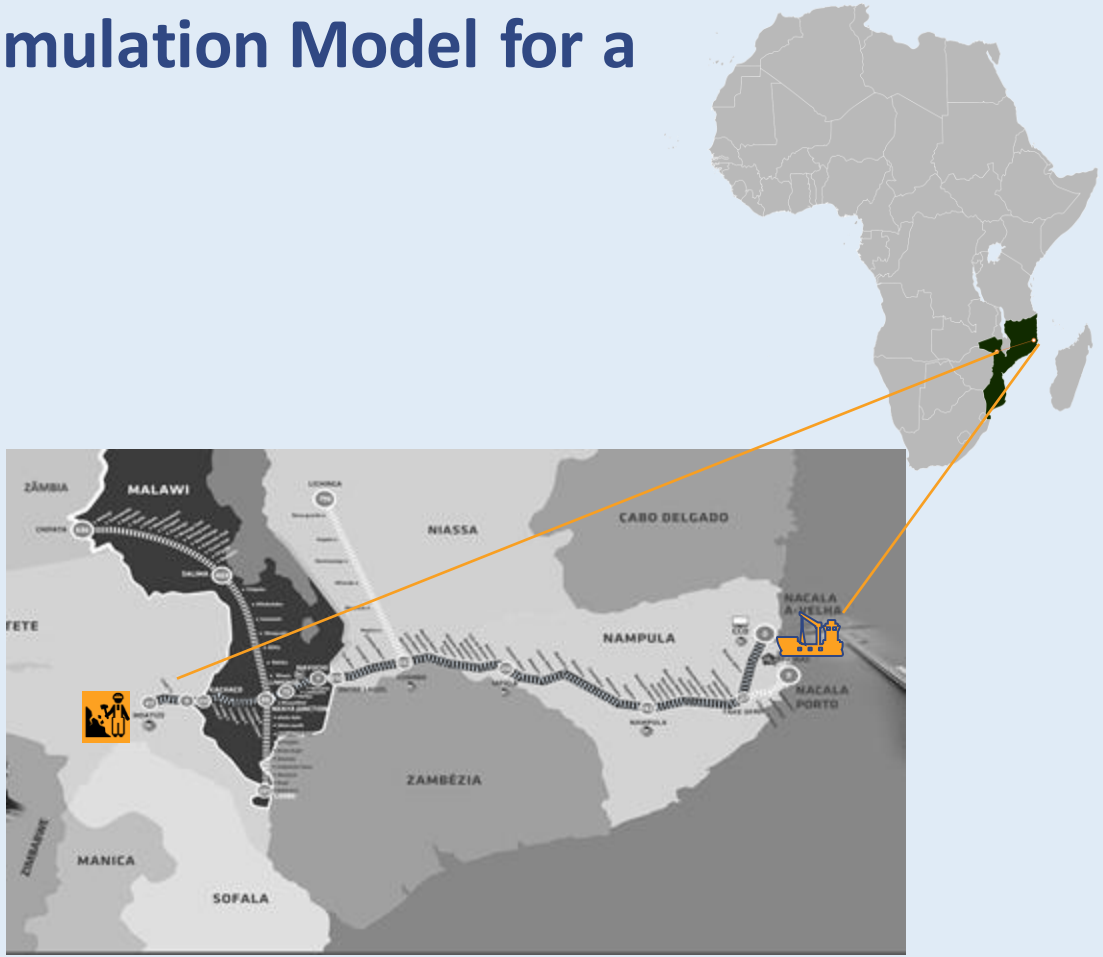

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motivation

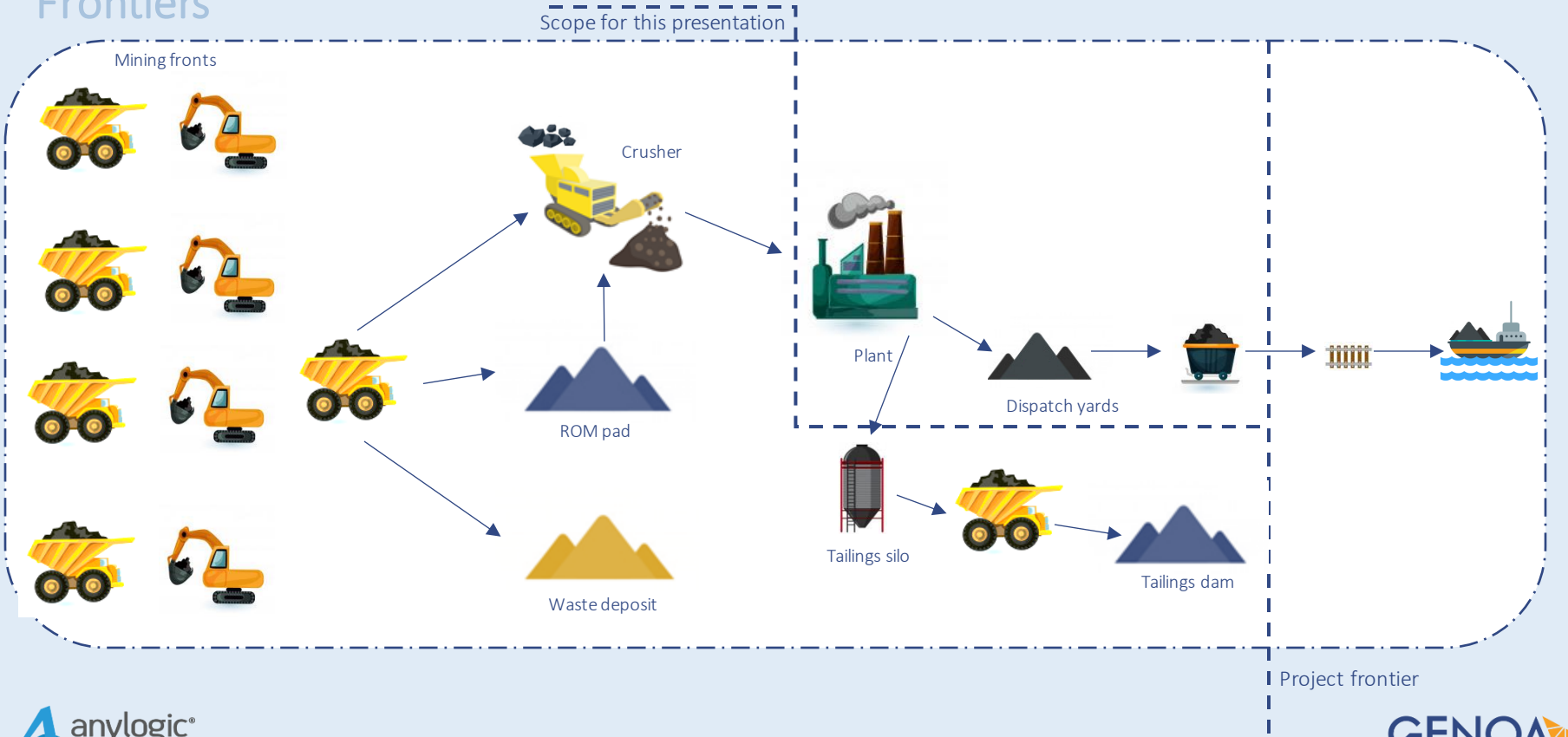
The problem

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



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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

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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

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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:

$$\sum_{i\in I} x_{ib}^{k} + x_{r_k b}^{k} \le V_{bk}, \forall\, b \in B, k \in K, r_k = \text{ply k from ROM pad}$$

  - ROM pad mass balance:

$$\sum_{b\in B} x_{r_k b}^{k} \le V_{r_k k} + \sum_{i\in I} x_{i r_k}^{k}, \forall\, k \in K, r_k = \text{ply k from ROM pad}$$

  - Meet the required volume of coal and waste to be taken from mining fronts:

$$V_{pk}^{+} \ge \sum_{j\in J} x_{pj}^{k} \ge V_{pk}^{-}, \forall\, k \in K, p \in P$$

$$V_{pe}^{+} \ge x_{pd_e}^{e} \ge V_{pe}^{-}, \forall\, p \in P,\ e=\text{waste}$$

- Time availability of the trucks:

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

- Capacity of trucks per fleet:

