VALE

Enhancing Mining Efficiency through Simulation: Case Studies in Material Handling and Autonomous Transport

Photo : 9Dstudio

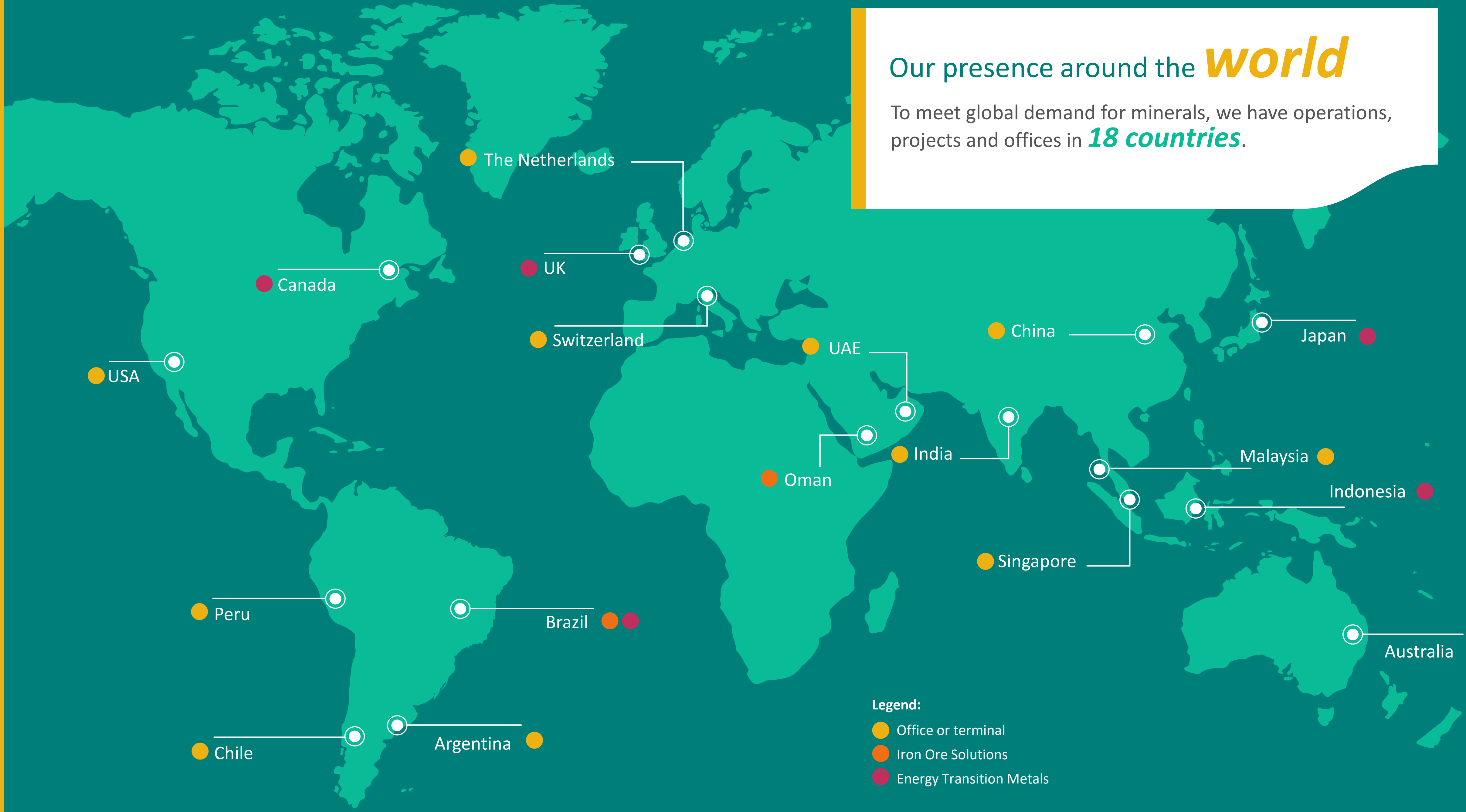
Our *business*

We are among the world's largest producers of ***iron ore*** and ***nickel***. We are also a major ***copper*** producer and have ***gold, silver and cobalt*** operations.

Bruna Brito and Luciano Grázzia in Congonhas, Minas Gerais, Brazil
Photo: Leo Lopes

Our presence around the *world*

To meet global demand for minerals, we have operations, projects and offices in ***18 countries***.



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1. Cases Overview

Case 1

- This study analyzes the current capacity of the ore transportation system between the mines and the beneficiation plant, focusing on identifying bottlenecks that limit its ability to meet the new demand.
- Based on this assessment, improvement and repowering alternatives are evaluated to support investment decisions that ensure operational efficiency and sustainable expansion.

Case 2

- This study evaluates the logistical feasibility of transporting 58.6 Mt of waste and tailings using autonomous 240-ton trucks via a new dedicated access road.
- The analysis focuses on this new access route, examining its capacity to meet the production plan under varying weather conditions (dry/rainy) and considering operational stoppages inherent to the process.

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2. Why we choose AnyLogic?

- Comprehensive Libraries for Specialized Domains: Offers robust libraries tailored to key areas such as fluid dynamics, rail systems, highways, and material handling, enabling efficient and accurate system modeling.
- Reusable Agent Architecture: Supports the development of modular agents that can be easily reused across different models, a capability rarely found in other simulation platforms.
- Intuitive and Powerful State Chart Functionality: Provides a versatile state chart feature that allows precise control over agent behavior and activity flow, enhancing model flexibility and clarity.
- Highly Customizable with Java Integration: Delivers a flexible simulation environment with extensive customization options through native Java support, empowering advanced users to tailor models to specific needs.
- Efficient Experimentation and Parallel Execution: Enables fast and reliable execution of experiments, including support for parallel evaluations, significantly accelerating scenario testing and decision-making.

