



# Optimization and Simulation Model for a Coal Mine



Authors:

Augusto Pereira - Genoa

Ricardo Pereira - VALE

Patryck Silva - VALE





GENOVA 

The word "GENOVA" is written in a light blue, sans-serif font. To the right of the text is a graphic element consisting of several white triangles of varying sizes, arranged to form a larger, abstract shape that resembles a stylized 'A' or a sail.



GENOA 



motivation

# The problem

## Description

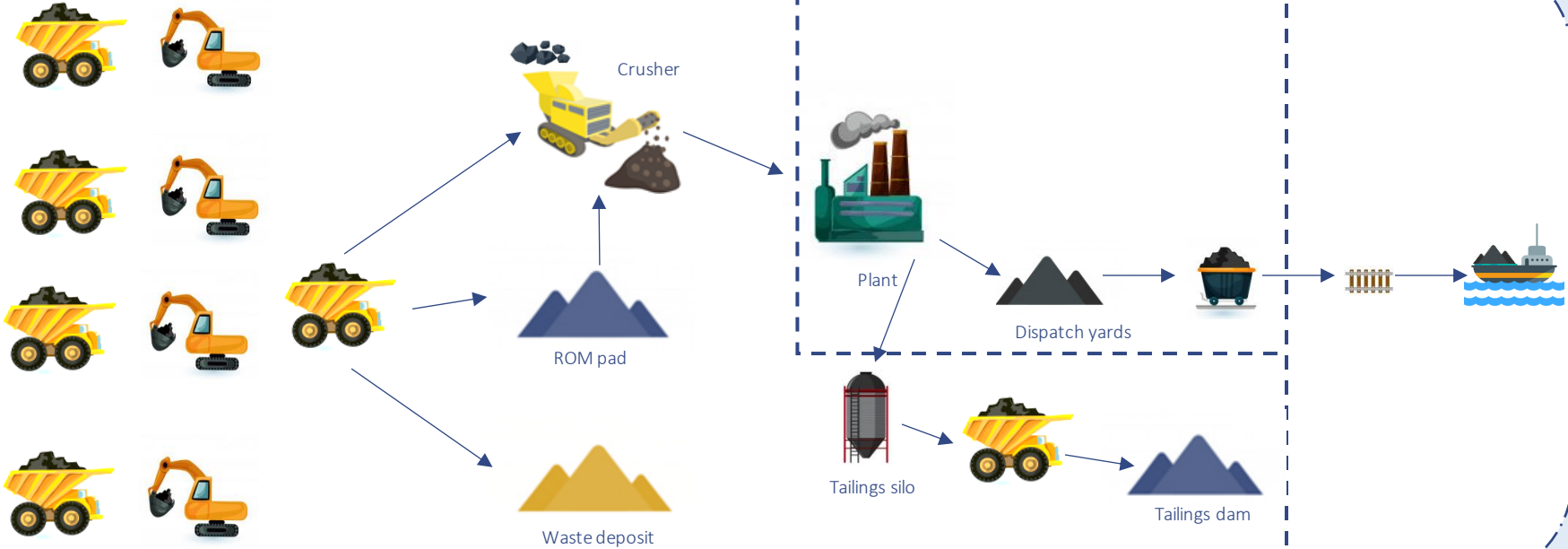
- The studied system encompasses two open pits mines located in Moatize/Mozambique and managed by Vale S.A.
- Each mine contains mining fronts from where many varieties of coal (named *plys*) can be retrieved. Moreover, those sites also contain waste, a material that, regardless of having no financial 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

Scope for this presentation

Mining fronts



Project frontier

# 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



GENOVA 

The word "GENOVA" is written in a light blue, sans-serif font. To the right of the text is a graphic element consisting of several light blue triangles of varying sizes, arranged to form a larger, abstract shape that resembles a stylized 'A' or a sail.



GENOA 

The word "GENOA" is written in a light blue, sans-serif font. To its right is a graphic element consisting of several light blue triangles of varying sizes, arranged to form a larger, abstract shape.

our solution

The text "our solution" is centered in the white triangular area at the bottom of the slide, rendered in a light blue, lowercase, sans-serif font.



