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ANALYSIS OF CAPACITY ASSOCIATED TO LEVELS OF SERVICE AT PORT TERMINALS USING SYSTEMIC APPROACH AND SIMULATION OF DISCRETE EVENTS

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ABSTRACT

The concept of capacity associated to service level is something that can be used with simulation in several situations that involve logistic and commercial planning of organizations, because it enables a practical vision of real behavior of a system, facilitating the comprehension of existent bottlenecks. This paper presents a methodology of determination of capacity of a port from offered service levels, using a discrete events simulation model developed in software ARENA. Moreover, it is considered the systemic approach as methodology, enabling a more practical and fast determination of operational bottleneck. The simulation model can to reflect strategies that would be implemented to boost the current port's capacity and demonstrates that it would increase capacity from 39.5 to 64.2 Mt/year, with the berths being the only resources that would achieve the 85% utilization threshold.

1 INTRODUCTION

This paper presents a methodology for dimensioning and evaluating the capacity of port terminals using simulation as the major tool to verify service levels offered by the terminal. The concept of capacity associated to service level is something that can be used along with simulation in several situations that involve logistic and commercial planning of organizations, because it enables a practical and direct vision of real behavior of a system, facilitating the comprehension of existent bottlenecks and being a way to see provided services from the point of view of who use those services.

A discrete events simulation model that represents the operations at the terminal is built, in which the systems are divided according to the characteristic of the tasks. This analysis considers the application of systemic approach.

The terminal that is the object of this study is used for the export of iron ore produced in Brazil, and the goal is to increase the quantity exported (annually) with operational improvements obtained at the acquisition of new equipment and other investments. The simulation will be used to give data necessary for the decision making in analysis that will consider the necessity of promoting efficient services and that guarantee better efficiency for resources.

For application of the methodology shall be considered the export of two distinct types of iron ore: Pellet Feed (density 2.25 t / m³) and Sinter Feed (density 2.58 t / m³). Both are transported to the port terminal by rail from their origin.. When they arrive at the terminal, products are unloaded from trains and directed to storage yards, where they wait for the moment to be loaded for exportation at ships that operate at berths.

1.1. The Terminal

The ore terminal has a pier with two berths for mooring of ships, where north berth (internal berth) has the capacity to receive ships up to 152,000 dwt, while south berth can receive up to 330,000 dwt, with respective draughts of 19 and 24 meters.

Berths are equipped with 1 line of loading with nominal capacity of 13,800 t/h and 1 ship loader (SL) with nominal capacity of 13,800 t/h.

Storage area has approximately 215,000 m² divided in 6 yards with total static capacity of 3,5 mt of ore. those yards are equipped with stackers - reclaimers (SR) with nominal capacity of 8,800/8,400 t/h and conveyor belts with different nominal capacities (from 4,200 to 8,000 t/h).

Iron ore arrives at terminal by railroads compositions with an average of 130 cars. At arrival, each train is divided into 2 batches, which are unloaded by two car dumpers with nominal capacity of 8,800 t/h (vv01/02) and 8.000 t/h (vv03).

It is desired to increase the quantity of iron ore exported through this terminal and, to make this happen, it must be verified the capacity of exportation of it, considering the changes of layout and planned operational premises. The expansion of the terminal contemplates the installation of new unload and moving of iron ore equipment, as well as the adoption of some new premises for loading of ore at ships, from a known fleet profile.

So, there is a inclusion of new storage yards and new equipment that will enable a greater capacity of movement to the terminal. It is highlighted that the SL with higher capacity can rotate from one berth to the other, increasing, this way, the efficiency of the loading.

2 LITERATURE REVIEW

Due to the increased use of maritime shipping to transport goods between countries geographically distant it became necessary to rely on port operations most efficient in order to maximize the capacity of port terminals across the planet leading to the existence of many works and researches whose main objective is measure the levels of service and ways to evaluate the operational capacity of a port.

Lima et al. (2015) evaluate port operations in accordance with the times that ships wait in queue at the port terminals emphasizing the need to control and manage the operations at the terminals. The authors constructed a model to maximize the quantity of delivered goods, using the queuing theory and simulation (using the Simian software) as tools to support in obtaining results. However, the results obtained were related more to routes to be followed than the infrastructure improvements. Lee and Choo (2015) dealt with the sea freight as a set of networks to be optimized while keeping the balance of mass between the nodes of these networks and seeking to maximize the quantity transported.

