

Yard Machine Automation – Hydro Paragominas Autonomous Yard

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Abstract

Yard machinery automation refers to the application of advanced technologies to optimize the operation of equipment such as reclaimers and forklifts in industrial and mining environments. At Hydro's Paragominas Mining site, a forklift and a reclaimer operate in the homogenization yard with a nominal capacity of 2 695 t/h, ensuring a continuous and stable ore supply to the plant's feed silos. The project was initiated to address limitations in manual operation, including low process standardization and inconsistencies in pile formation, which compromised material homogeneity and steady feed flow. Shift changes were performed directly on the machines, often in isolation, disrupting operational continuity. The adopted solution involved the implementation of an advanced control system integrating several technologies: GPS for precise machine tracking, 3D laser scanners for digital pile mapping, 360-degree radars and ultrasonic sensors for collision prevention, and high-definition mobile cameras for remote supervision from the plant's control room. Machine Learning was applied to the reclaimer's mass estimator, improving the accuracy of ore dosing. The initiative resulted in higher productivity, better pile standardization, more consistent feed rates, lower operational costs, and enhanced safety. Hydro Paragominas thus positions itself as a Mining 4.0 reference, advancing toward safer, more efficient, and sustainable operations.

Keywords: Automation, Autonomous Yard, Control, Machine Learning, Bauxite.

1. Introduction

Bauxite, the primary raw material for aluminium, has followed the trend of increasing demand in aluminium. Between 2019 and 2020, domestic consumption of bauxite in Brazil grew by 10.8 %, while national production increased by 5.9 % over the same period [1]. Currently, the state of Pará accounts for approximately 83 % of Brazil's bauxite production, consolidating its position as a strategic hub for both domestic supply and the international competitiveness of the sector [2, 3].

Norsk Hydro is a global company operating in over 40 countries, with 119 years of history and more than 30 000 employees. The company operates in an integrated manner across the entire aluminium value chain—from bauxite mining to the production, transformation, and recycling of the metal. Recognized for its leadership in sustainability, Hydro invests in the development of so-called green aluminium, characterized by a low carbon footprint, use of renewable energy, and socio-environmental traceability. In Brazil, this value chain is represented by the units Hydro Paragominas (mining), Alunorte (refining), Albras (primary aluminium), and Hydro Extrusion (final products), forming an efficient and sustainable industrial system. Figure 1 presents a macro flowchart of the aluminium production chain.

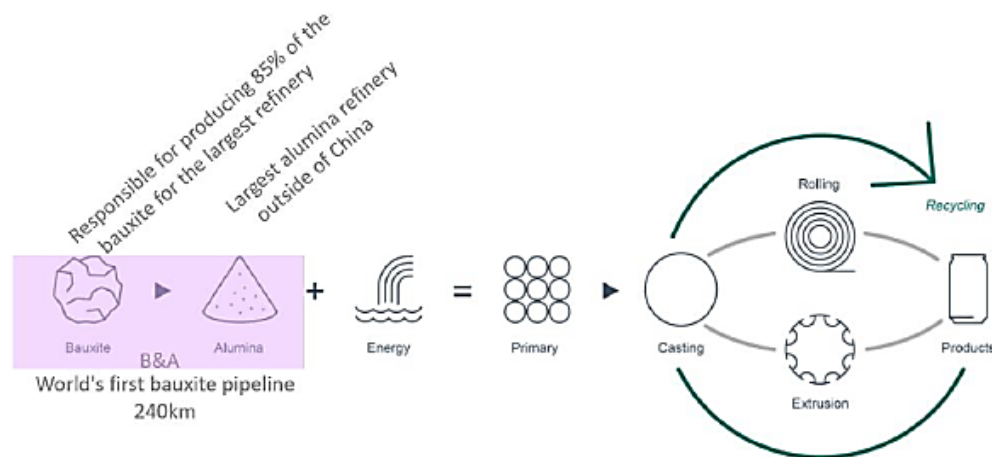


Figure 1. Aluminium Production Chain.

