

## Dynamic Simulation of a Port Terminal Shipment Operation for Iron Ore Exportation

Edenilson Silva Filho<sup>1</sup>, Gustavo Gilberti<sup>2</sup>, Luiz Montenegro<sup>3</sup>

<sup>1</sup>Hatch  
Rua Henrique Furtado Portugal, 67 – apt 302 – Bloco 1, Belo Horizonte, Minas Gerais, Brazil, 30493-175  
Phone: +55 (31) 9 9185-8708  
Email: edenilson.silva@hatch.com

<sup>2</sup>Hatch  
Bulgersteyn 7191, Rotterdam, Zuid Holland, Netherlands, 3011AB  
Phone: +31 616 479952  
Email: gustavo.gilberti@hatch.com

<sup>3</sup>Universidade Federal de Minas Gerais  
Zilah Correia de Araújo, 96 – apt 302, Belo Horizonte, Minas Gerais, Brazil, 31310-450  
Phone: +55 (31) 9 8449-0661  
Email: lcmm@demin.ufmg.br

Keywords: Iron Ore; Dynamic Simulation; Shipment Regularization.

### INTRODUCTION

#### Iron Ore Exportation Logistics

One of the main commodities in the world, iron ore is primarily used for steel production, which accounts for 98% of its global consumption. In 2021, international production was estimated at 2,537 million tonnes, with price fluctuating from US\$116 to US\$214 per tonne, depending on each month's demand.<sup>1</sup> Iron ore is usually commercialized as lump (small blocks), sinter feed (fine product) or pellet feed (further screened material), the latter being the most common in the market.<sup>2</sup>

As the major global consumers, Asian countries are also the main iron ore importers, with 89% of the worldwide accounted expenditure in 2021. Europe comes in the second place, with 8.7% of the importation spending. A breakdown of the main importing countries is given in Figure 1.<sup>3</sup>

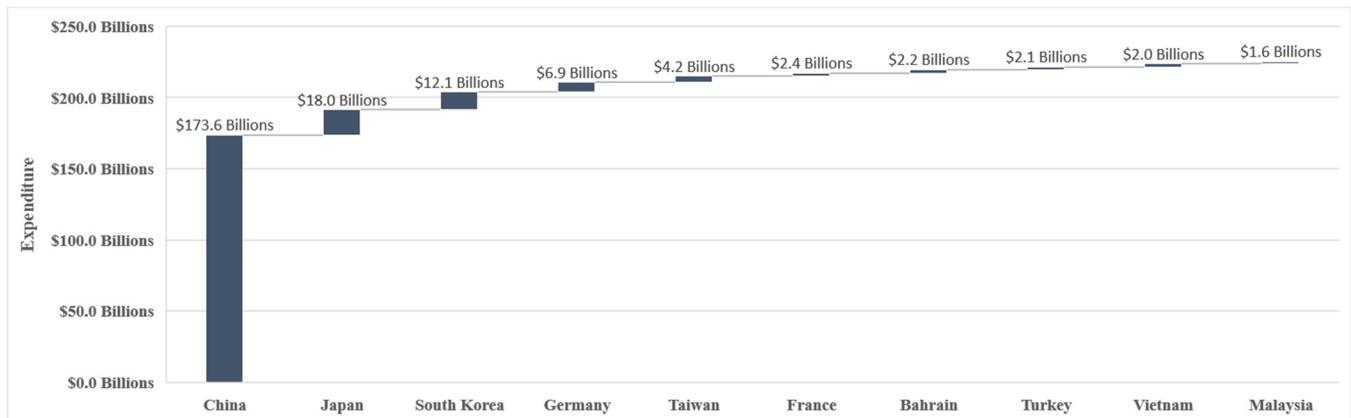


Figure 1. Iron ore imports by country in 2021<sup>3</sup>.

The high transportation volumes add complexity to iron ore’s supply chain, which is subject to challenges such as cost, security of supply and inventory management. Port terminal operations involve varied loading and unloading rates and quantities, always aiming to ship iron ore in the consignment size required by consumers. In this context, iron ore producers with integrated mine-rail-port logistics are often the most efficient. By owning and operating their own ports, railways and even ships, these companies can achieve increased capacity, improved inventory management and higher profitability.<sup>4</sup>

In order to meet their growing overseas clients demands, iron ore producers with integrated transportation logistics located outside Asia and Europe, the main consuming regions, must invest in strong and reliable shipping operations in their port terminals. Reclaimers, conveyors and ship loaders capacities and availabilities often restrict achieved shipping rates, with logistics gaps from the stockpile reclaiming to ship loading. Considering the growing external consumption, addressing these issues to optimize port operations can prove itself a valuable improvement, resulting in increased exportation capacity and higher sales profits.