Zehendner et al. (2015) studied a way to increase the efficiency of available port equipment at a terminal by reducing delays in loading and discharge and also reducing the time of wait in queue of attended ships reinforcing the time on queue as the object of efforts to increase the offered level of service.

Another highlight in this review is the large amount of iron ore produced each year in Brazil, making this product an object of many studies related to its supply chain and alternatives to make it a more sustainable industry, such as the study Macedo et al. (2002).

Finally, authors such as Gualda (1995) and Schwif and Medina (2007) were studied to a better understanding of the methodology used in this study, to be presented afterward.

3 METHODOLOGY

The used approach for the determination of capacity of the terminal, with a new layout, consider three important steps. Firstly, it was used the so-called systems approach, in order to conduct the analysis with accuracy and more detailed characteristics of the system. The port terminal is divided into subsystems according to the characteristics of the operations performed.

Following, a simulation model of discrete events is built to represent the reality of operations of subsystems that compose the terminal, starting from the collection of premises and the creation of a conceptual model that should list all characteristics to be represented. This model should be validated according to real and existent data to gain reliability and to enable analysis of terminal expansion in a direct way, through the construction of scenarios.

Finally, using the validated model and the constructed scenarios, it is applied the concept of capacity associated with the service level, to determine the actual capacity of the terminal in accordance with the improvements (expansion) and to investigate which of the subsystems will be the system bottleneck.

3.1. Systemic approach

Before to evaluate the capacity of exportation on port terminal, associated to pre-established service levels, a systemic approach of the terminal after expansion should be applied so that by a discrete events simulation model may be possible to identify the bottleneck of the project and the actions to be taken in order to ensure that the subsystems operate at maximum operational capacity.

The systemic approach is applied in a project or masterplan of a terminal of transport because allows a more detailed analysis of the existing components and subsystems and determining the system that limits the capacity of the terminal, its "bottleneck".

According to Gualda (1995), is necessary to apply a suitable method for the treatment of a problem with systemic approach. To detail the subsystems of the terminal of transports enables to solve a problem neatly, and the systemic approach is a method based on premises of scientific methodology to analyze a system by the build of a model.

Thus, for the application of the systemic approach on a terminal of transport, its subsystems and components must be identified through the links between its objectives in order to facilitate the modelling and analysis of the obtained results afterward. So the systemic approach method will be used in solve of the proposed problem and therefore the terminal will be divided into three subsystems: discharge system, storage system and loading system.. The Figure 1 presents the layout of the terminal considering its expansion and divided into subsystems according to what is described.

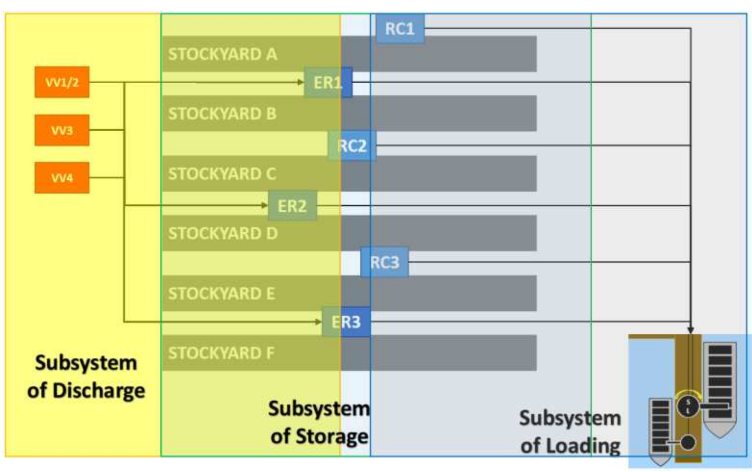

Figure 1: Layout of expansion of ore terminal divided into subsystems.

The discharge system is composed by the arrival of trains at terminal from the railway, by car dumpers, that operate along with unload lines and direct ore to the function of stacking of stackers-reclaimers, what can be called as interface between discharge subsystem and storage subsystem. After being stacked at yard, iron ore is stored at the terminal waiting for ships to moor and get loaded, this is the storage subsystem.

Finally, reclaimers take off the stored material that is directed by the loading line until loading subsystem, composed by ship loaders and mooring berths, with limited capacity to certain types of ships.