Within this structure, Hydro Paragominas plays a fundamental role, being responsible for the extraction and beneficiation of bauxite in the state of Pará. The unit stands out for its sustainable operational practices and its broad adoption of technology as a competitive advantage [4]. One of the most significant milestones in this process was the implementation of a fully autonomous bauxite homogenization yard – one of the first of its kind in Brazil. Through the complete automation of the stacker and reclaimer, the system began operating without direct human intervention, enhancing operational stability, safety, process standardization, and efficiency in supplying the beneficiation plants [5–7].

This paper presents the automation project that transformed the Hydro Paragominas homogenization yard into an autonomous operating environment, detailing its implementation, the main technical aspects involved, and the positive impacts generated. It serves as a concrete example of how technological innovation can transform traditional mining processes into smarter, safer, and more sustainable operations.

2. Description of the Beneficiation Process at Hydro

After extraction, the bauxite beneficiation process at Hydro Paragominas includes the stages of crushing, grinding, and classification. The crushed bauxite is transported via conveyor belts to the homogenization yard, where it is stockpiled by a stacker. This stage is essential to ensure the chemical and physical uniformity of the ore.

Subsequently, the reclaimer retrieves the material from the stockpiles and feeds it into the grinding system consisting of rod and ball mills, further reducing particle size. The resulting slurry is directed to hydrocyclones for classification: the fine fraction, which is rich in alumina, is forwarded as the final product, while the coarse fraction is recirculated to the grinding stage for further size reduction.

It is worth noting that the tailings are directed to temporary storage areas for drying, and after approximately 60 days, they are returned to previously mined areas [8].

This study focuses on the implementation of automation solutions applied to the bauxite homogenization yard machines (stacker and reclaimer), as well as the tracking system for material position and volume from the crushing stage to the feeding of the plant silos. The objective is to ensure full traceability of the ore and enable operation under the autonomous yard concept.

The automated yard machines include the stacker EP-114-01 and the reclaimer RP-121-01, both equipped with translation, slewing, and lifting movements, as well as an anti-collision system.

The storage yard measures 300 meters in length by 45 meters in width, resulting in a total usable area of approximately 13 500 m².

Figure 2 provides an overview of the homogenization yard, highlighting the designated operational area and identifying the yard machines in operation.



Figure 2. Bauxite homogenization yard at Hydro Paragominas.

3. Yard Machine Automation

The initial phase of implementing the automation system for the yard machines consisted of defining the appropriate instrumentation for the system and its environment, as well as determining the optimal positioning of the instruments on the machines in the field. This step is critical to ensure the accuracy of operational data and the stability of the control system.

3.1 Instrumentation

The instrumentation required for the autonomous operation of the yard machines, along with its detailed description, is presented in Table 1.

Table 1. List of instruments installed on each machine in the homogenization yard.

Stacker (EP-114-01)	Reclaimer (RP-121-01)
1 - GNSS RTK rover receiver with dual antennas	2 - GNSS RTK rover receiver with dual antennas
1 - 3D laser scanner	1 - 3D laser scanner
1 - Radar-type level sensor	2 - 360° radar scanner
1 - 360° radar scanner	4 - Ultrasonic obstacle sensors
3 - Laser-type sensors	4 - IP Cameras
2 - Ultrasonic obstacle sensors	
3 - IP Cameras	

Figure 3 illustrates the arrangement of the instruments described in Table 1, as installed on the stacker. Similarly, Figure 4 presents the configuration of these instruments on the structure of the reclaimer.