**Studied Iron Ore Port Terminal**

Inserted in this global scenario, the studied port terminal located in South America is part of an integrated mine-rail-port operation to export iron ore to the main global consumers in Europe and Asia, transporting hundreds of millions of tonnes per year.

Five ships can be accommodated at the same time, and 95% of the material handled in this port terminal is sinter feed. The iron ore is received by car dumpers, and stored in longitudinal stockpiles distributed in two independent yards (A and B). bucket reclaimers are responsible for recovering this material, sending it to belt conveyor and shiploader systems that load the ships. A block flow diagram of the port is given in Figure 2.

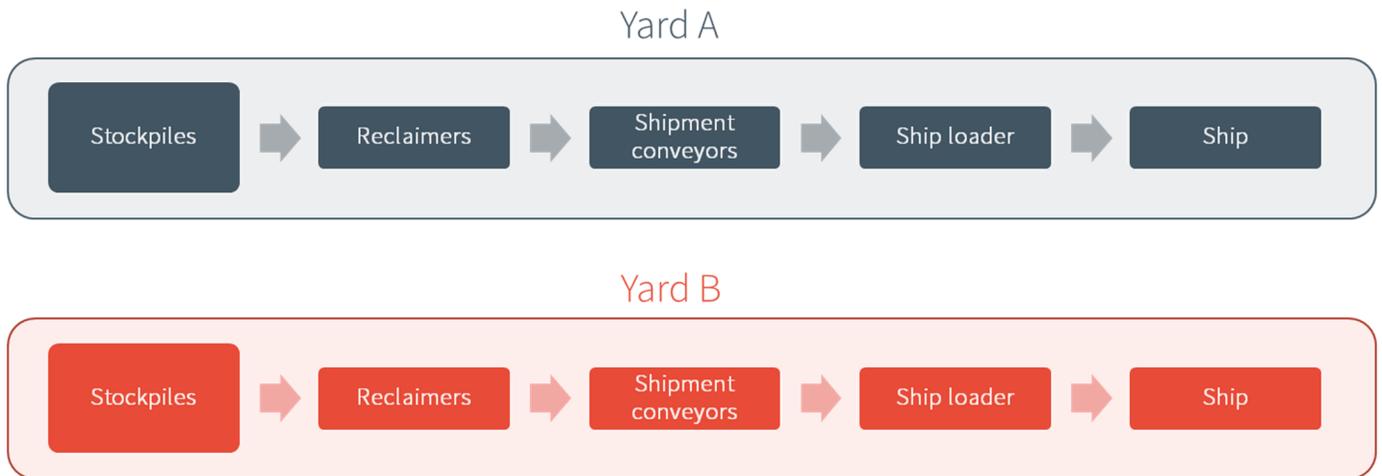


Figure 2. Port shipment operation block flow diagram.

The bucket reclaimers have 8 ktph nominal capacities, but can reach higher peak rates. These rates are subject to large variations depending on the position of the reclaimer, with substantial decrease in pile ends and pile shifts. An example is given in Figure 3, showcasing an operation with average reclaiming rate of approximately 6.2 ktph.

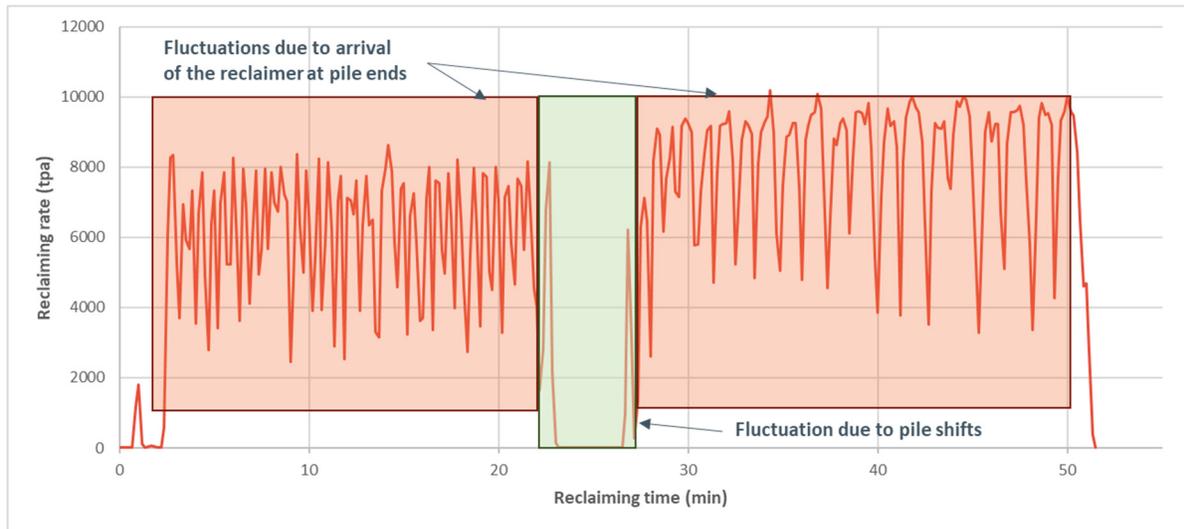


Figure 3. Reclaiming profile of an 8 ktp nominal capacity bucket reclaimer.