3. Performance evaluation of an iron ore handling and transportation system

3.1. Problem Overview

- Vargem Grande is a major mining complex located in Minas Gerais, Brazil, responsible for producing approximately 40 Mt of iron ore annually.
- The complex comprises two open-pit mines, two crushing stations, a homogenization yard, a processing plant, and over 30 km of conveyor belts connecting those facilities;
- Run-of-mine (ROM) ore is initially processed at the crushing stations before being sent to the homogenization yard, where it is blended to ensure consistent feed quality for the processing plant, ultimately resulting in the final product.

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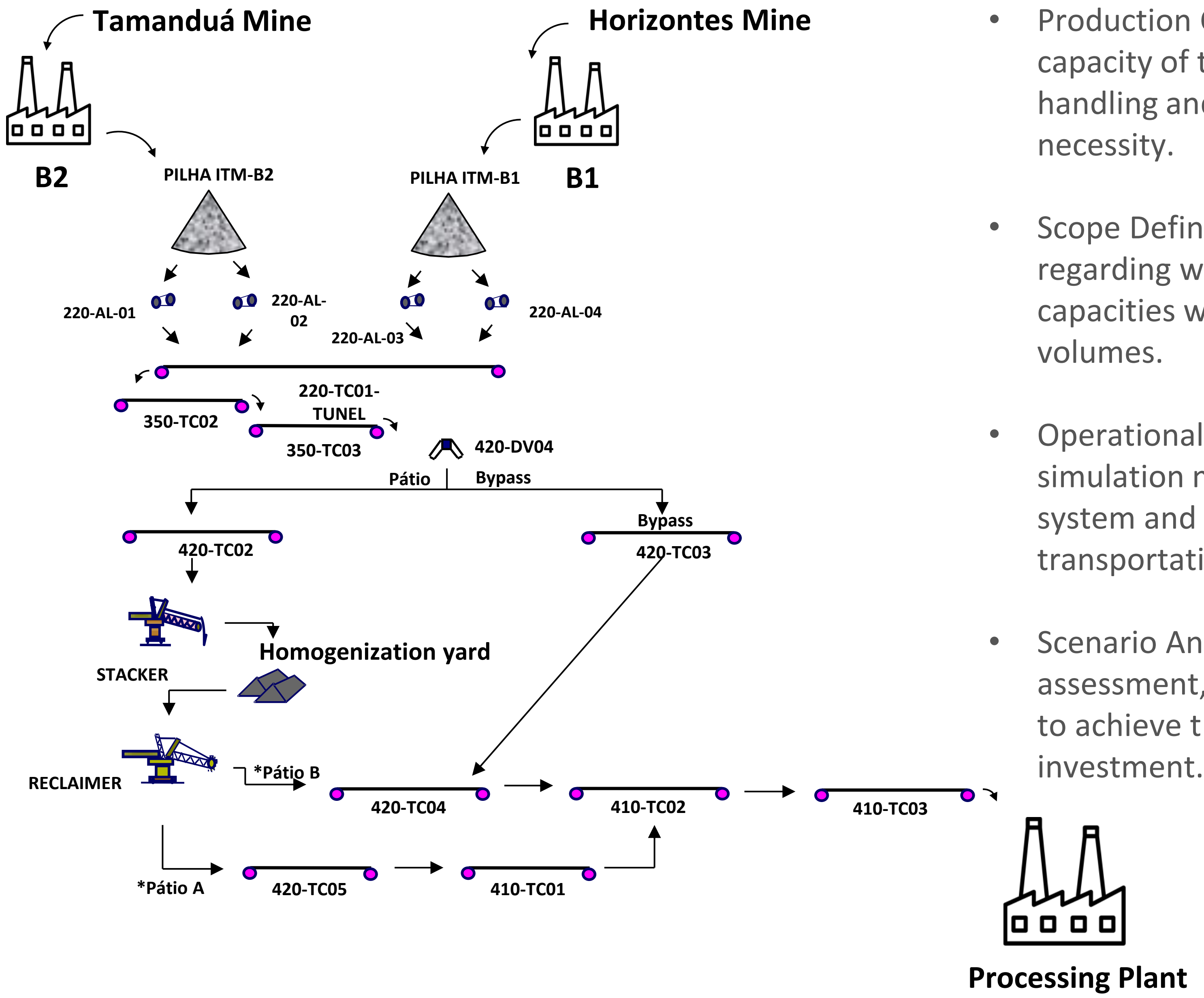
3.1. Problem Overview



- Production Capacity Expansion: To support the increased capacity of the processing plant, repowering the ROM handling and transportation system became a strategic necessity.

- Scope Definition Challenges: There were uncertainties regarding which assets required repowering and what new capacities would be needed to handle the higher ROM volumes.

- Operational Modeling and Bottleneck Identification: A simulation model was developed to represent the current system and accurately identify the bottlenecks limiting transportation capacity.

- Scenario Analysis and Investment Optimization: Based on this assessment, multiple repowering scenarios were simulated to achieve the required capacity with the lowest possible investment.