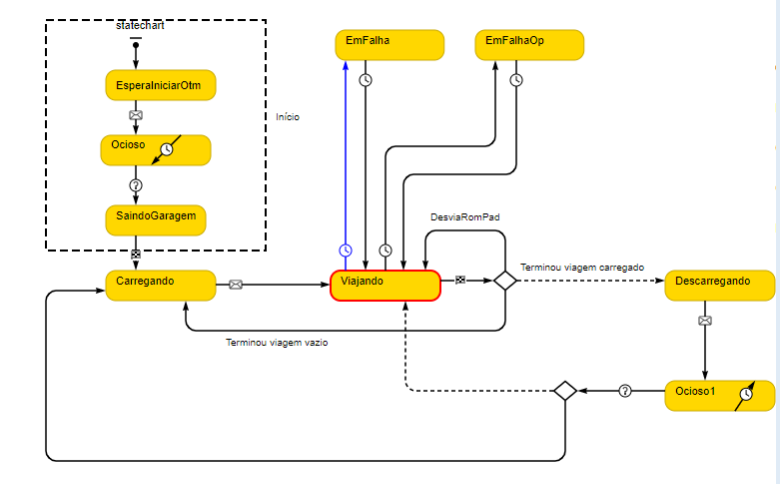
$$\sum_{c\in C} y_{ijc}^{k} S_c \ge x_{ij}^{k}, \forall i \in I, j \in J$$

- Mass balance in the nodes:

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

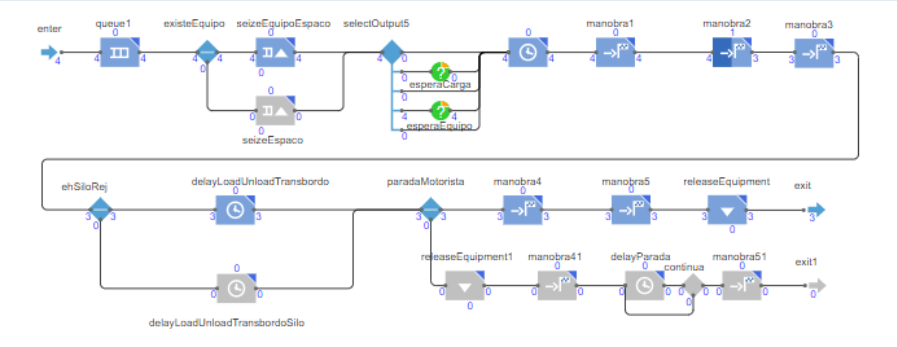
Why AnyLogic?

- 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:



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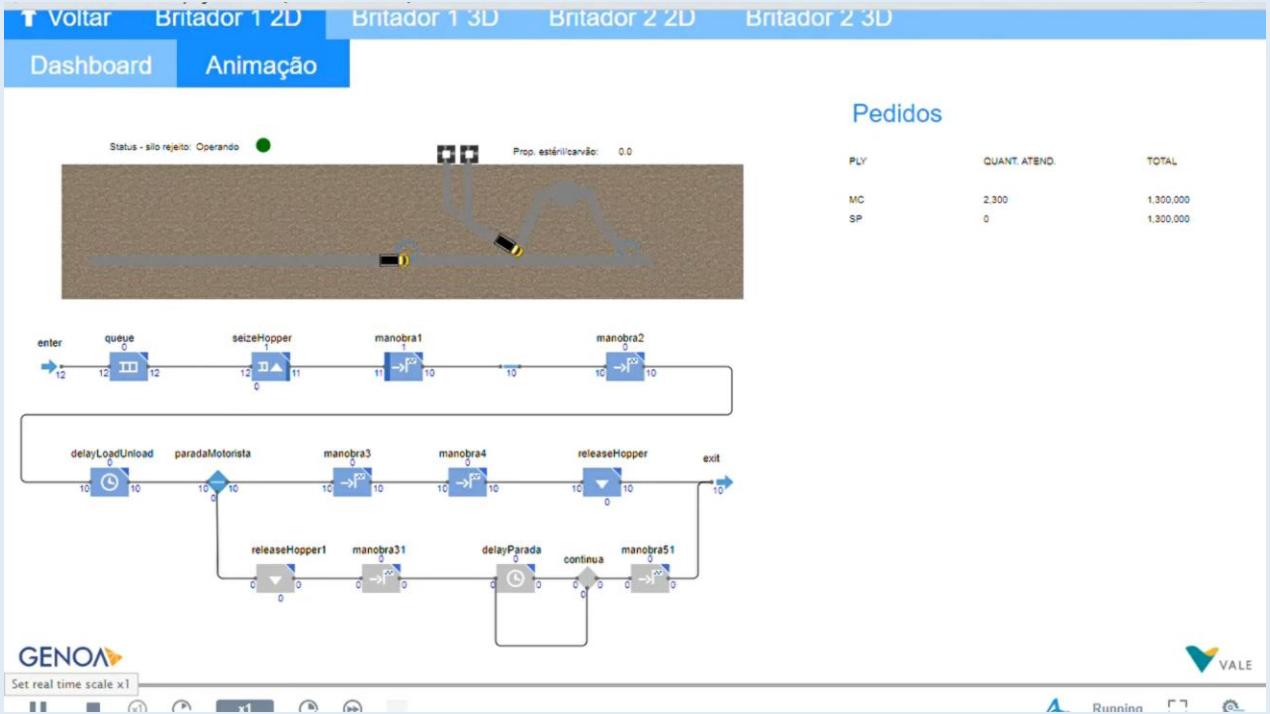
results