The terminal configuration allows for multiple reclaimers feeding one line of shipment conveyors up to a total capacity of 16 ktp. However, given the reclaiming rate fluctuating behavior, conveyors total capacity of 16 ktp restrain the operation with multiple reclaimers at the same time: a maximum of two simultaneous reclaimers is allowed, since the inclusion of a third one could extrapolate the conveyors transporting capacity during peak reclaiming rates. Even when two reclaimers are operating simultaneously, the sum of peak rates on both machines can surpass conveyor capacity and lead to overload of the shipping line. This issue, combined with the reclaiming fluctuation, results in ship loading rates below nominal capacity, limiting the port's iron ore exportation capacity.

Aiming at optimizing operations in this port terminal and increasing loading capacity, this study developed a dynamic simulation model to assess the port shipment process, with bottlenecks and opportunities identification. Based on the assessment, new engineering solutions were proposed and modelled, to quantify the associated benefits in terms of exportation capacity increase.

## THEORETICAL BACKGROUND

### Dynamic Simulation

Working as a data analysis method, dynamic simulation can be used in cases where variables present high codependences, interrelations, and process variability, as illustrated in Figure 4. Operational complexity is an integral part of the model simulation, including equipment dynamics, failures frequency and duration profiles. Integrated analysis allows a better estimation of the system and identification of risks and opportunities, which can also be incorporated in the model for further simulation.<sup>5</sup>

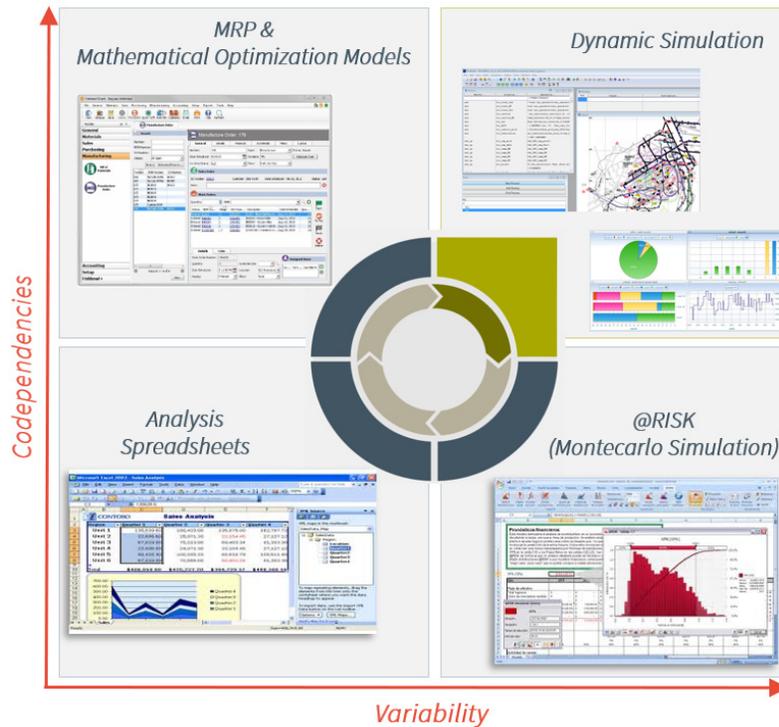


Figure 4. Data analysis chart.<sup>5</sup>

In dynamic simulation models, equipment and operations are modelled by interconnected nodes, each of them containing representative statistic distributions of the main variables and how they can be affected by eventual failures. The level of accuracy of this type of study is very dependent on the information level of the input data. Therefore, it is essential to have a reliable and representative set of available data, supported by adequate statistic summarization.<sup>5</sup>

One of the main advantages of dynamic simulation is the establishment of a risk-free virtual environment that allows evaluating a wide range of scenarios and the behavior of the system under different operational conditions. This results in lower cost and higher flexibility to achieve business improvement.<sup>5</sup>

## METHODOLOGY

The study was based on a set of material movement data, combined with ship loading history and also movement, unloading and loading rules available within the range of a year of operation. Since sinter feed corresponds to over 95% of the total iron ore handled in this port, the study was limited to the movement of this material, so that proposed solutions result on significant gains in capacity.