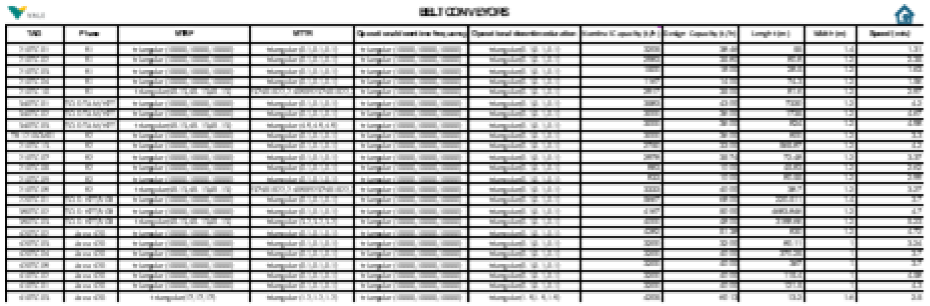
3.2. Data Collection

- System Composition: The system under analysis consists of 67 operational assets, including feeders, crushers, screens, conveyor belts, silos, stockpiles, stackers, and reclaimers—forming an integrated ROM handling and transportation network.

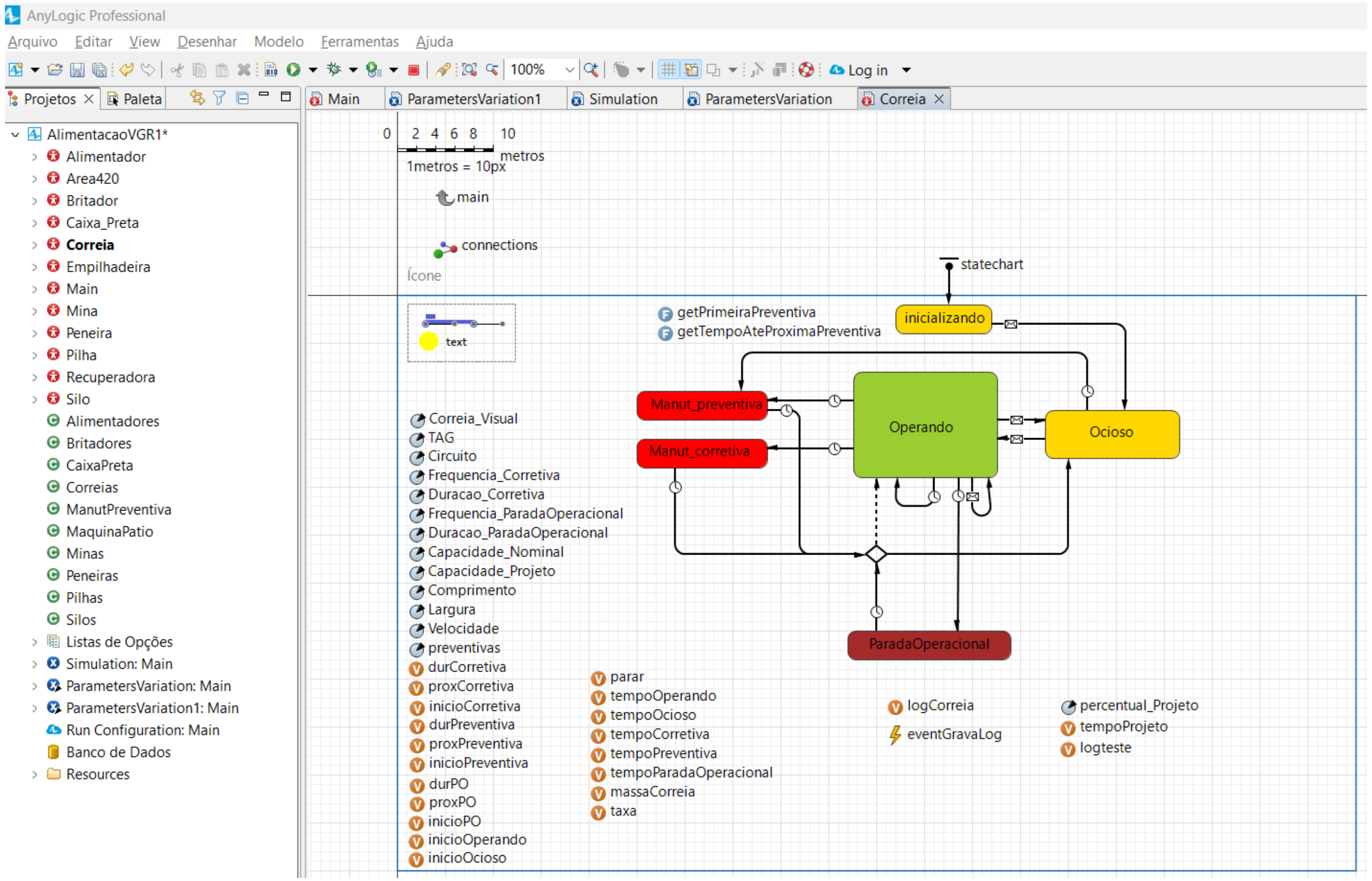
- Operational Data Collection: For each asset, key information was gathered: TAG, nominal and design capacity, frequency and duration of corrective maintenance and operational stoppages (e.g., blockages, overloads), as well as the preventive maintenance schedule.

- Simulation Interface and Scenario Testing: A Microsoft Excel-based interface was developed to streamline data input into the simulation model, enabling agile creation and testing of scenarios with updated capacity configurations.