# 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:

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

- ROM pad mass balance:

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

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

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

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

- 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:

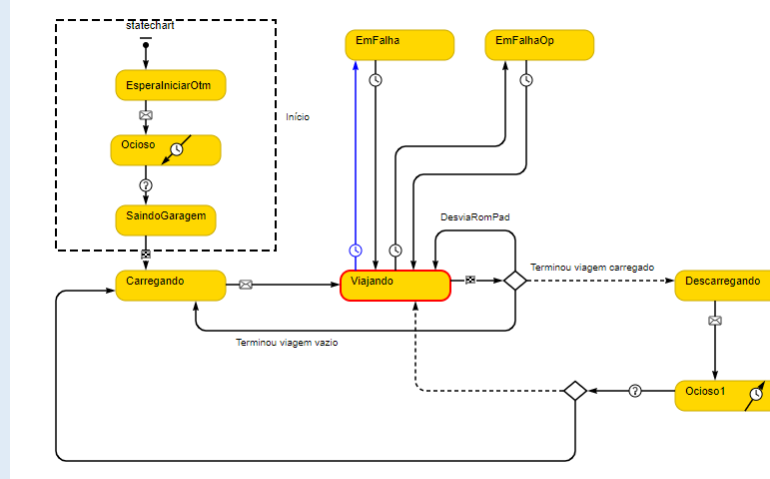
$$\sum_{c \in C} y_{ijc}^k S_c \geq x_{ij}^k, \forall i \in I, j \in J$$

- Mass balance in the nodes:

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

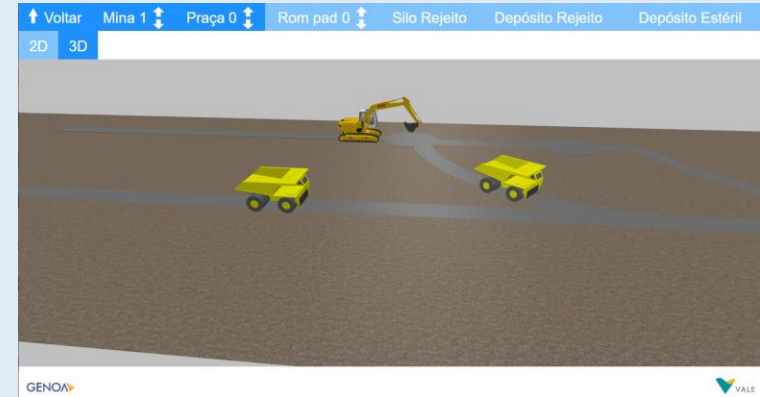
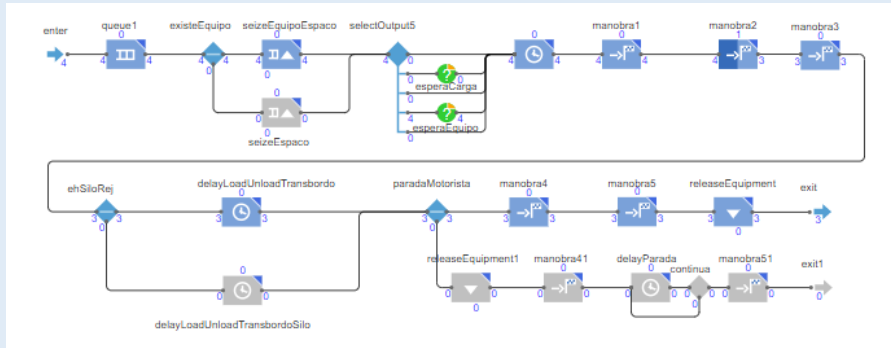
# Why AnyLogic?

- 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:





GENOVA 

The word "GENOVA" is written in a light blue, sans-serif font. To the right of the text is a graphic element consisting of several white triangles of varying sizes, arranged to form a larger, abstract shape that resembles a stylized 'A' or a sail.