For the port optimization study, a dynamic simulation model was developed in Rockwell's Arena® software, aiming to identify bottlenecks and opportunities for improvement in port operation with the goal of increasing the shipping rate. The optimization model covers the entire port operation with hourly resolution, including from the material reception (car dumpers) to the ships loading. The main variables considered for the modelling were:

- Unplanned outages
- Ship capacity
- Reclaiming capacity
- Reclaimer curve
- Number of reclaimers (max. 3 due to conveyors capacity restriction)
- Bin capacity (for scenarios with regularization bin inclusion)

Engineering improvements that allow a better operation of the port were proposed, considering the distribution of sinter feed in the yards, boarding priorities, ships scheduling, among others, with the objective of increasing shipping capacity. The design options evaluated in the study were:

- Higher reclaiming capacity:
  - New reclaimers
  - Existing reclaimers power increase
- Higher ship loading capacity:
  - Ship loader power increase
- Shipment rate regularization:
  - Addition of a regularization bin

These scenarios were also modelled in Arena®. Each simulation was replicated 10 times to ensure an adequate statistical sensitivity of the model. The shipping capacity increase for each one was estimated, comparing to real data, in order to assess the benefits and define the most adequate engineering solution for the port operation.

## RESULTS AND DISCUSSION

### Data Statistical Analysis for Modelling

In order to obtain distributions to represent the main parameters in the Arena® modelling, a statistical assessment of the available set of data was provided.

#### Reclaimers Data

The individual profiles of all bucket reclaimers presented a similar behavior, but around different modal flowrates. As an example, the histogram for one of the reclaimers is shown in Figure 5.

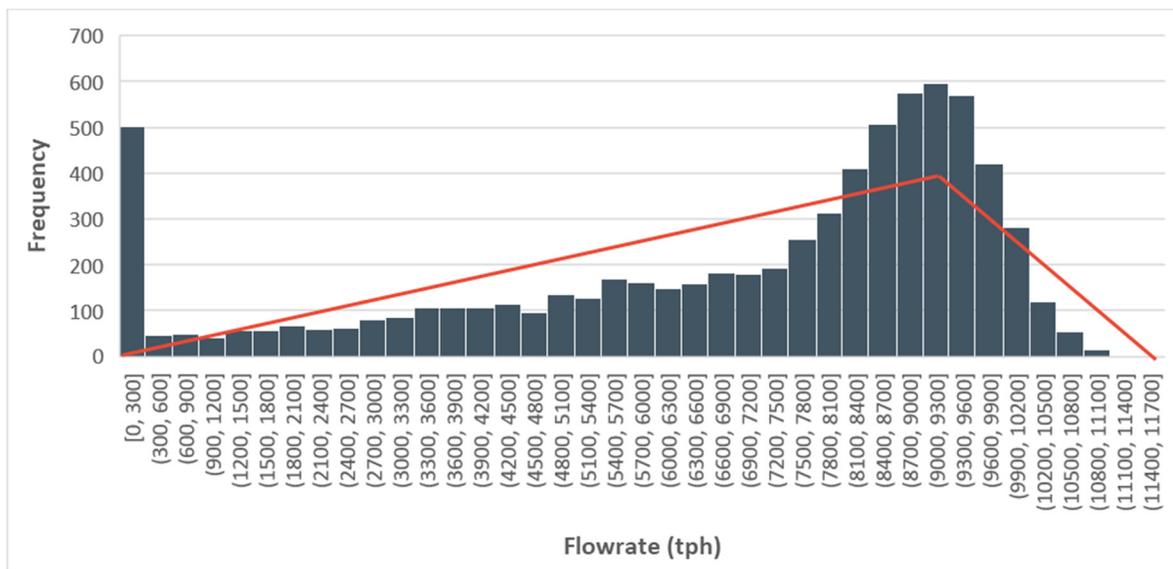


Figure 5. Individual reclaimer flowrates histogram.

The histogram shows that the instantaneous recovery rates are concentrated in one point (recovery setpoint), but that they have a long variation, with a certain concentration in values close to or equal to zero.

The Input Analyzer software was used to determine the distribution that best fits the reclaimers' profiles, resulting in a triangular distribution. The triangular distribution (TRIA) presents a linear behavior between a minimum value and an average value, and another linear behavior between the average value and the maximum value. These parameters are presented, for the three statistical curves used for the modelling, in Table 1.

Table 1. Reclaimers Statistical Distributions

Scenario	Statistical Distribution (tph)
Worst reclaimer	TRIA(0;7,930;10,700)
Average reclaimer	TRIA(0;7,590;12,400)
Best reclaimer	TRIA(0;9,900;12,400)

### Failures Data

Based on this history of ship loadings, it was possible to determine the stoppages for corrective maintenance that occurred in the port during periods of shipment. These data are representative so that the dynamic simulation model reflects real problems during the shipping operation.