Details – Belt Conveyors

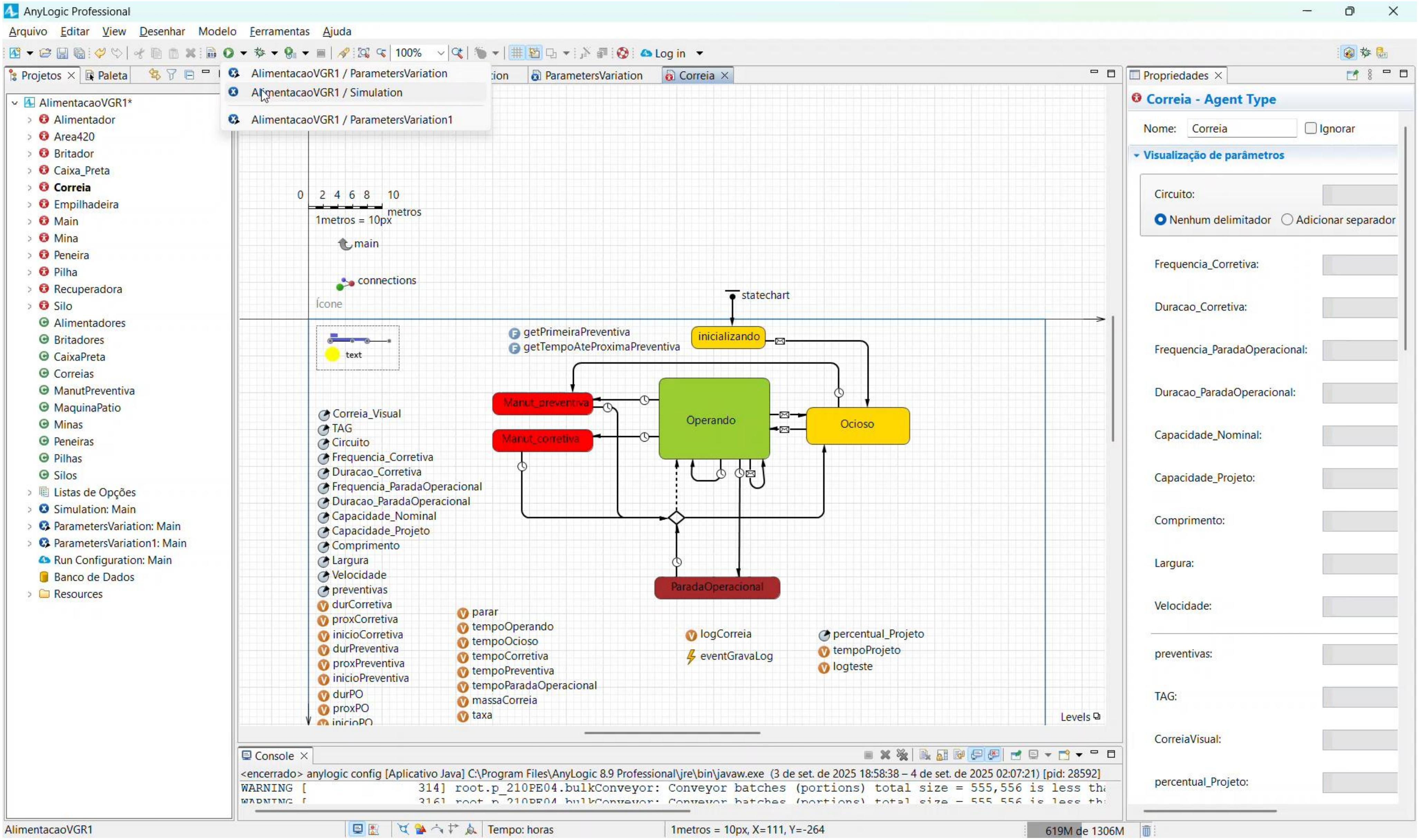


3.3. Modeling



- Asset-Specific Agent Modeling: A dedicated agent was developed for each asset category, accurately representing its operational behavior within the system.
- Operational Status Management via State Charts: The state chart functionality was used to manage asset statuses (idle, operating, under corrective maintenance, etc.), with clearly defined transition rules. This approach streamlined time tracking and KPI calculation.
- Dynamic Capacity Logic: Logical structures were implemented to allow assets to reach their maximum design capacity during periods of high demand, enhancing the realism and responsiveness of the simulation.
- Agent Interconnection and Realistic System Representation: The integration of agents and their respective status transitions enabled a highly accurate representation of the system's real-world operation.

3.3. Modeling



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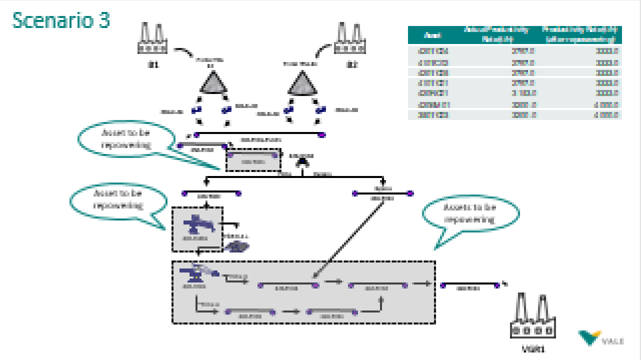
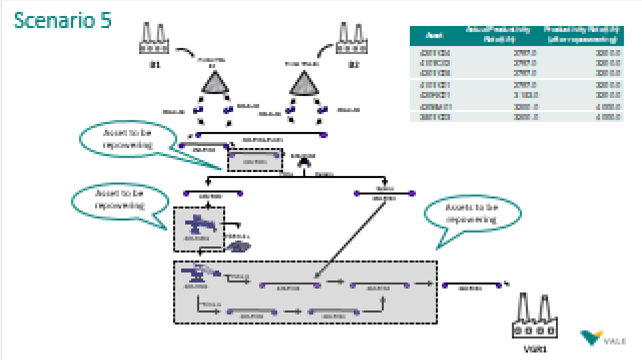
3.4. Results

- Twelve distinct scenarios were analyzed, each with different intervention configurations, aiming to achieve the new annual handling capacity target.
- For each scenario, a one-year operational period was simulated, with 10 replications to ensure robustness of the results.
- Among the evaluated scenarios, only two reached the desired handling level. The selected scenario was the one that met the target with the lowest implementation cost.
- The next step is to develop a comprehensive model of the beneficiation plant, capturing its key stages and operational parameters to support integrated planning and decision-making.
- Integrate the entire production chain, connecting the models of mining, transportation, handling, and mineral processing, aiming for a systemic and optimized view of the operation.