It must be noted that this systemic approach can be considered for any kind of port terminal, since all of them can be divided into three types described above.

3.2. The simulation model

The simulation of the expansion scenario of the ore terminal will be executed through a model validated with current operations and service level, obtained through analysis of data and collection of information together with mining company. The validation of the discrete events simulation model is a really important stage on the process of analysis of the capacity of the new terminal, from which the simulation model will may be considered a reliable tool to answer the questions of project.

The conceptual model is the enumeration of premises and rules to be considered at implementing the computational model. With the computational model ready it can be possible the search for the validation through input data that represent the performance and characteristics of simulated system (validation) which can generate a review of conceptual model and reimplementation of computational logic. Figure 2, adapted from Chwif and Medina (2007), represents this interactive process, executed until the model is validated and able to be used to represent the system with its improvements and expansion.

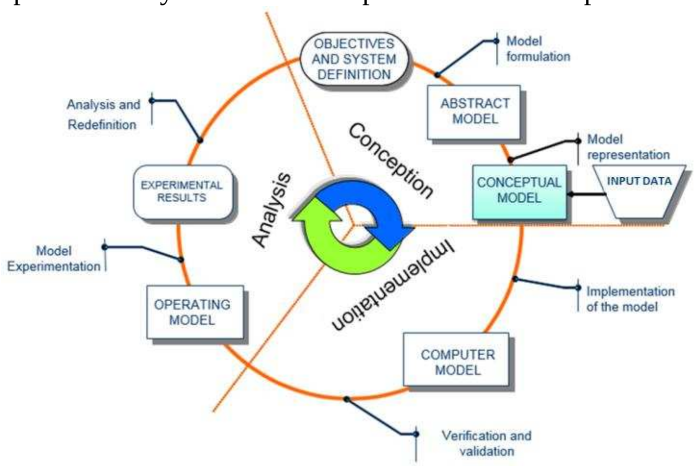

Figure 2: Representation of steps followed in a simulation project (Source: Chwif and Medina 2007).

With a simulation model representing expansion scenarios, it is possible to determine the capacity of the terminal using the concept of capacity associated with the service level for operations at the terminal.

3.3. Capacity associated with the service level

According to Gualda (1995), modeling of transport terminals should help the planning and decision making about solutions to be adopted at planning, conception or expansion of a terminal. Still, the capacity of a transport terminal is obtained through the determination of maximum level of the demand imposed to the terminal in a pre-defined period of time, without any criteria of stipulated service level is violated.

Service level is a rate of performance “offered by a component, subsystem or system, that aims to translate the quality of the service offered by the terminal and that can be measured” (Gualda 1995). The capacity of the terminal, therefore, is given by the lower capacity of components and subsystem, that is to say, by the bottleneck. This offered service level can be a competitive differential that is so important as the discount at prices, advertisement or favorable payment conditions.

With the simulation model, it will be possible to obtain several rates and service level obtained at operation of constructed scenarios and, from those results, major service levels of the terminal will be highlighted. Those who are not attended before will be verified, limiting, this way, the capacity of movement and exportation of iron ore.

Such methodology will be used for all defined subsystems and will allow a definition of what are bottlenecks of the operation. More than that, which subsystem will limit the capacity of exportation of this terminal.

4 CONSTRUCTION OF MODEL AND ANALYSIS

As described above, a simulation model that represents the operations on subsystems of the port terminal was built and, from the level of services to be considered, the expected answers about the capacity of the terminal will be obtained. It is important, however, that logics incorporated by the model are detailed, as well as expected service levels, by who use the services of the port terminal.

4.1. Discrete events simulation model

The discrete events simulation model was built in software ARENA® and it was included the modeling of three subsystems, interconnected. The Figure 3 shows the layout of discrete events simulation model developed with all the considered logics (discharge, storage and loading).