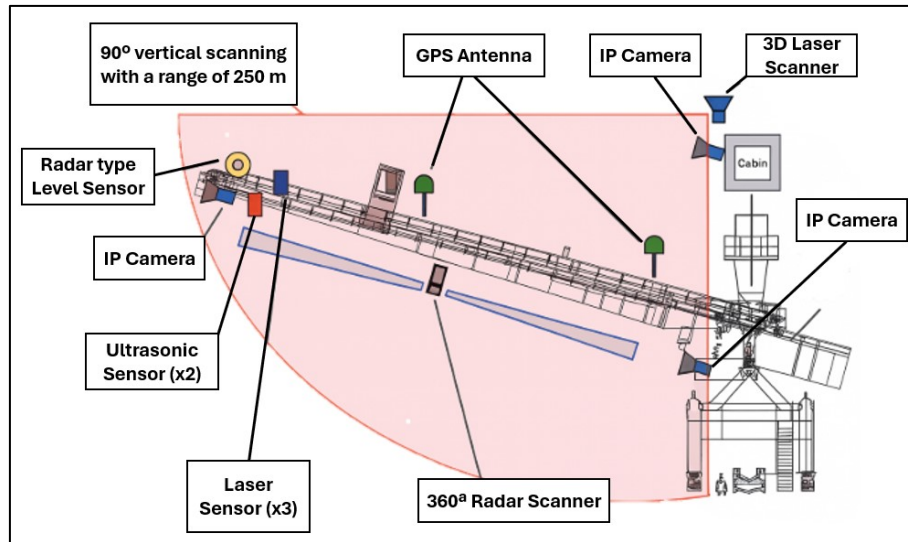


Figure 3. Instrument layout on the stacker – side view

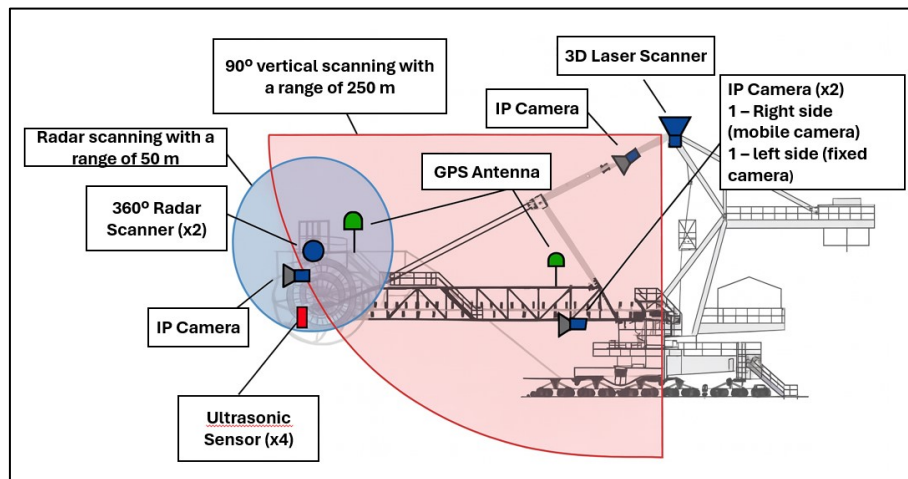


Figure 4. Instrument layout on the reclaimer – side view

In addition to the onboard instrumentation on the machines, a GNSS RTK base station (Global Navigation Satellite System – Real-Time Kinematic) was installed at the substation near the yard. This base receiver transmits real-time differential corrections to the mobile receivers (rovers) installed on the machines, using the RTK (Real-Time Kinematic) technique, which enables high-precision geolocation by correcting the signals received from GNSS satellites.

3.2 Application of Sensors and Devices in Autonomous Control

This section describes the function of each installed instrument, highlighting its role in the autonomous navigation and operation system of the machines.

3.2.1 GNSS Rover Receiver

It is used by the system to determine the georeferenced position of the machine in relation to the yard. The rover receiver implemented in this solution receives signals from GPS and GLONASS satellites and allows the calculation of the machine's translation position, slewing angle, and boom elevation angle.

3.2.2 GNSS Base Receiver

The GNSS base receiver is responsible for transmitting RTK corrections to the rover receivers on the machines. Installed at a fixed location with known coordinates, it compares the signals received from GPS and GLONASS satellites with its actual position, calculating the real-time error. The corrections are then transmitted to the rovers, enabling positioning accuracy of up to 10 mm horizontally and 15 mm vertically. With a range of 50 km, the base receiver simultaneously supports all mobile receivers in the system.

3.2.3 3D Laser Scanner

The 3D laser scanner is responsible for generating a three-dimensional digital model of the stockpile by capturing its spatial geometry. Mapping is performed based on the machine's absolute position—provided by the GNSS receiver—and distance measurements acquired by the scanner relative to the pile surface.

The device performs a 90° vertical and 360° horizontal sweep, with up to four adjustable rotation speeds, dynamically controlled by the autonomous system according to the current operation. It has a range of 300 meters, a scanning rate of 20 Hz, and captures 1 000 measurements per scan, totalling 20 000 data points per second.