The time between failures (TBF) and time to repair (TTR) data for each operational problem that occurred during shipment operations were used to build two histograms, which are presented in Figure 6.

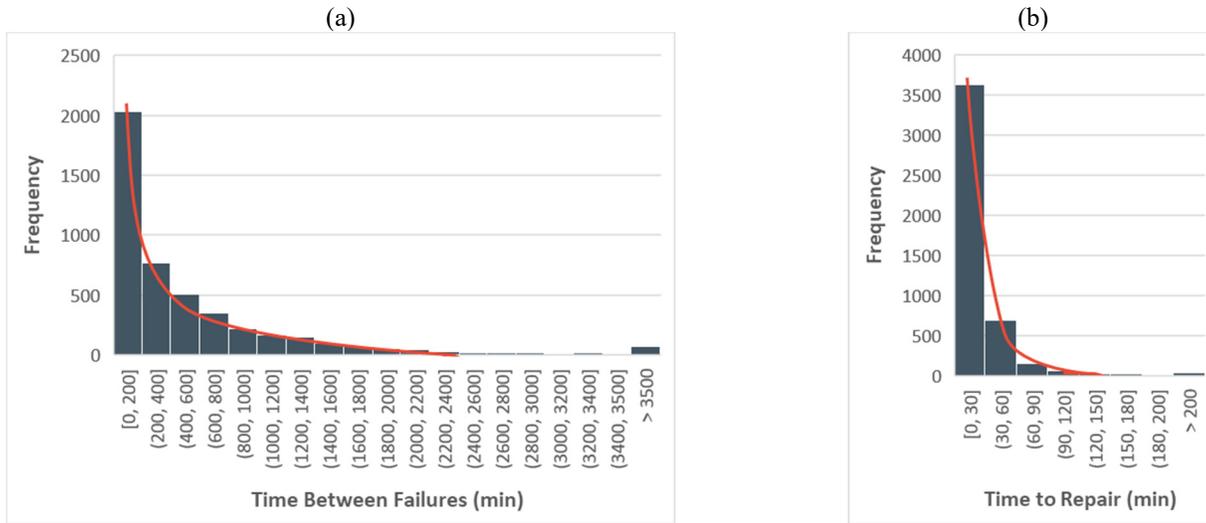


Figure 6. (a) TBF and (b) TTR duration histograms.

From the histograms, statistical distributions that best represent the TBF (exponential function) and TTR (Weibull distribution) were obtained, using Input Analyzer, as shown in Table 2.

Table 2. TBF and TTR Statistical Distributions

Scenario	Statistical Distribution (min)
Time between failures (TBF)	EXPO(77.3)
Time to repair (TTR)	WEIB(20.3; 0.782)

### Base Case Simulation

Used for model calibration, the base case for the simulation consisted of replicating the loading of a 180,000 tonnes capacity ship, for which real data were available for comparison. Failure times were not considered for this specific simulation since there were no outages in the original shipment. Therefore, only the actual time in which the reclaimers were working and directing material to the ship was represented.

The ship's total feed rate is given in Figure 7, for both reference operation and simulated base case. Two simultaneous reclaimers were always used for shipment, except for the 200 min to 400 min period in the reference operation, during which only one reclaimer was available.

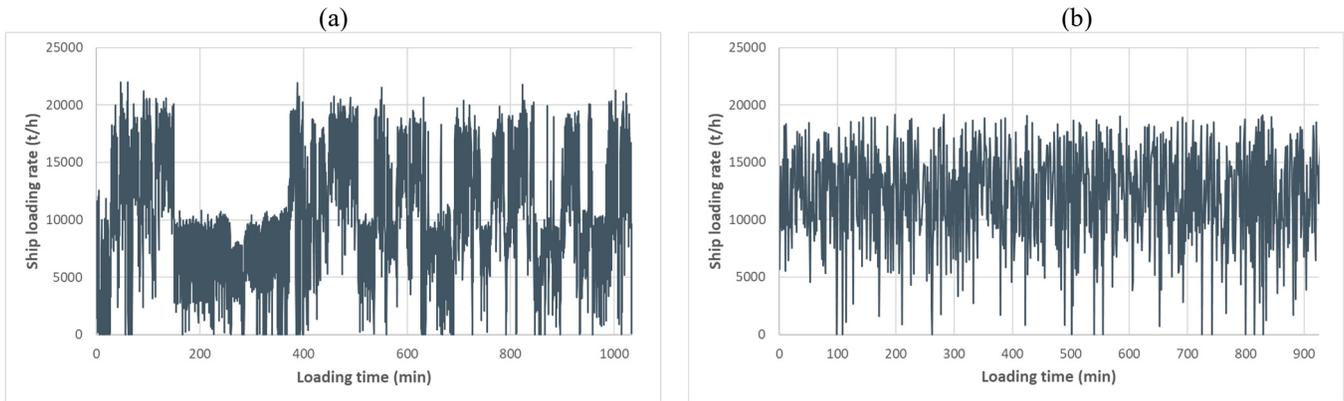


Figure 7. Ship's total feed rate in (a) real operation and (b) base case simulation.