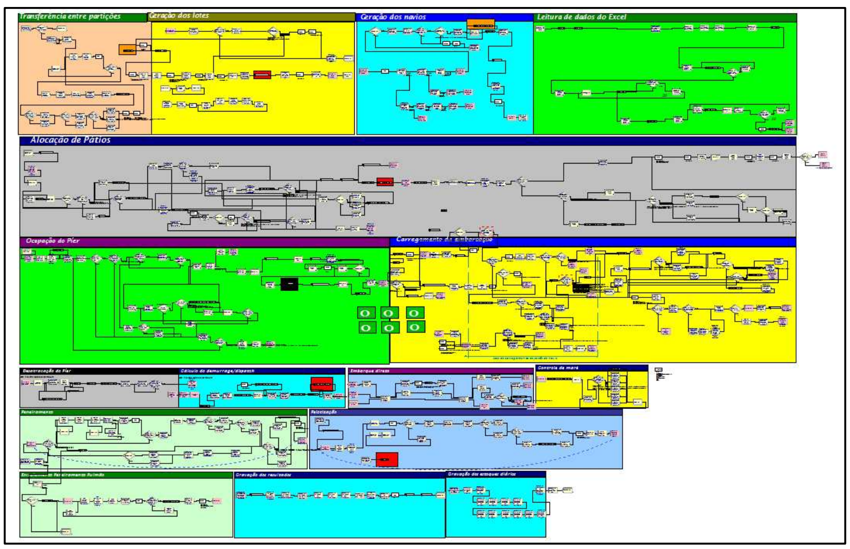

Figure 3: Layout of the discrete events simulation model developed in ARENA®.

The model size is 11 MB and its processing speed depends on the exported demand, lasting 2 or 3 minutes per replication (all simulations were done with 10 replications).

4.2. Conceptual model: Characteristics of subsystems

In a conceptual model, all logics and premises to be incorporated at computational model should be listed. Considering that the project uses systemic approach, a particular analysis of subsystems that compose the terminal, characteristics of each subsystem are numbered. The discrete events simulation model can be used with a few alterations to represent other terminals, since it aims to increase its coverage ability. That is to say, represent several terminals from a generic logic for port terminals.

- Discharge subsystem: major characteristics of this subsystem refers to trains and premises of operation of unload, that result at the operation of STACKING of ore at YARDS. Cargo to be unloaded is generated at the model from characteristics of ships to be attended and there is a concern with the maintenance of mass balance, since all products that arrive at the terminal should be divided into exported quantities and formed stocks. Major characteristics of this subsystem are:

- Trains are batches of 134 wagons with capacity to carry 103.5 t each one;
- Maximum number of trains (13,869 t of iron ore) per day: 20
- In order to start its discharge, the train must perform a maneuver at car dumper. This maneuver lasts, on average, 28.8 minutes according to a triangular distribution with a variation of 10% (TRIA(25.9, 28.8, 31.7))

- Storage subsystem: the storage of ore occurs from the moment products are unloaded and stacked at storage yard until the moment when the ship moored at the berth asks the loading of those products. In other words, the subsystem occurs since the stacking until the reclaiming of stacks.

Two different products will be moved at the terminal: pellet feed (99% of total) and sinter feed (1% of total), and the capacity of storage of yards vary according to the product due to different densities. Figure 4 presents the capacity of all six yards, divided into operational stacks, varying according to the product stored. Figure 4 also shows which stacks will be captives for both products.

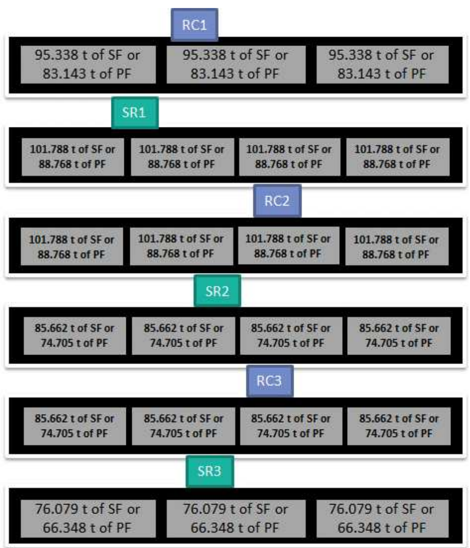

Figure 4: Layout of stockyard with location of piles and their allocated capacity for the different types of iron ore (SF: Sinter Feed, PF: Pellet Feed).