3.2.4 360° Radar Scanner

The 2D radar scanner performs four vertical 360° sweeps per second, with 400 measurements per sweep (angular resolution of 0.9°). It has a range of 50 meters and a resolution of 6.25 cm.

It is used for collision avoidance with the stockpile, predictive rate control, and redundant pile mapping in case of 3D laser scanner failure. In this condition, the machine can continue operating in automatic mode, executing autonomous manoeuvres and bench recovery, although pile positioning must be performed manually via remote control.

3.2.5 Ultrasonic Sensors

A total of four ultrasonic sensors were installed on the reclaimer for obstacle detection—three for protecting the walkway and one for the frontal protection of the bucket wheel.

On the stacker, two ultrasonic sensors are used for collision avoidance, each oriented to monitor one side of the boom.

3.2.6 Flow Measurement Sensors

On the walkway of the stacker EP-114-01, three laser distance sensors with 4–20 mA analog output are used to monitor the ore profile on the conveyor belt.

The distance measurements are processed by the machine's PLC (Programmable Logic Controller), which calculates the height of the moving material profile. Based on this profile and the conveyor speed, the material flow rate is estimated in tonnes per hour (t/h), enabling continuous control of the stacking rate.

3.2.7 Stockpile Height Measurement Sensors

A radar-type sensor with a 4–20 mA output is used on the stacker to measure the height of the stockpile. It is installed at the tip of the stacker boom.

3.3 Network Architecture of the Autonomous System

The data flow begins with the collection of information from sensors embedded in the machines, which continuously monitor the operational environment and machine conditions in real time.

These signals are routed to field panels equipped with Ethernet switches and PoE (Power over Ethernet) converters. From there, they are transmitted to the PLC (Programmable Logic Controller), responsible for real-time control, and to the RPU (Remote Processor Unit), which executes the navigation algorithms and autonomous logic. Communication with the central system is established via industrial radio, ensuring connectivity even while the machines are in motion.

At the central server, the data is processed and integrated, enabling overall system coordination and real-time availability of information to remote operation stations. These stations, previously distributed, are now centralized in the plant’s control room – integrated with other industrial operations – facilitating unified yard supervision and real-time decision-making.

System visualization and interaction are performed through graphical interfaces that display machine status, stockpile mapping, and process variables.

3.4 Operating Modes of the Automated Yard Machines

The automatic system includes three operational modes: Automatic, Semi-Automatic, and Manual, which are remotely configured through the supervisory interface. This interface is responsible for consolidating, displaying, and enabling real-time machine operation, 3D visualization of the yard, and access to Closed-Circuit Television (CCTV) monitoring. It is important to note that all operational modes are executed directly from the operation station in the control room, with no need for intervention from the machine’s operator cabin. Figure 5 shows one of the supervisory system’s operational interface screens.

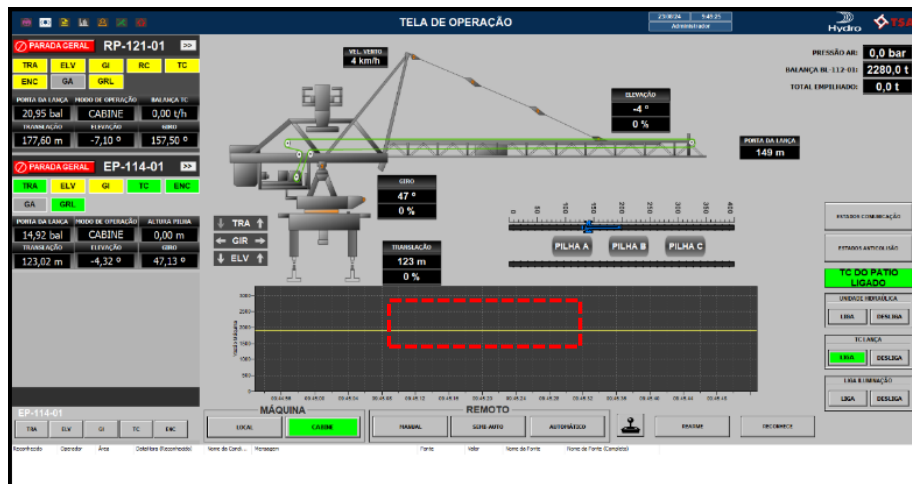


Figure 5. Operation screen highlighting the operating modes.