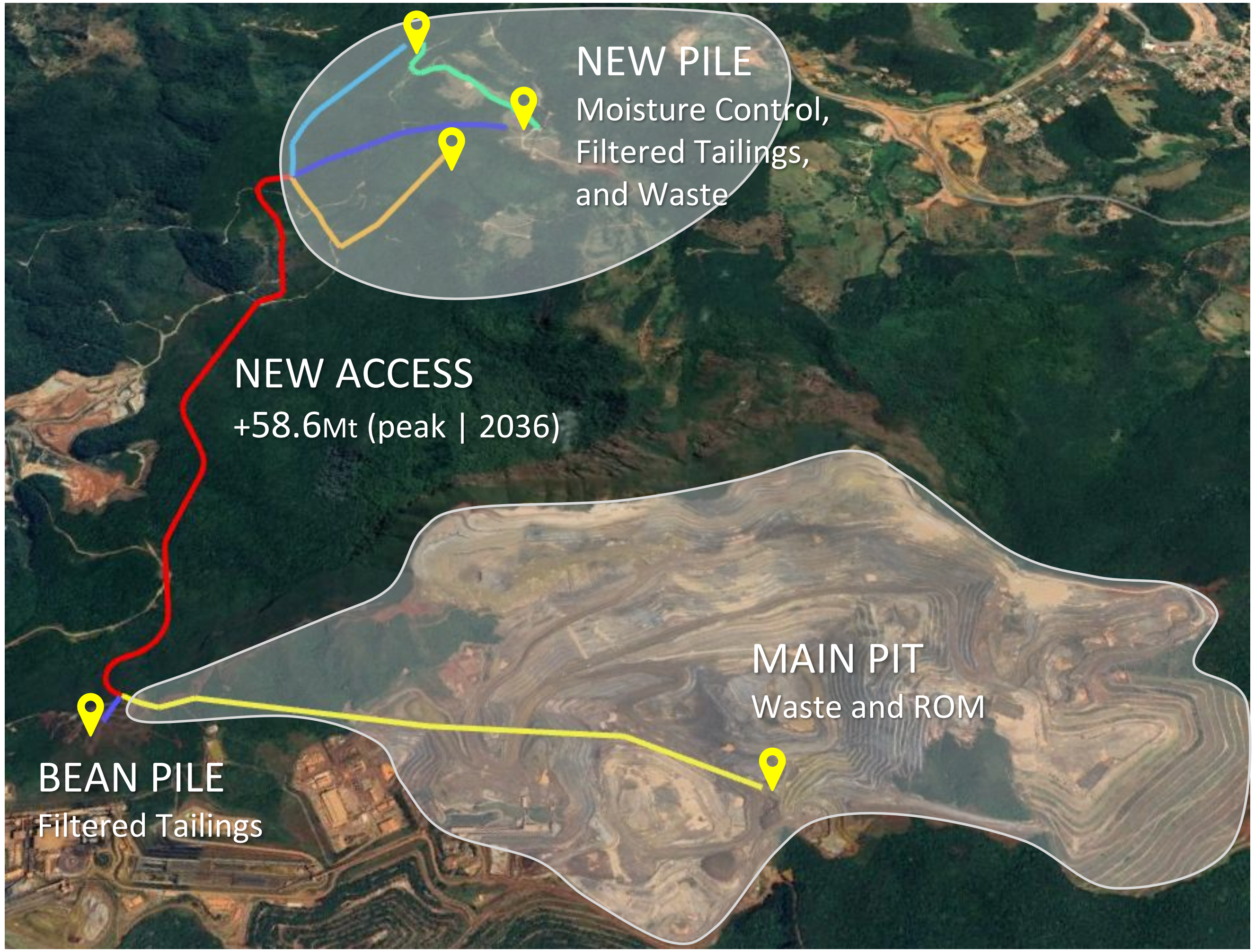
Asset	Scenario 3 *				
	Availability (%)	Utilization (%)	Utilization Rate (%)	Productivity Rate (t/h)	Capacity (Mt)*
B1	87.0%	73.3%	63.8%	1934.4	10.8
B2	86.6%	68.0%	58.9%	2 096.3	10.8
Stacker	87.5%	75.5%	66.1%	3 741.0	21.6
Reclaimer	87.2%	89.0%	77.6%	3 180.7	21.6

Asset	Scenario 5 *				
	Availability (%)	Utilization (%)	Utilization Rate (%)	Productivity Rate (t/h)	Capacity (Mt)
B1	87.0%	71.3%	62.0%	1930.4	10.5
B2	86.6%	66.1%	57.2%	2 092.8	10.5
Stacker	87.5%	73.0%	63.9%	3 753.4	21.0
Reclaimer	87.2%	90.0%	78.5%	3 053.8	21.0

* The data presented in this analysis has been modified to preserve the confidentiality of the original information. These changes do not affect the validity of the conclusions drawn.