The base case simulation resulted in a ship loading profile comparable to the reference shipment, with high instantaneous rate variability due to reclaimer load at end of pile and end of pile shifts. The simulation showcased the necessity of 15.4 h of operation with two simultaneous reclaimers to load the 180,000 tonnes capacity ship, and the real operation's duration was 17.2 h. Considering the downtime period of one of the reclaimers in the reference operation (which increases total loading duration), the results are comparable and indicate an adequate calibration of the model.

### Design Improvements Simulation

Three proposed design improvements were assessed, with the associated shipping capacity increases quantified through modelling, as described in the following subsections. The results were used to select the most adequate improvement for implementation in the port terminal.

#### Higher Reclaiming Capacity

Reclaiming capacity can be increased through repowering of the existing reclaimers, or acquisition of new reclaimers. Three main options were simulated in the dynamic model:

- Option 1: substitution of two existing 8 ktph bucket reclaimers by two new 16 ktph bucket reclaimers
- Option 2: acquisition of one new 8 ktph bucket reclaimer and one new 16 ktph bucket reclaimer
- Option 3: acquisition of one new 8 ktph bucket reclaimer and repowering of one existing 8 ktph bucket reclaimer to reach new capacity of 12 ktph

Modelling results showed the first option is the only one that actually increased overall shipping capacity. A higher number of reclaimers (as proposed in options 2 and 3) does not necessarily result in higher shipping capacity, because of the reclaiming dynamics and safety restrictions associated to the downstream conveyors capacity of 16 ktph. As an example, the first new reclaimer inserted in option 2 would spend much time out of operation (blocked), because the other reclaimer already occupies most of the shipping capacity, as illustrated in Figure 8.

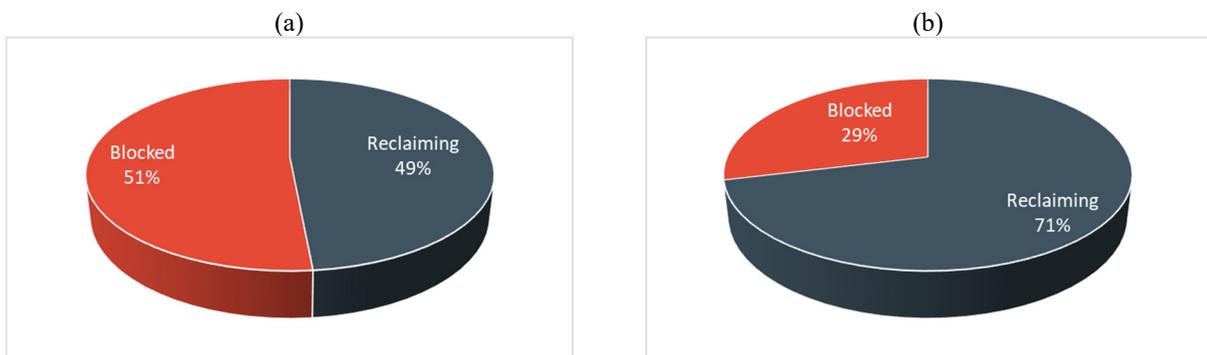


Figure 8. New (a) 8 ktph and (b) 16 ktph reclaimers operation in option 2.

The resulting improvements in terms of shipping capacity for the three options are quantified in Table 3.

Table 3. Shipping Capacity Increases for Higher Reclaiming Capacity Options

Option	Description	Annual Shipping Capacity Increase
1	Substitution of two existing 8 ktpa bucket reclaimers by two new 16 ktpa bucket reclaimers	3.1%
2	Acquisition of one new 8 ktpa bucket reclaimer and one new 16 ktpa bucket reclaimer	0
3	Acquisition of one new 8 ktpa bucket reclaimer and repowering of one existing 8 ktpa bucket reclaimer to reach new capacity of 12 ktpa	0

### Higher Ship Loading Capacity

An increase in the loading capacity can be achieved through repowering of the ship loaders. The analysis was conducted considering two alternative loaders that could be repowered from the current 8 ktpa capacity to reach a new capacity of 16 ktpa. The improvement quantification of both modelled options is given in Table 4.