GENOA 

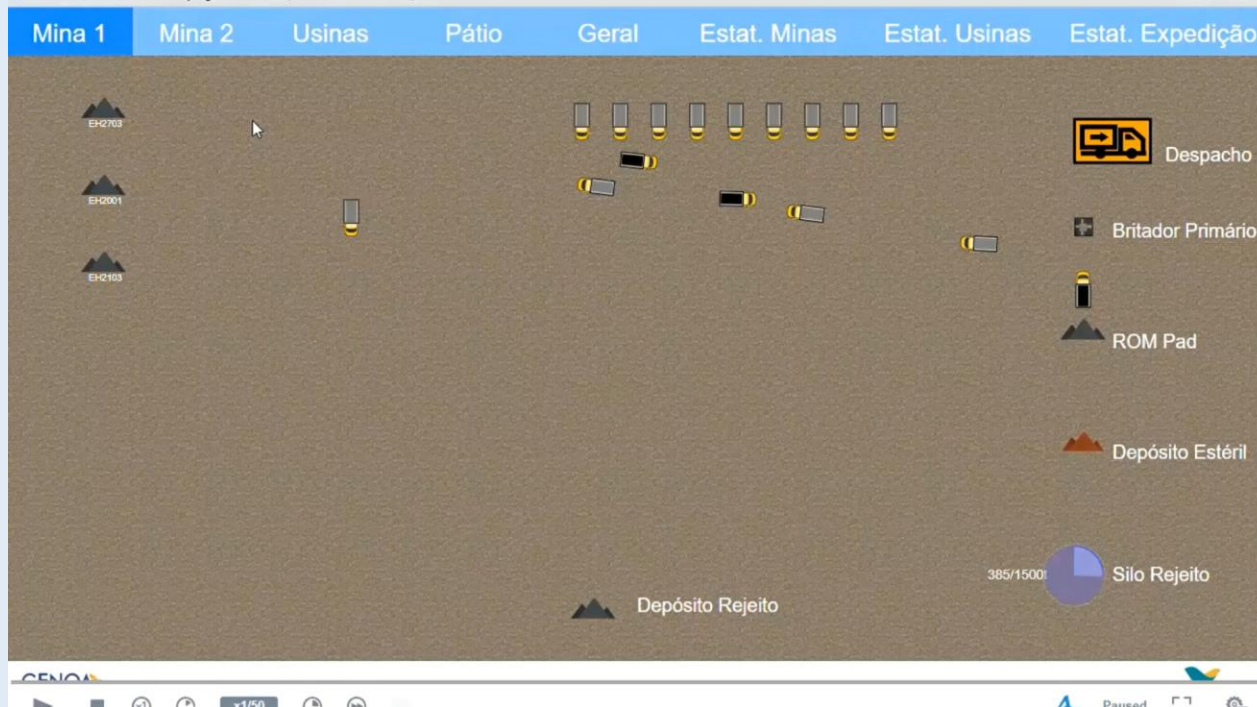
The word "GENOA" is written in a bold, blue, sans-serif font. To the right of the text is a graphic element consisting of several overlapping, semi-transparent triangles that form a larger, abstract shape pointing to the right.

results

The word "results" is written in a blue, sans-serif font, centered within a white triangular area that points towards the right.