4. Dynamic Simulation for Evaluating the Hauling Capacity of a New Access

4.1. Problem Definition



The mine operates 240-ton trucks. The hauled volume is expected to DOUBLE and will be dumped at a NEW PILE using an EXCLUSIVE ACCESS.

EVALUATE

- Impacts related with SEASONALITY (dry x rainy)
- If the TRUCK FLOW on the new access will meet the production plan
- Check the TRUCK SIZE (240-ton x 300-ton)

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4.2. Data Collection

Selection of Key Variables

Identification of the main variables that influence the transportation and maintenance process of autonomous trucks.

Data Collection

Extraction of relevant information directly from the autonomous truck database.

Statistical Processing

Cleaning, organizing, and structuring the data for analysis, considering events such as failures, downtime, and operational time.

- MTBF (Mean Time Between Failures)
- MTTR (Mean Time To Repair)

Curve Fitting and Distribution Generation

Use of Python code to calculate and visualize statistical distributions of events.

4.3. Modeling

The model was developed using road traffic and process libraries, incorporating the following components:

Road Traffic Library: controls vehicle flow with realistic traffic rules (speed, priority, lane changes, restrictions)

+

Process Modeling Library: models process flows and discrete events (queues, services, resources, priorities, scheduling)

=

Integration: vehicles enter the road network, go through operational processes (e.g., loading, unloading), and then return to the traffic flow.

Model

Weather (dry/rainy)

- Seasonality: impact on speed, Minimum distance between vehicles and operational stops.

Roads

- Length
- Grade

AUTONOMOUS TRUCKS

Operational Parameters

- Truck length
- Acceleration/Deceleration
- Speed (loaded/empty) adjusted for road grade and weather conditions

Specific Events

- Signal losses
- Vehicle blockages
- Road blocked
- Obstacles on the track

Additional Operational Events

- Preventive and corrective maintenance
- Refueling

4.3. Modeling

Each autonomous truck is subject to specific events that can stop it on the road, impacting flow and potentially triggering a convoy effect.

Events

Intensified during the rainy season

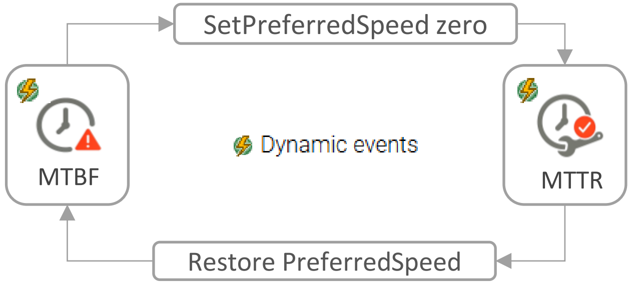
Truck failures + Signal losses + Obstacle detection + Vehicle blockages

Truck Agent

anylogic

Occurrences modeled in the truck agent using dynamic events. When triggered, they set the preferred speed variable to zero, causing the vehicle to stop.

Stop Model truck



Convoy Effect

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4.4. Results

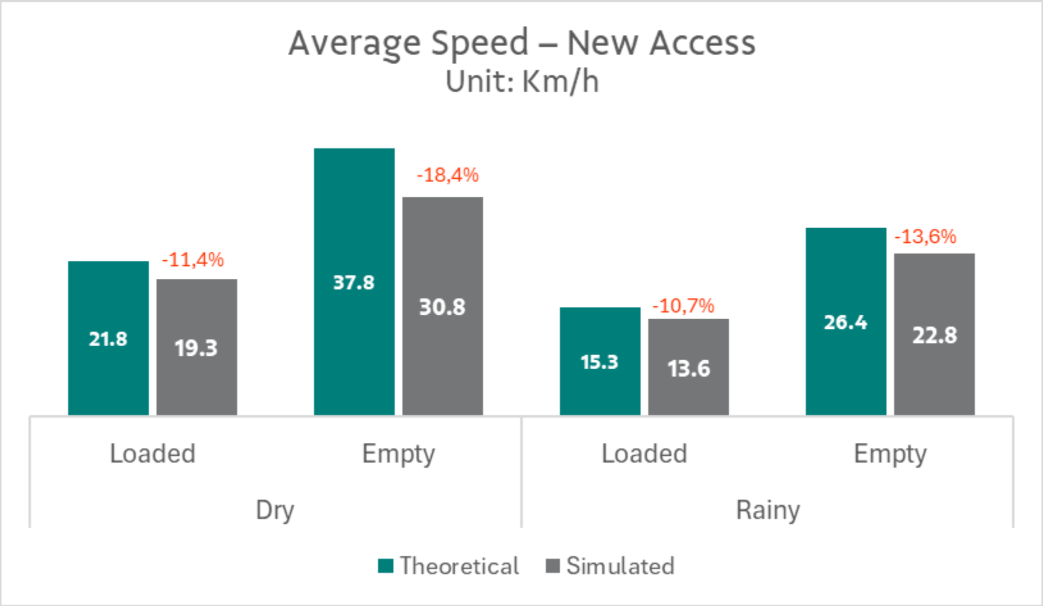
Scenarios were **simulated** for **dry and rainy periods** in the **year** of highest demand **(58.6 Mt)**, with the following results:

Movement achieved: Projected demand met under both seasonal conditions.

Impact on Average Speeds:

- Dry: -11.4% (loaded), -18.4% (empty)
- Rainy: -10.7% (loaded), -13.6% (empty)

Fleet increase: A 10% increase in fleet required due to lower average speed caused by road stoppages.



Strategic Impact: The 240 t truck fleet meets **projected demand** with operational adjustments, avoiding the need for **larger equipment** and major infrastructure works (**mining geometry** and **maintenance workshops**), generating a **positive impact** on **CAPEX**.