Table 4. Shipping Capacity Increases for Higher Ship Loading Capacity Options

Option	Description	Annual Shipping Capacity Increase
1	Pier A ship loader repowering to 16 ktpa	1.5%
2	Pier B pier ship loader repowering to 16 ktpa	2.3%

### Shipment Rate Regularization

For this design improvement, it was considered the insertion of a regularization bin in yard B. In this concept, several reclaimers direct material to this bin, which then distributes the sinter feed to the ships, as illustrated in Figure 9.



Figure 9. Shipment rate regularization block flow diagram.

The simulation was initially carried out considering two simultaneous reclaimers functioning, such as in the current terminal operation philosophy. Resulting loading rates and bin inventory variation are shown in Figure 10.

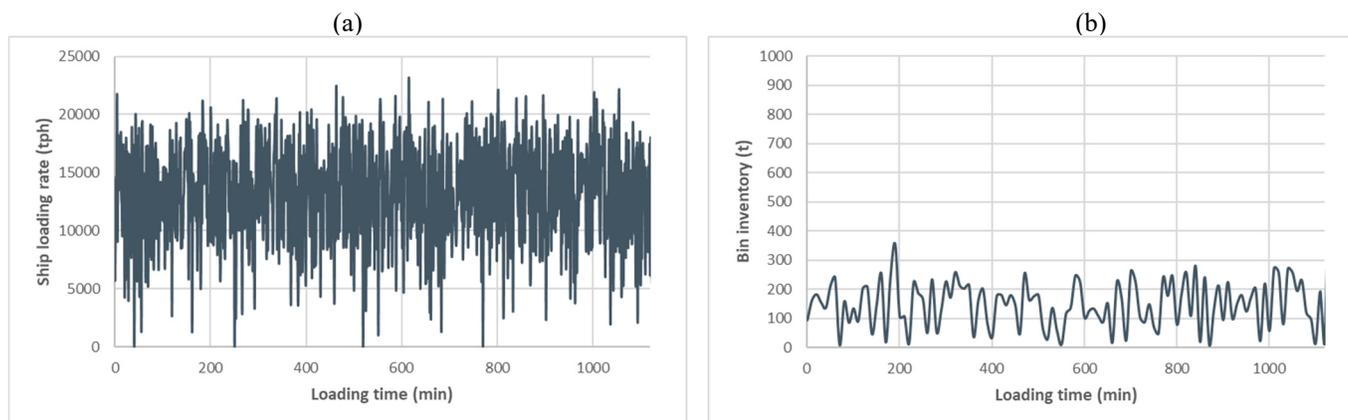


Figure 10. Regularization simulation with two simultaneous reclaimers: (a) Ship loading rate, (b) Bin inventory variation. From the graphs, it can be noticed that when only two reclaimers operate, the bin does not function as a buffer because, in general, the amount of material arriving at the bin is lower than the shipment capacity. As a consequence, the ship loading rate is still subject to high variations, with little or no regularization observed.

To address this issue, a new simulation was carried out considering three simultaneous reclaimers operating, to keep the bin at a high level. For this case, it was determined that the minimum capacity for the bin to be able to maintain a practically steady flow in the material reclaiming is 500 t. This value would accommodate reclaimer rate end-of-cone and end-of-pile fluctuations. However, due to equipment failures and as a safety measure, a 1,000 t capacity was adopted.

The regularized loading rate with three simultaneous reclaimers in operation is shown in Figure 11, alongside the inventory variation of the bin.