In automatic mode, both machines, the stacker and the reclaimer, operate fully autonomously based on the parameters previously configured by the operator in the supervisory system. The stacker automatically performs stacking path alignment, positioning of the stacking carriage, the formation of new stockpiles, and the reorganization of partially reclaimed piles. The system manages full stacking cycles according to the defined strategy (e.g., longitudinal or transverse).

The reclaimer continuously executes material recovery operations, automatically aligning with the pile, advancing and retracting the boom, and performing bench change manoeuvres, ensuring a stable feed rate to the downstream process.

In semi-automatic mode, the machines operate with operator assistance, combining automated and manual actions. This is an intermediate solution for situations where some sensors are unavailable. For the stacker, the alignment within the stacking area and the selection of the stacking location are performed manually by the operator, while the carriage movement and stacking rate are automatically controlled. For the reclaimer, even if the 3D scanner or GPS is unavailable, operation remains feasible using encoders: The operator manually adjusts the slewing angle and positions the boom on the pile, while the system controls the advance and extraction rate. For that, the use of the CCTV system is essential to ensure manoeuvring accuracy.

Manual mode is primarily intended for testing, calibrations, and maintenance interventions. In this mode, the operator has full control over all machine movements via the supervisory system using virtual joysticks. The use of field-installed cameras is critical for real-time monitoring and risk prevention during manual operations.

3.5 Collision Avoidance System (CAS)

The Collision Avoidance System (CAS) for the yard machines is centralized and applies to all equipment in the plant. Its operating logic is based on the continuous analysis of the relative positions of the machines, performed by the central server. Protection is defined by calculating the minimum distance between virtual protection zones—represented by lines extending beyond the physical contours of the machines. Based on this calculation, the system generates logical interlock signals that automatically restrict or block machine movements, preventing real-time collisions.

The system features three interlock levels: alarm (green), speed reduction (yellow), and motion lock (red). Figure 6 illustrates the lines used for distance calculation and the defined protection zones around each machine.

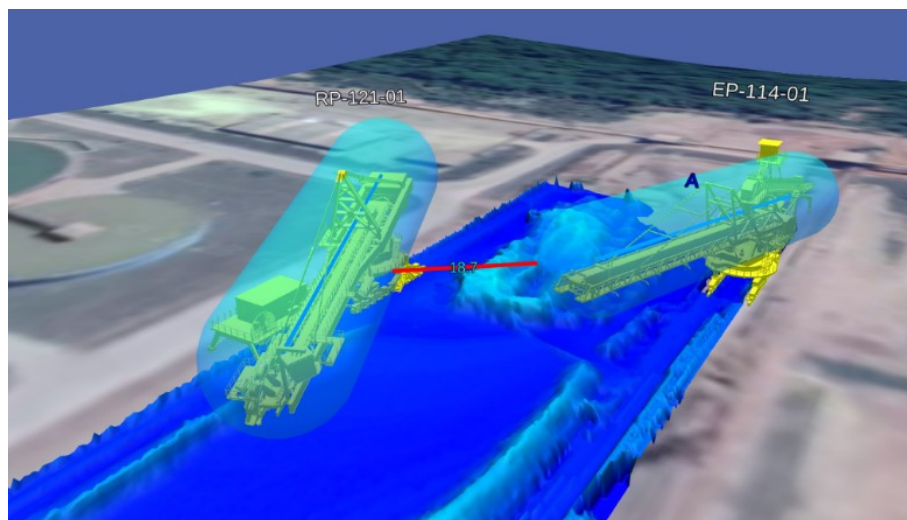


Figure 6. Protection zone and distance measurement between each machine.

The interlock bits are sent to the machine controller to restrict movements, while the supervisory system displays alarms for speed reduction and motion lock. Initially, the system operates with a blocking threshold set at 23 meters and a speed reduction threshold at 36 meters.

The collision avoidance system also allows the configuration of temporary safety zones via the 3D interface. In the example shown in Figure 7, a safety zone was created to delineate the area where a backhoe was operating in the yard.

With this configuration, if the stacker or reclaimer approaches the defined zone, their movements will be automatically blocked. Once the restriction period has ended, the configured zone can be deleted, removing the interlock conditions for that area.