AnyLogic Model

Trucks travelling through mine

AnyLogic Model

Crusher



AnyLogic Model

Mining front

Results

Optimizer ouput

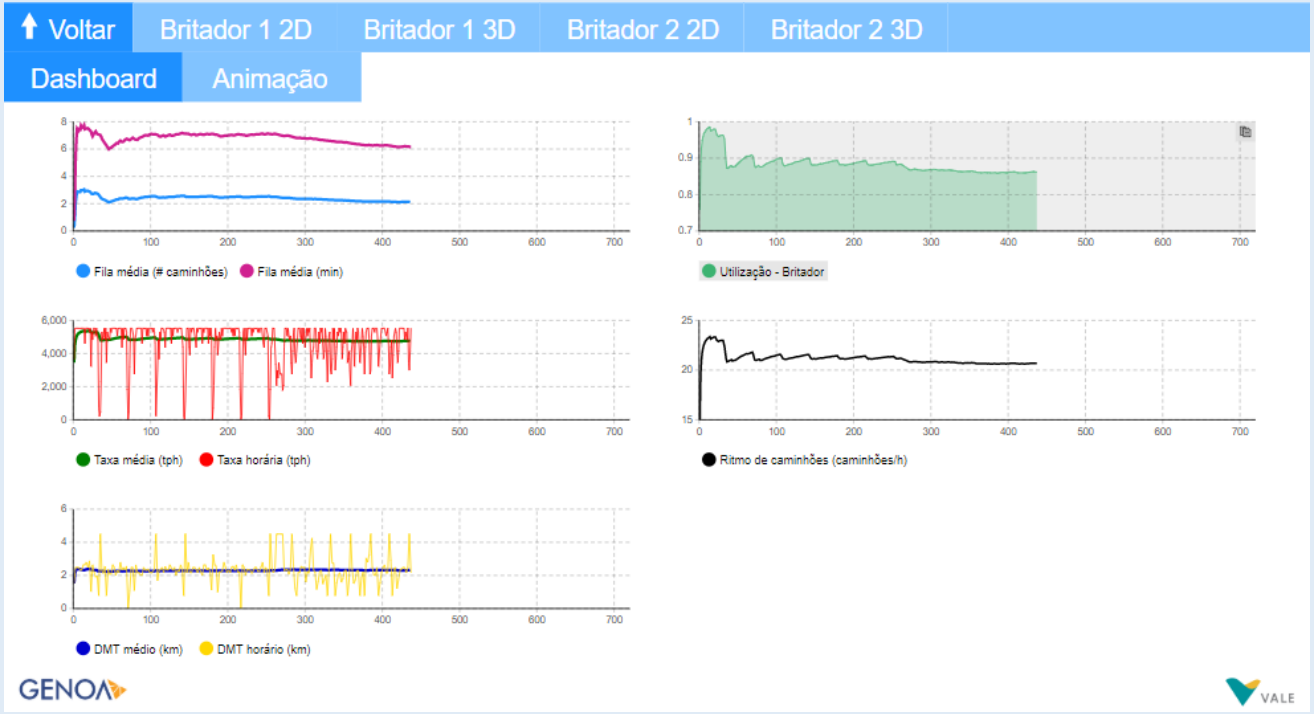
```
x[0][10][1] = 350000
x[0][10][2] = 350000
x[1][10][1] = 200000
x[1][10][2] = 200000
x[2][10][1] = 150000
x[2][10][2] = 50000
x[3][11][8] = 546238
x[4][11][4] = 300000
x[4][11][8] = 253761
x[6][10][1] = 600000
x[7][10][2] = 700000
x[8][11][4] = 1000000
x[9][11][8] = 500000
x[13][15][12] = 1435199
x[14][15][12] = 1528800
```

```
Status: OPTIMAL

função objetivo: 1.04E7
```