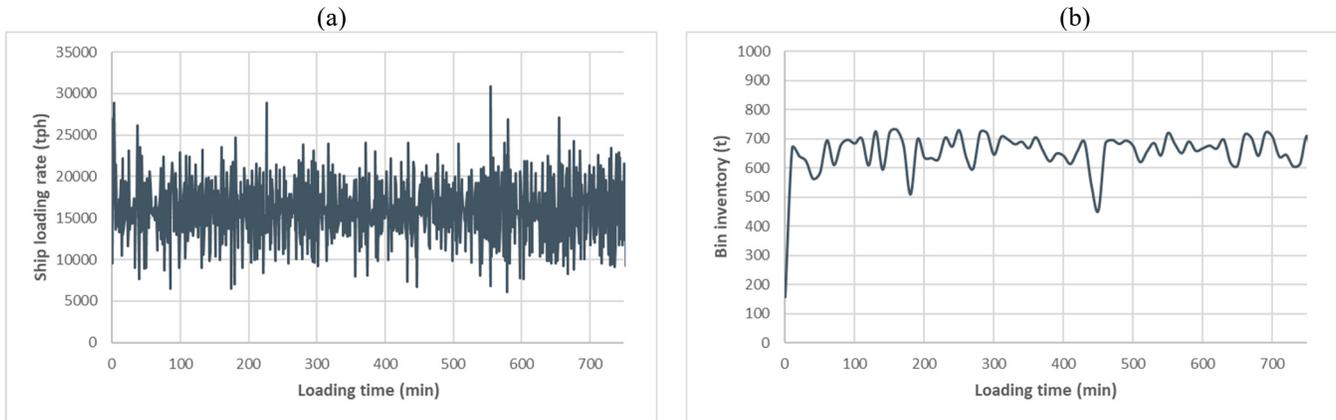


Figure 11. Regularization simulation with three simultaneous reclaimers: (a) Ship loading rate, (b) Bin inventory variation.

The simulation showcased loading rates close to the nominal 16 ktph capacity, with a large reduction in the fluctuations observed in the base case (Figure 7), and elimination of downtimes with null loading rates. Effective loading time was reduced by 23%, which represents a 14% improvement in total time. The resulting annual shipment capacity increase is given in Table 5.

Table 5. Shipping Capacity Increase for Shipment Rate Regularization

Option	Description	Annual Shipping Capacity Increase
1	1,000 t capacity bin insertion	11.9%

### Design Improvement Selection and Implementation

A comparison of the three design improvements, in terms of shipping capacity increase, is provided in Table 6.

Table 6. Shipping Capacity Increases for All Simulated Design Improvements

Design Improvement	Option Description	Annual Shipping Capacity Increase
Higher reclaiming capacity	Substitution of two existing 8 ktpa bucket reclaimers by two new 16 ktpa bucket reclaimers	3.1%
	Acquisition of one new 8 ktpa bucket reclaimer and one new 16 ktpa bucket reclaimer	0
	Acquisition of one new 8 ktpa bucket reclaimer and repowering of one existing 8 ktpa bucket reclaimer to reach new capacity of 12 ktpa	0
Higher ship loading capacity	Pier A ship loader repowering to 16 ktph	1.5%
	Pier B pier ship loader repowering to 16 ktph	2.3%
Shipment rate regularization	1,000 t capacity bin insertion	11.9%

With the highest improvement in terms of capacity increase, the shipping regularization solution was selected for implementation, involving the insertion of a 1,000 t bin and utilization of three simultaneous reclaimers. Besides the capacity

increase, this design improvement also results in an optimization of the port terminal operations, reducing loading rate fluctuations and increasing flexibility to deal with equipment failures.

An available area between yards A and B was selected for later conceptual engineering development of the new regularization system.

## CONCLUSIONS

The dynamic simulation model developed in Rockwell's Arena software was calibrated by simulation of a base case, with very similar results in comparison to the real shipping. After calibration, the model was used to simulate the shipping operations of three scenarios, each one containing proposed design improvements: higher reclaiming capacity, higher ship loading capacity and shipment rate regularization. Showing the best results in terms of operations improvement, including a projected increase in annual exportation capacity of 11.9%, the shipment rate regularization solution was selected as the best option for implementation, with addition of a 1,000 t bin and operation of three simultaneous reclaimers. The dynamic simulation proved itself a valuable tool to evaluate the proposed design improvements in a risk-free environment, providing numerical data to each of the solutions and serving as the basis for the selection and dimensioning of the new equipment to be designed in the conceptual engineering phase.

## REFERENCES

1. "Iron ore facts" [website]. *Natural Resources Canada*; 2022 [cited 2023 Jan 02]. Available at: <https://www.nrcan.gc.ca/our-natural-resources/minerals-mining/minerals-metals-facts/iron-ore-facts/20517>.
2. "Iron ore" [website]. *Companhia Siderúrgica Nacional*; 2020 [cited 2023 Jan 02]. Available at: [https://www.csn.com.br/en/homepage/iron-ore/#:~:text=Sinter%20Feed%20\(6.3%20mm%20%2D%200.150,sinter%20feed%20usually%20exceeds%2063%25](https://www.csn.com.br/en/homepage/iron-ore/#:~:text=Sinter%20Feed%20(6.3%20mm%20%2D%200.150,sinter%20feed%20usually%20exceeds%2063%25).
3. "Iron Ore Imports by Country Plus Average Prices" [website]. *World's Top Exports*; 2022 [cited 2023 Jan 02]. Available at: <https://www.worldstopexports.com/iron-ore-imports-by-country/>.
4. C. Comtois and B. Slack, "Dynamic determinants in global iron ore supply chain," *CIRRELT*, 2016.
5. Hatch Ltd. *Dynamic Simulation General Services*; 2020. Unpublished internal company document.