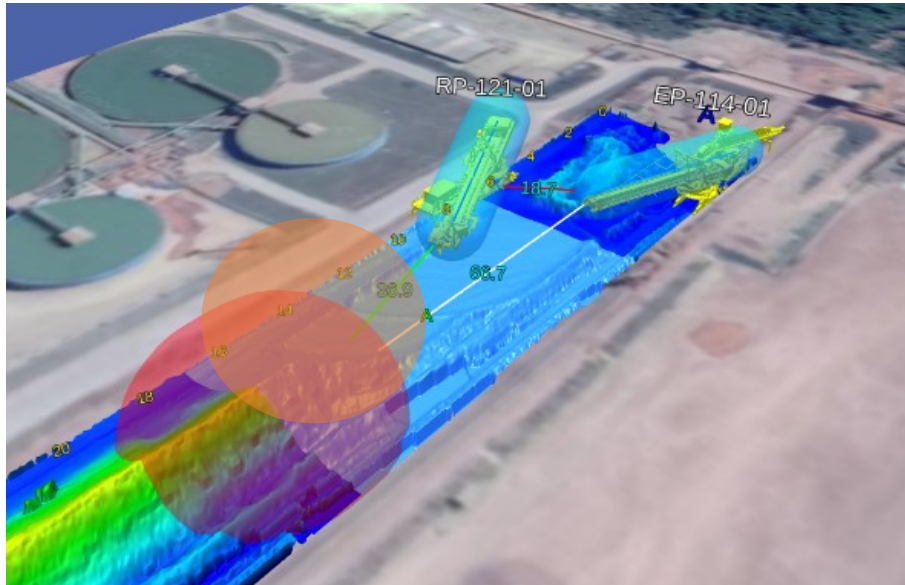


Figure 7. Temporary safety zone created via the 3D interface.

In addition to machine-to-machine and temporary zone collision avoidance, the system is also configured for pile collision prevention, using data from 3D laser scanners, 360° radars, and virtual sensors. The stacker boom collision avoidance is implemented using ultrasonic sensors that detect short-range obstacles (< 2 meters). Additionally, walkway collision prevention, on the reclaimer, is achieved through dedicated ultrasonic sensors positioned for lateral detection along the machine's walkway, helping to avoid collisions in low-visibility areas or during transverse manoeuvres.

3.6 Material Tracking System – Tracking

The material tracking system for the conveyor belts aims to monitor the real-time flow of bauxite throughout the transport system up to the feed silo.

Its operation is based on continuous sampling of data from integrator scales, combined with the reading of operational statuses from conveyors, feeders, and flow diverters. Through this integration, the system is capable of accurately tracking the instantaneous flow rate and total mass transported. In the supervisory system, as shown in Figure 8, it is also possible to monitor the real-time levels of the plant silos.