At the model, if a stack is occupied with a unload operation, it is blocked to the loading operation and vice-versa. About yard equipment:

- Reclaimers has a nominal rate of 8,000 t/h, but they operate with a commercial rate of 4,000 t/h, as well as reclaiming operations of SRs;
- SRs can operate as stackers and reclaimers, but operate prior as stacker and only reclaim at opportunities. That is to say, when there isn't demand for stacking;
- If a SR is reclaimed to a ship and there is the necessity to stack, it interrupts the reclaiming instantly;
- Car dumpers operate with commercial rates of 3,620 t/h;
- Stacking rate will be a consequence of productivity rates of car dumpers, since the nominal capacity of stacking of SRs is higher than the nominal rate of dumpers;

- Subsystem of loading: major characteristics of this system consider berths of mooring, ship loaders (SL) and the load line that direction the ore reclaimed at yards to the loading of vessels.

Figure 5 present berths of mooring and two installed SLs.

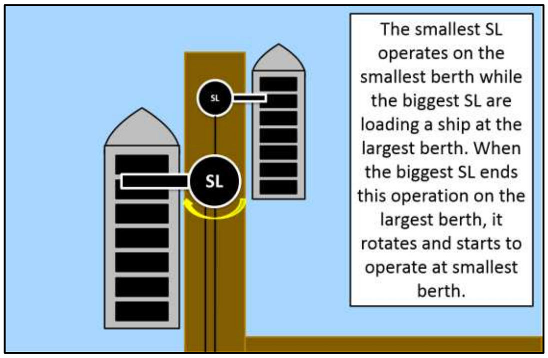

Figure 5: Layout of berths of mooring after expansion and improvements of the terminal.

Its major characteristics are:

- There are two SLs that operate at internal and external berths of the terminal, where one of them has a nominal capacity of 16,000 t/h and the smaller one has a nominal capacity of 12,500 t/h;
- The smaller SL operates only at the internal berth and the bigger SL can operate at both berths (preferably at external berth), with two reclaimers simultaneously;
- If there is a ship at external berth, it loads with SL of 16,000 t/h with 2 reclaimers, independently of having or not a ship at the internal berth (that, in this case, operates with the smaller SL and two reclaimers, limiting the load rate to nominal 12,500 t/h);
- While there is a ship only at the internal berth, it can operate with SL of 16,000 t/h and 2 reclaimers, considering a setup of 30 minutes after the end of load of the internal berth, and 30 minutes before the start of loading at external berth, due to the rotation of SL;
- It is important to say that during setup times the ship of internal berth continues operating with SL of 12,500 t/h. There is not an interruption of loading;
- The capacity of loading system of bigger SL is 16,000 nominal t/h or 8,000 t/h of commercial rate, and it can operate with 2 reclaimers;
- The capacity of loading system of the smaller SL is 12,500 t/h or 6,250 t/h of maximum commercial rate of this equipment;
- So, the SL of 16,000 t/h will always have priority at using two reclaimers for loading;
- Rates of stackers and ship loaders are a consequence of sequences of dumpers and reclaimers operations. However, if the smaller SL is operating with two reclaimers, the commercial rate of loading cannot be over 6,250 t/h, due to the limitation of the carrier of this SL;
- The model considers a setup time every time the SL of 16,000 t/h rotates to operate in other berth;
- The loading happens, preferably, with RCs, while SRs can reclaim only when they have the opportunity.
- A ship will never be loaded by two SL simultaneously;

Finally, it was defined the characteristics of ships considered at the simulations and how demands (total quantity of products) should be distributed for each type of ship:

- Small Cape (80,000 – 100,000 t): 0.8% from total demand;
- Cape (140,000 – 185,000 t): 63.9% from total demand;
- Large Cape (190,000 – 220,000 t): 2.1% from total demand;
- Very Large Cape (230,000 – 350,000 t): 33.2% from total demand.

In order to generate the vessels at simulation model, the amount of them required to meet the demand to be exported is calculated considering the fleet profile mentioned. With the amount, the interval between ships is obtained: average interval is calculated ensuring that these vessels arrive at port all within an year and it is used at an exponential distribution (EXP) to represent the arrivals of ships.

4.3. Considered service levels

The company of the maritime terminal established some service levels considered limiting to prevent the performance of the terminal to fail and, this way, to prevent the generation of unnecessary costs due to the payment of fines stipulated at contracts with navigation companies. Such fines generally take into consideration the time that ships wait on queue what is called demurrage, charged when the waiting is higher than the one stipulated at the contract.