Results

Crusher KPIs



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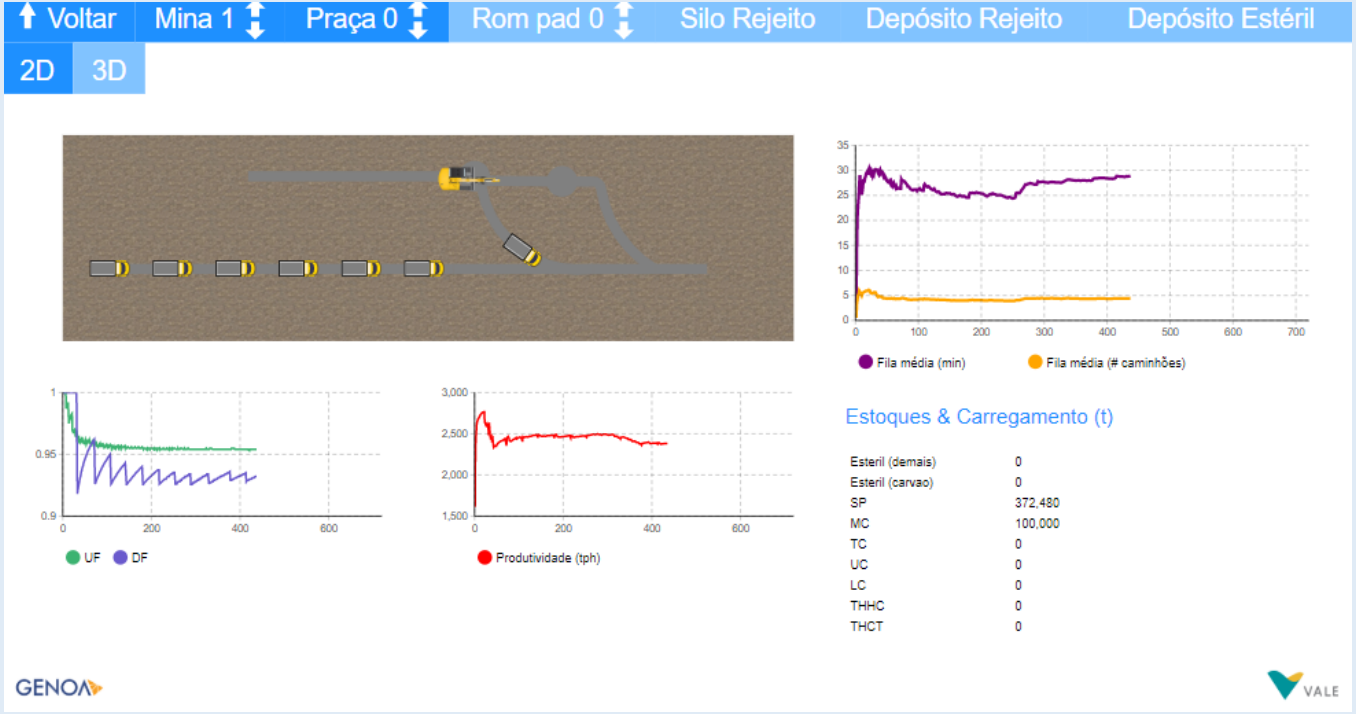
Results