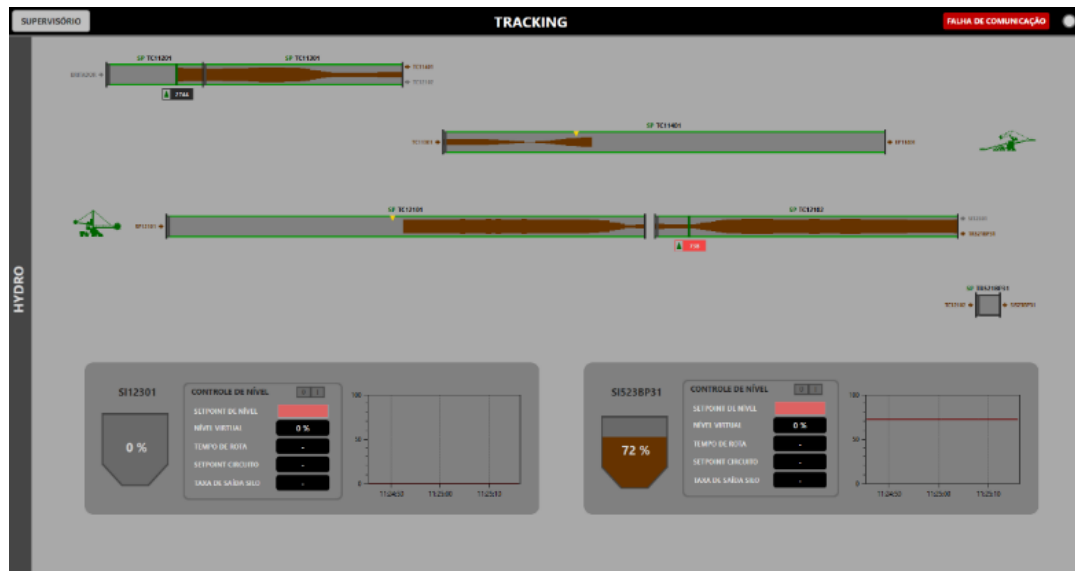


Figure 8. Tracking screen displaying silo control information.

4. Results and Discussion

The comparative analysis between manual and automatic operating modes of the yard machines demonstrated significant improvements in flow stability, safety, and operational performance during testing and assisted operation phases.

4.1 Flow Stability and Operational Performance

During pile reclaiming, the automatic system was able to maintain the flow rate close to the nominal value (2 800 t/h), even during cut transitions. Figure 9 illustrates the smoothness of the flow rate curve in automatic mode, showing reduced variation despite changes in the pile profile, thus demonstrating the effectiveness of the predictive control integrated into the system.

The first part of the graph shows the automatic operation of reclaimer RP-121-01 during the last cut of ore pile "A." Shortly thereafter, a drop in flow rate can be observed due to the machine shifting to a new cut, where the flow becomes more unstable because of ore profile irregularities.

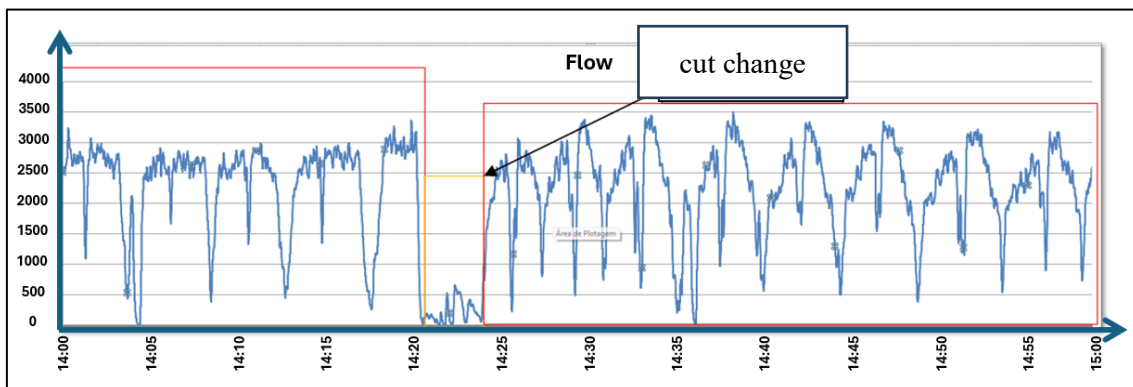


Figure 9. Flowrate during automatic operation of RP-121-01.

In contrast, Figure 10 illustrates the flow rate peaks recorded during manual operation, where fluctuations exceeding 3 500 t/h were observed. These abrupt variations can compromise the mechanical integrity of the bucket wheel and increase energy consumption.