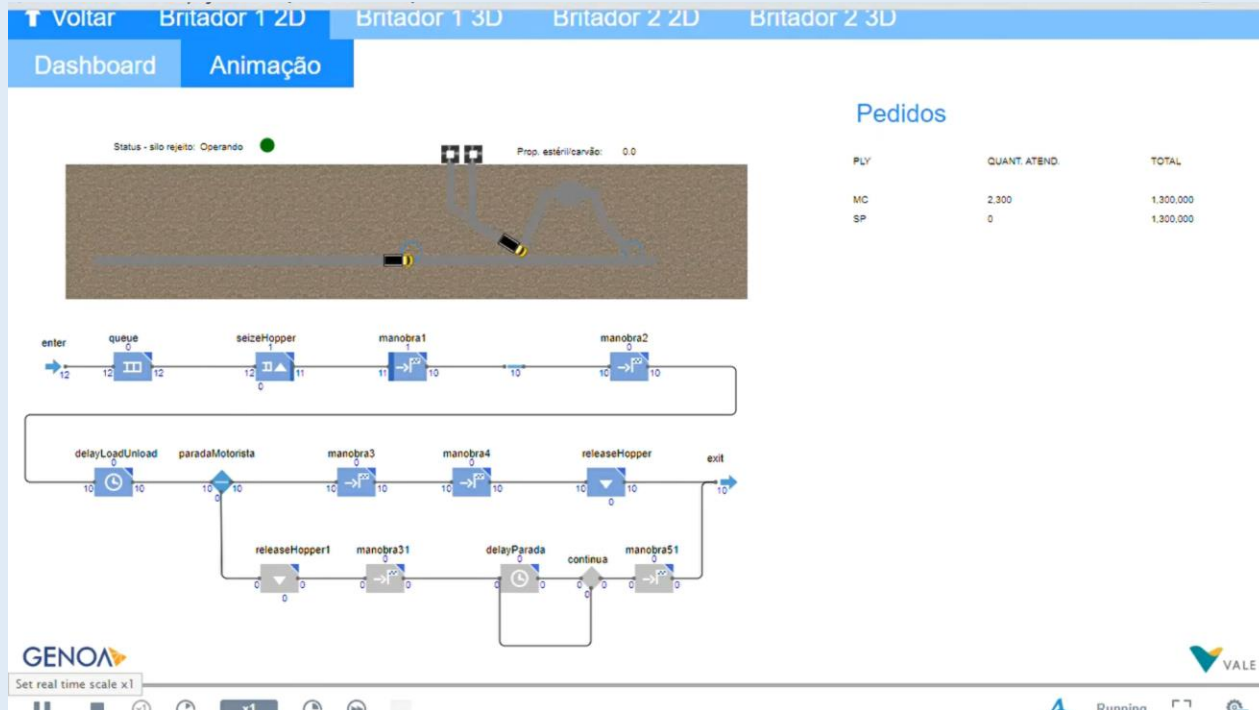
# AnyLogic Model

Trucks travelling through mine



# AnyLogic Model

## Crusher





# AnyLogic Model

## Mining front



# Results

## Optimizer output

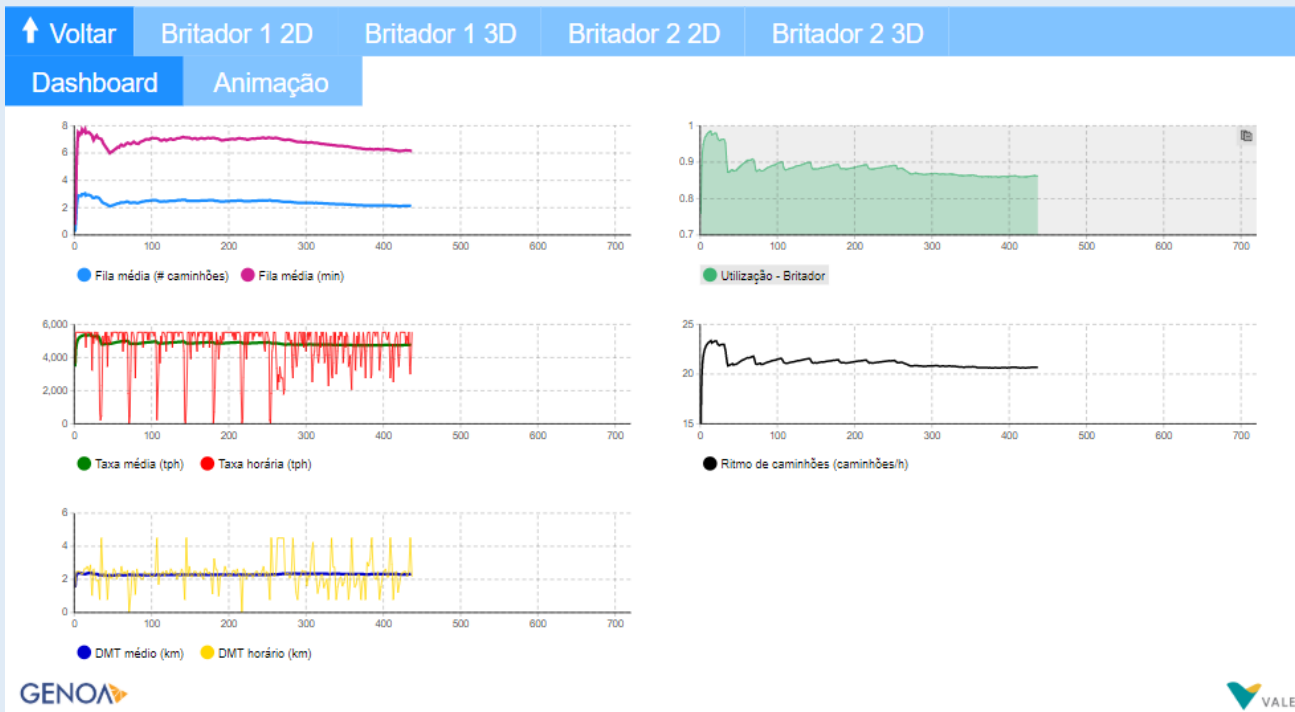
```
x[0][10][1] = 350000
x[0][10][2] = 350000
x[1][10][1] = 200000
x[1][10][2] = 200000
x[2][10][1] = 150000
x[2][10][2] = 50000
x[3][11][8] = 546238
x[4][11][4] = 300000
x[4][11][8] = 253761
x[6][10][1] = 600000
x[7][10][2] = 700000
x[8][11][4] = 1000000
x[9][11][8] = 500000
x[13][15][12] = 1435199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

Status: OPTIMAL

função objetivo: 1.04E7
```