Mining fronts KPIs



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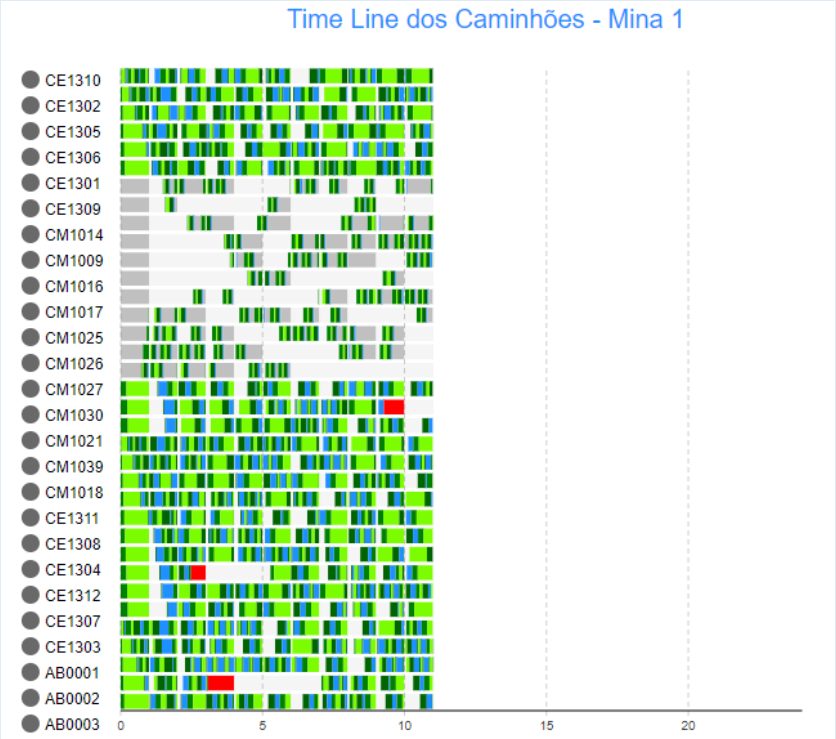
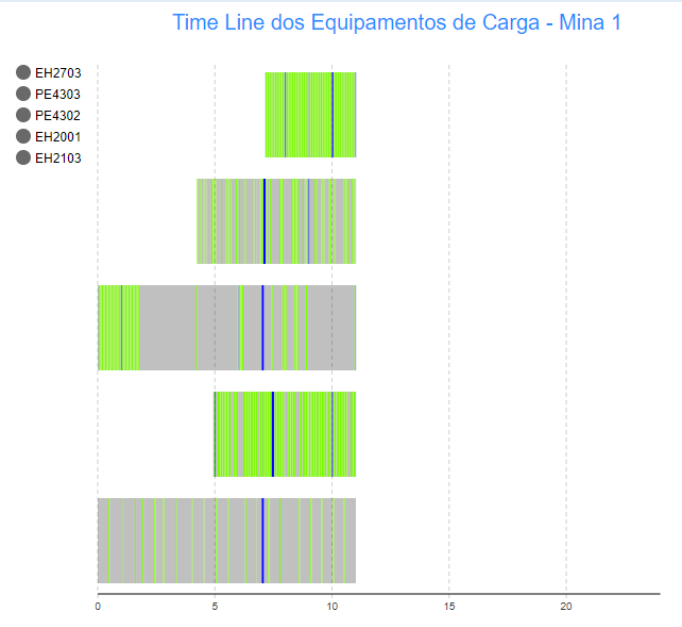
Results

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**

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Teams

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THANK YOU!

Na terminologia ná enoa" ou "**Genoa**" é situada à proa da é ao mastro vertical.

A contribuição da ra um veleiro é uma me do nosso papel a **Genoa** interage com a **V Grande**, melho to de ar entre as duas velas permitindo qu elocidades cada vez maiores.

É assim que : acelerando o seu negócio!

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