To minimize queues, the terminal should operate with maximum efficiency. All subsystems should operate together to result in high productivity rates for ore loading so that the ships will keep moored for an acceptable time, minimizing the time that other ships wait on queue. Loading rates generally are measured in tons per hour and depend directly of reclaiming rates of ore at storing yards, at the interface between storage and loading subsystems. This way, it is considered the average time that ships wait on queue as an indicator that represents the service level of the terminal.

Other indicator that is verified by professionals responsible for the operation at the port is the occupation of installed equipment at the terminal. This occupation is the relation between time when equipment are operating and hours calendar of the period which the analysis is done, generally all 8,760 hours of an year. To mooring berths, the occupation is the relation between total time during the period considered for the berth to be unavailable for mooring of a ship because it is already being used by another vessel and it includes, also, the period in which ships are executing maneuvers of mooring and unmooring of berths.

The occupation of the equipment and the berth is very important because can result on an increase of the possibility of a ship wait a time bigger than the acceptable. Furthermore, very high occupations can compromise the terminal in case of necessity of preventive maintenance on the components of all the subsystems.

Therefore, the average waiting time of ships on the queue and the occupation of equipment and berths are the two main indicators that represent the level of service on the port terminal and the considered values are pre-set by the responsible for the operation of the terminal. The values to be considered are:

- Average time waiting on queue: 240 hours or 10 days
- Occupation of equipment and berths: 85%

A waiting time about 240 hours to begin the maneuver on berth is considered the maximum acceptable because is a time utilized in most contracts signed by the terminal and represents acceptable costs to be paid on demurrage. Moreover, the existence of a queue may be interesting to the terminal, since it decreases the idleness of system.

Uncertain events such as bad weather, equipment failure (corrective maintenance) and repairs are considered in estimating of commercial rates of equipment, valuated at 50% of the nominal rate (maximum capacity), a significant reduction in productivity of these machines. This reduction is based on standards that the mining company verifies at the operation of its terminals located along the Brazilian coast.

The occupation of resources of 85% is considered because, according to the company that commands the operation of the terminal, it enables that 5% of the time is used with preventive maintenance of subsystems and generate a commitment of 90%, a value that corresponds to the limit to prevent risks of stopping operations. This would cause loss of efficiency and, consequently, increase of queues.

5 VALIDATION OF THE MODEL

When the model is constructed it is necessary to verify if existent logics and rules were implemented in a correct way, if the model represents correctly the system we are studying. This verification of validity of a simulation model is called validation and should be done through performance rates and other parameters obtained at the analysis of real data from operation of the system.

In this paper it is considered a maximum absolute error of 10% between data provided by the company (owner of terminal) and the results of simulation model. If the model results present an error about 10% in comparison with the real data, the model is considered validated.

To the validation, it will be considered the operation done at 2013, and parameters obtained with the company referring to the operation of this year are:

- Attended demand (Mt/year): total quantity of ore loaded at ships;
- Total time of occupation of internal berth (smaller) and external berth (higher) (hours): time in which the internal berth is occupied by a vessel (remembering that this time includes periods of maneuver);
- Total occupation of internal berth (%): relation between time in which the internal berth is occupied and hours calendar of one year (8,760 hours);
- Total loaded at internal berth and external berth (mt/year): total quantity of ore loaded at ships at internal berth;
- Average commercial rate of loading at internal berth and external berth (t/h);
- Average occupation of berths (%): average occupation of both mooring berths;
- Total demand loaded directly at VVs to ships: this is the quantity loaded from the operation known as Direct Loading, where the ore that is discharged by trains passes through the storage subsystem directly to the loading of ships.

Having those values given by the terminal, it was possible to start the process of validating the model. So, some simulations were executed, input parameters and logics implemented were examined until obtained results were close to real values. This way, Table 1 present results of validation scenario, comparing them to real data given by the terminal and with absolute errors of each result.

Table 1: Results obtained at validation of the simulation model.