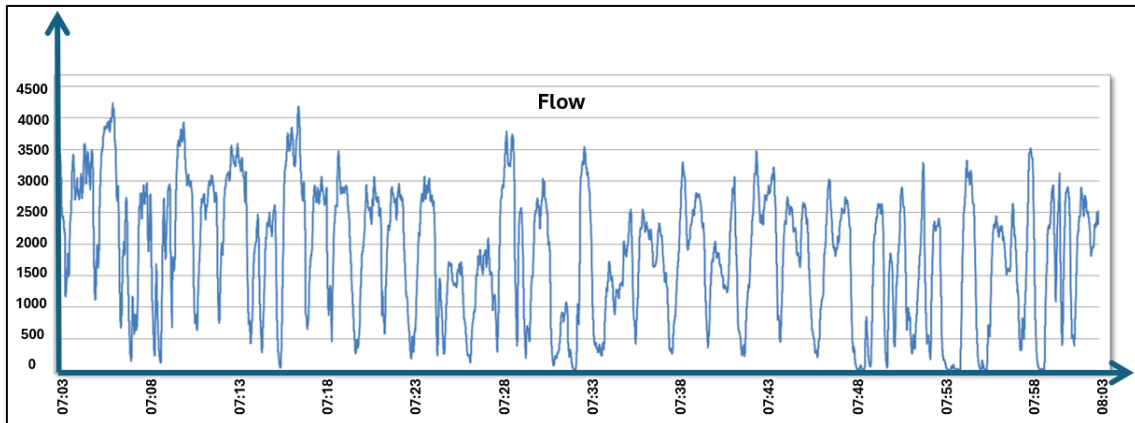


Figure 10. Flowrate during manual operation of RP-121-01.

4.2 Smoother Reclaiming and Reduced Mechanical Stress

Automatic control enabled smoother and more controlled reclaiming operations, as evidenced by the gentler slope of the flow rate curves during transition phases, as previously shown in Figure 12. This behaviour significantly reduces stress on the bucket wheel drive motor and contributes to increased lifespan of the mechanical components. Although these effects become more evident over time, they clearly indicate a trend toward reduced preventive and corrective maintenance costs.

4.3 Safety and Operational Comfort

In addition to technical improvements, automation brought positive impacts to the operators' routines in terms of operational safety and working conditions, especially for field operators. Eliminating the need for physical presence in the machine cabins during work shifts and shift changes represented a significant improvement.

5. Conclusion

The results obtained during the assisted operation phase of the yard machine automation project confirm the practical and operational benefits of the autonomous system implemented at Hydro Paragominas. The automatic mode demonstrated superior performance in terms of flow stability, reduced mechanical wear, increased operational safety, and greater consistency in feeding the plant silos.

Additionally, the relocation of the operator to the integrated control room represents a strategic shift in operational management. By moving from an isolated and exposed environment to a centralized, climate-controlled space interconnected with other areas of the plant, the operator now benefits from improved working conditions and increased engagement. Embedded in a collaborative decision-making environment, the operator gains a broader view of the process and contributes more effectively to production control, operational safety, and the identification of improvement opportunities based on their experience. This integration strengthens team communication, creates operational synergy, and reinforces the value of human involvement in a highly automated context.

This project is fully aligned with Hydro's values and commitments, recognizing technological innovation as a key driver in the transformation of industrial processes.

By integrating operational efficiency, safety, sustainability, and people development, the company reaffirms its leadership in the mining and metals sector, investing in intelligent solutions that address present-day challenges without compromising the future.

The automation of yard machines represents more than a technical advancement. It marks a milestone in the development of a safer, more efficient, and more responsible operation, in line with Hydro's strategic pillars.

6. References

1. ABAL – Brazilian Aluminium Association. Aluminium Industry Sector Report – 2023. <https://abal.org.br> (Accessed: May 12, 2025).
2. IBRAM – Brazilian Mining Institute. Mining 4.0: Challenges and Opportunities for the Brazilian Mineral Sector. Brasília: IBRAM, 2022.
3. International Aluminium Institute. *World Aluminium Market Outlook 2030*. London: IAI, 2023. <https://international-aluminium.org> (Accessed: May 13, 2025).
4. HYDRO. Technology and Innovation in Bauxite Mining at Paragominas. Oslo: Norsk Hydro ASA, 2023. <https://www.hydro.com>.
5. C. Takano and F. A. Silva, Automation in stockyard stacking and reclaiming systems, *Tecnológica Magazine*, São Paulo, v. 21, n. 4, 2018.
6. J. A Damasceno et al., Simulation and optimization of automatic reclaimer in ore stockyard by using 3D mapping, *Proceedings of the 17th Brazilian Seminar on Industrial Automation and IT*, Vitória, Brazil, 2013.
7. M. R. Ferreira, T. V. Lima and J. D. F. Jesus Junior, Stockyard Management System, *Proceedings of the 15th Brazilian Seminar on Industrial Automation and IT (Seminário de Automação e TI Industrial)*, São Paulo, Brazil, 2011.
8. HYDRO. *Tailings management*. Oslo: Norsk Hydro ASA, 2025. <https://www.hydro.com/en/global/sustainability/our-approach/nature/tailings-management/>. (Accessed: May 13, 2025).