Questions?

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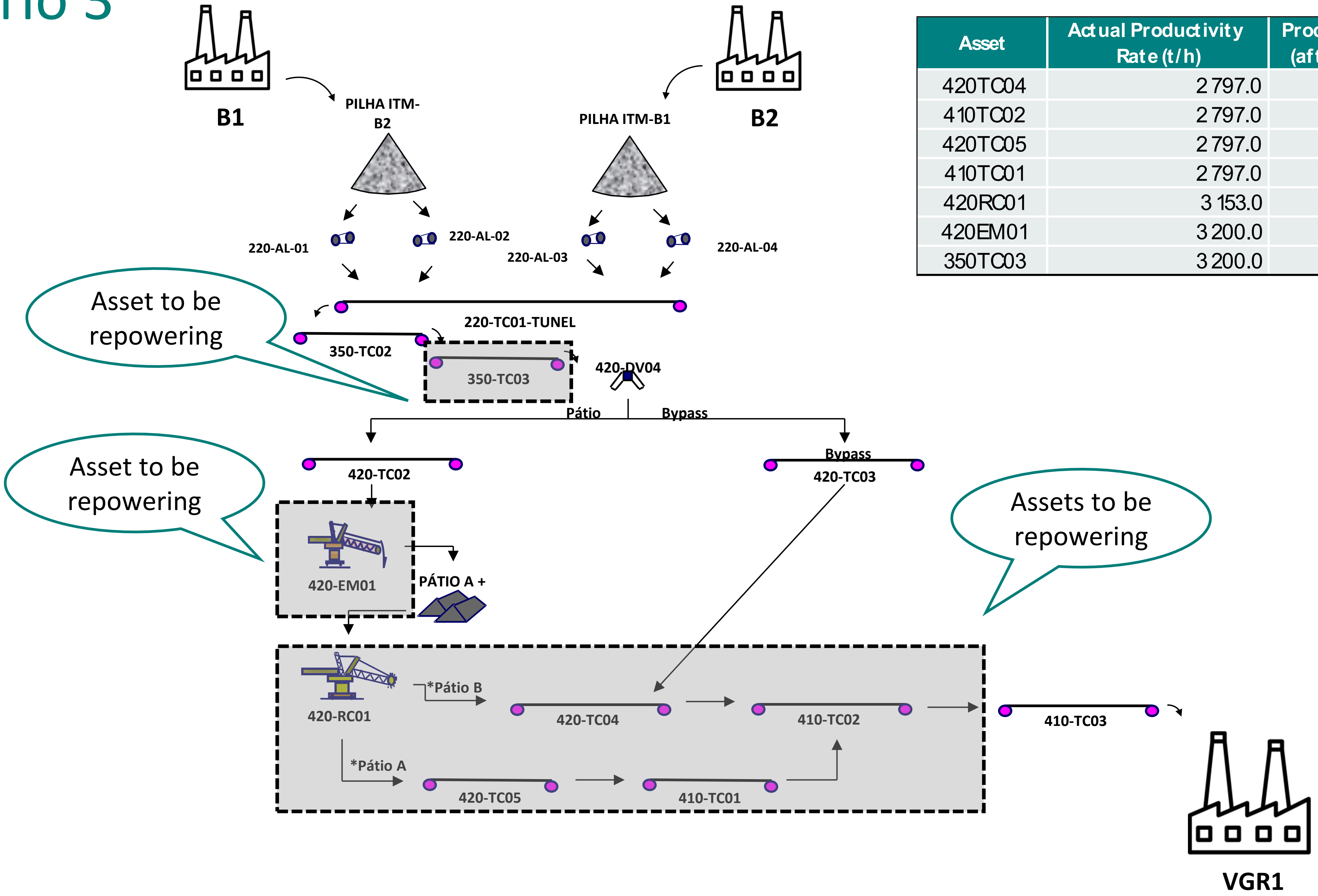
Details – Belt Conveyors

BELT CONVEYORS

TAG	Phase	MTBF	MTTR	Operational downtime frequency	Operational downtime duration	Nominal Capacity (t/h)	Design Capacity (t/h)	Lenght (m)	Width (m)	Speed (m/s)
210TC01	B1	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	3205	3846	55	1.4	1.31
210TC02	B1	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	2983	3580	80.8	1.2	2.35
210TC03	B1	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	1500	1800	28.5	1.2	1.63
210TC04	B1	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	1167	1400	74.3	1.2	1.56
210TC10	B1	triangular(48.13,48.13,48.13)	237481822,2.48589237481822,2	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	2917	3500	81.6	1.2	2.97
340TC01	TCLD TAM/HZT	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	3583	4300	7330	1.2	4.2
340TC02	TCLD TAM/HZT	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	3000	3600	1735	1.2	4.67
340TC03	TCLD TAM/HZT	triangular(48.13,48.13,48.13)	triangular(4.5,4.5,4.5)	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	3000	3600	824	1.2	4.98
TR1210CM01	B2	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	3000	3600	800	1.2	3.3
210TC13	B2	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	2750	3300	565.87	1.2	4.2
210TC07	B2	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	2978	3574	72.48	1.2	3.37
210TC08	B2	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	883	1000	45.83	1.2	2.62
210TC09	B2	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	833	1000	80.55	1.2	2.99
210TC05	B2	triangular(48.13,48.13,48.13)	237481822,2.48589237481822,2	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	3333	4000	38.7	1.2	3.27
220TC01	TCLD HZT/VGR	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	5667	6800	220.511	1.4	3.7
350TC02	TCLD HZT/VGR	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	4167	5000	4683.846	1.2	4.7
350TC03	TCLD HZT/VGR	triangular(48.13,48.13,48.13)	triangular(3.2,3.2,3.2)	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	4000	4800	3188.66	1.2	5.23
420TC02	Área 420	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	4282	5138	830	1.2	4.72
420TC03	Área 420	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	3200	3200	80.11	1	3.24
420TC04	Área 420	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	3200	4000	370.25	1	3.7
420TC05	Área 420	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	3200	4000	367	1	3.7
410TC02	Área 420	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	3200	4000	115.4	1	4.58
410TC01	Área 420	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	triangular(10000,10000,10000)	triangular(0.1,0.1,0.1)	3200	4000	121.5	1	4.3
410TC03	Área 420	triangular(17,17,17)	triangular(1.2,1.2,1.2)	triangular(10000,10000,10000)	triangular(1.5,1.5,1.5)	4205	6013	13.2	1.6	2.5