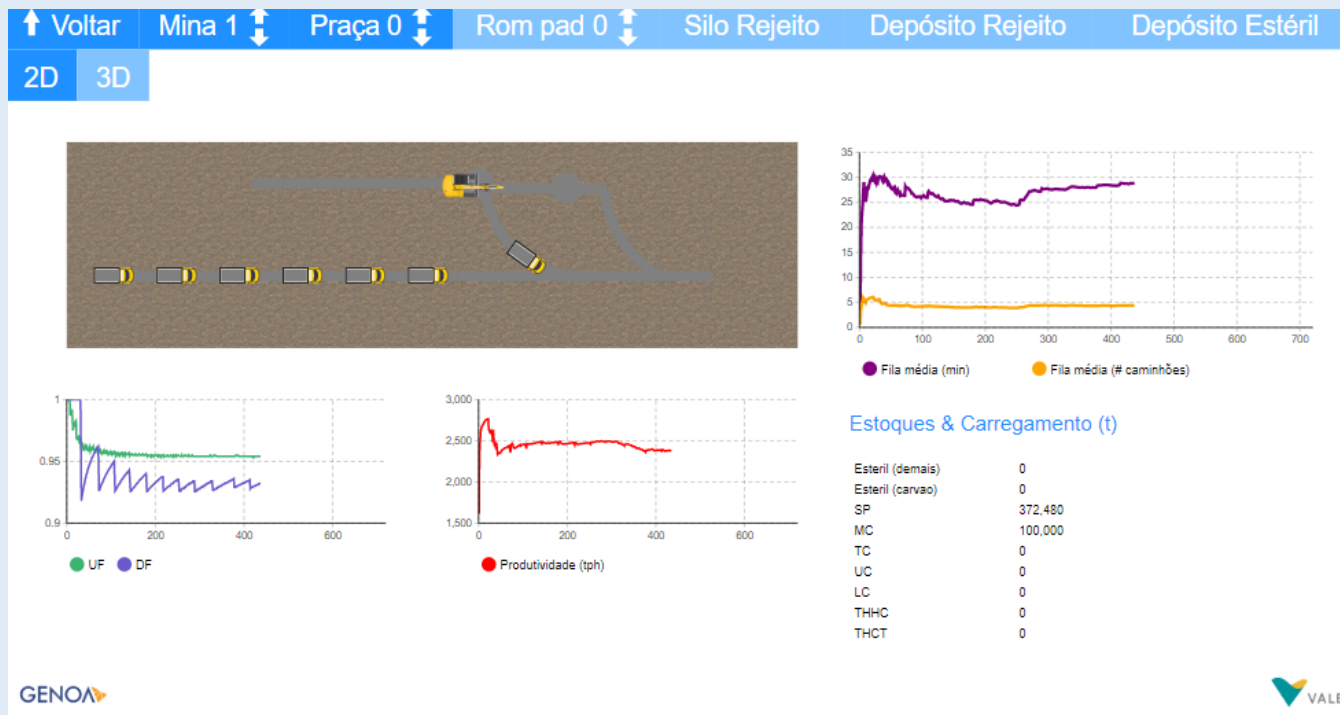
# Results

## Crusher KPIs



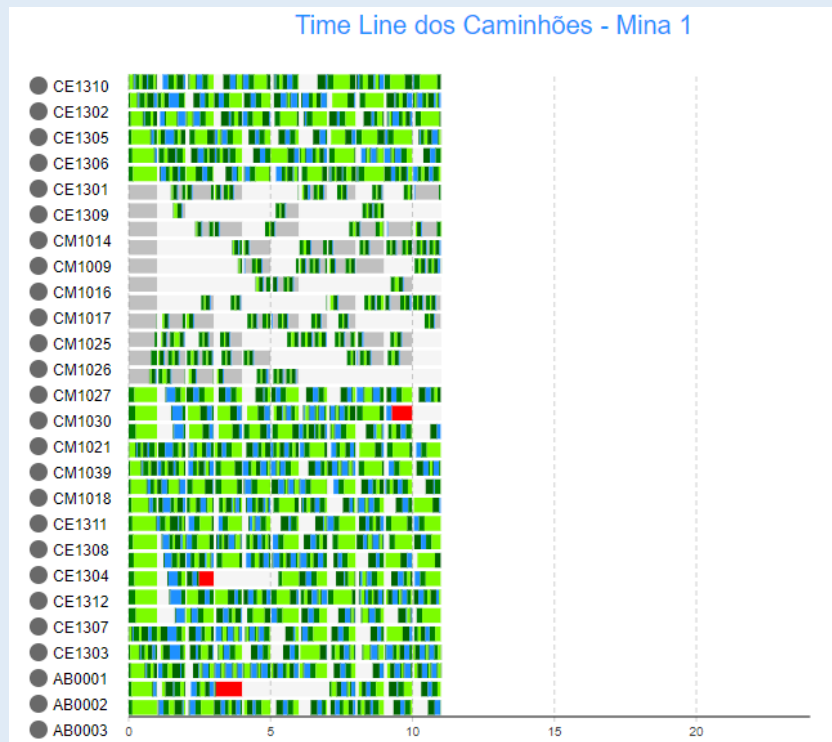
# Results

## Mining fronts KPIs



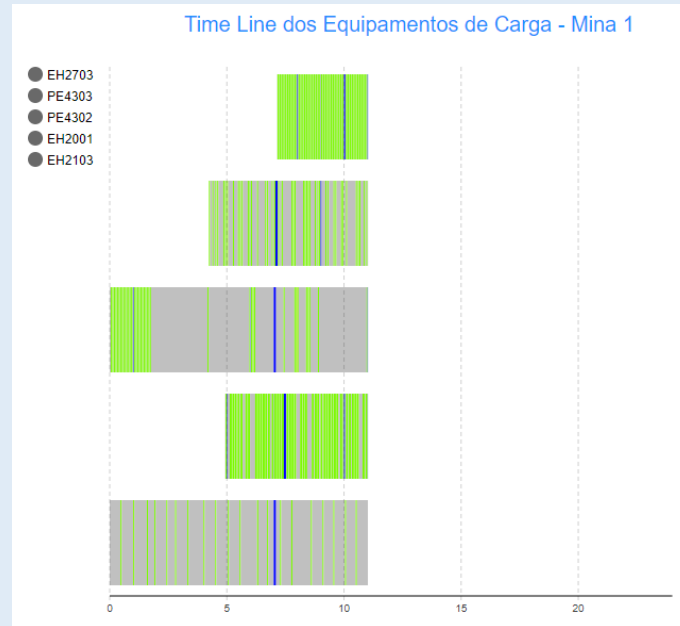
# Results

## 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

## Genoa

Augusto Pereira

[augusto.pereira@genoads.com.br](mailto:augusto.pereira@genoads.com.br)

Karen Kimura

[karen.kimura@genoads.com.br](mailto:karen.kimura@genoads.com.br)

Jonathan Carvalho

[jonathan.carvalho@genoads.com.br](mailto:jonathan.carvalho@genoads.com.br)

Renata Rodrigues

[renata.rodrigues@genoads.com.br](mailto:renata.rodrigues@genoads.com.br)

Afonso Medina (coord.)

[afonso.medina@genoads.com.br](mailto:afonso.medina@genoads.com.br)

## VALE

Ricardo Pereira

[ricardo.pereira1@vale.com](mailto:ricardo.pereira1@vale.com)

Patryck Silva

[patryck.giovani@vale.com](mailto:patryck.giovani@vale.com)







GENOVA 





GENOA 



# THANK YOU!

[www.genoads.com.br](http://www.genoads.com.br)  
[contato@genoads.com.br](mailto:contato@genoads.com.br)  
+55 (11) 3032 6742

Na terminologia náutica, o **Genoa** ou **"Genoa"** é a vela situada à proa da embarcação e ao mastro vertical.

A contribuição da **Genoa** para um veleiro é uma melhoria do nosso papel. A **Genoa** interage com a **Vela Grande**, melhorando o fluxo de ar entre as duas velas, permitindo que o veleiro alcance velocidades cada vez maiores.

É assim que o **Genoa** acelera o seu negócio!