Scenario 3



Asset	Actual Productivity Rate (t/h)	Productivity Rate (t/h) (after repowerering)
420TC04	2 797.0	3 333.0
410TC02	2 797.0	3 333.0
420TC05	2 797.0	3 333.0
410TC01	2 797.0	3 333.0
420RC01	3 153.0	3 333.0
420EM01	3 200.0	4 000.0
350TC03	3 200.0	4 000.0

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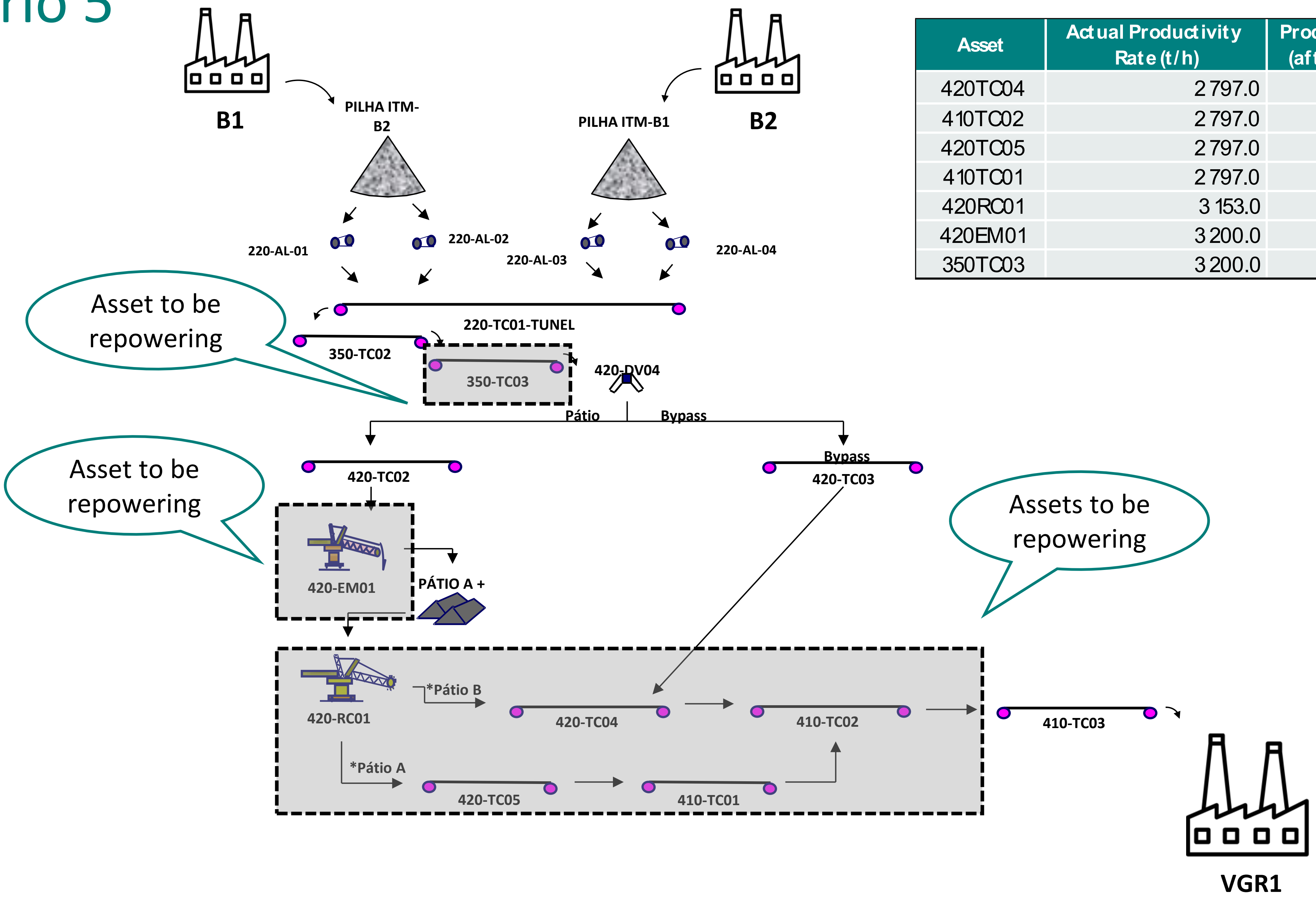
Scenario 5



Asset	Actual Productivity Rate (t/h)	Productivity Rate (t/h) (after repowering)
420TC04	2 797.0	3 200.0
410TC02	2 797.0	3 200.0
420TC05	2 797.0	3 200.0
410TC01	2 797.0	3 200.0
420RC01	3 153.0	3 200.0
420EM01	3 200.0	4 000.0
350TC03	3 200.0	4 000.0

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