Parameter	**Data**	**Results Model**	**Abs. Error**
Attended demand (Mt/year)	39.5	39.3	0.4%
Total occupation time of internal berth (smaller) (hours)	7,218.19	7,125.70	1.3%
Total occupation of internal berth (%)	82.4%	83.2%	1.0%
Total loaded at internal berth (Mt/year)	10.3	10.2	0.7%
Total time of operation at internal berth (h)	5,341.77	5,399.03	1.1%
Average commercial rate of loading of internal berth (t/h)	1,932.3	1,875.7	2.9%
Total time of occupation of external berth (bigger) (hours)	7,858.66	7,689.34	2.2%
Total occupation of external berth (%)	89.7%	87.6%	2.4%
Total loaded at external berth (Mt/year)	29.2	29.0	0.4%
Total operation time of external berth (h)	6,384.95	6,035.69	5.5%
Average commercial rate of loading of external berth (t/h)	4,566.0	4,443.9	2.7%
Average time of waiting on queue (h)	156.36	170.83	9.3%
Average occupation of berths (%)	86,1%	85,4%	0,8%
Total demand loaded directly from VVs to ships (Mt/year)	12.3	11.1	9.7%

The Table 1 shows that the maximum error obtained was 9.7%, within 10% acceptable limit and thus the model can be considered validated and ready for simulation of scenarios of expansion.

6 RESULTS

With a validated model aims obtaining the capacity of ore terminal with expansions planned by its owner. To make this happen, it should be observed service levels listed at section 3.2 that limit the capacity of the terminal. After configuring the scenario with previewed improvements, the demand to be moved by the terminal should be gradually increased until one of the subsystems present itself as a bottleneck, with an occupation higher or equal to 85% in any of its resources (equipment). So, simulating the expansion scenario and using a scenario with 40 million tons per year of moved demand, we varied this demand (4 to 4 Mt/year) and it was observed that amongst all occupations of systems and equipment, the one that had a fast growth was the average occupation of mooring berths, from loading subsystem (Figure 6).

It was obtained a scenario where the average occupation of berths reached the value of 85% and became the service level that limits the capacity of terminal.

Results obtained at simulating the movement of those 64 Mt/year are presented on Table 2.

Table 2: Results obtained at simulating the expansion scenario.

Operational indicator	**Simulation Result**
Total demand discharged at the terminal (t)	64,167,563.6
Total demand loaded on ships (t)	64,111,300.9
Number of vessels generated during simulation	340
Average time in queue of ships (h)	75.6
Average occupation of berths	84.8%
Average occupation of extern berth	85.7%
Average occupation of intern berth	84.0%
Average occupation of smaller SL	79.7%
Average occupation of biggest SL	48.8%
Average loading rate in smaller SL (t/h)	6,960.9
Average loading rate in biggest SL (t/h)	3,624.5
Total demand (t) attended by biggest SL	48,628,992.1
Total demand (t) attended by smallest SL	15,482,308.8
Total demand (t) attended by external berth	41,419,462.5
Total demand (t) attended by internal berth	22,691,838.4
Total waiting time for tide - mooring at external berth (h)	504.4
Total waiting time for tide - mooring at internal berth (h)	704.5
Occupation Stacker-Reclaimer SR1	76.6%
Occupation Stacker-Reclaimer SR2	77.1%
Occupation Stacker-Reclaimer SR3	76.8%
Occupation Reclaimer RC1	41.4%
Occupation Reclaimer RC2	73.7%
Occupation Reclaimer RC3	63.6%
Load at biggest SL with 1 reclaimer	2,933,423.1
Load at smallest SL with 1 reclaimer	4,555,805.4
Load at biggest SL with 2 reclaimers	45,695,569.0
Load at smallest SL with 2 reclaimers	10,926,503.4
Average Occupation of Car Dumper's	62.0%
% of time with interference between the SL's	60.2%
Turns of SL between internal and external berth's	128.0
Percentage of time of biggest SL in the Internal Berth	14.7%

It can be observed, then, that the maximum demand to be moved at the terminal, to prevent a loss of service level, according to the concept of capacity associated to service level, is 64.1 Mt/year. This means that, with the expansion, moved demand (capacity of terminal) increase from 35 Mt/year to 64 Mt/year. Analyzing results of Table 2 it can be observed that amongst considered service levels (occupations and time on queue), the average occupation of berths obtained was 84.9%, the only rate of performance that reached a value close to the limit of 85% and the average time of waiting on queue was 75.8 hours. As mooring berth is a component of loading subsystem, it can be concluded through systemic approach that this subsystem is the bottleneck of the studied ore terminal, and the capacity of the terminal after expansion is 64 Mt/year.

Figure 6 presents a graphic that relates the average occupation of mooring berths to the annual demand moved at the terminal as mentioned.

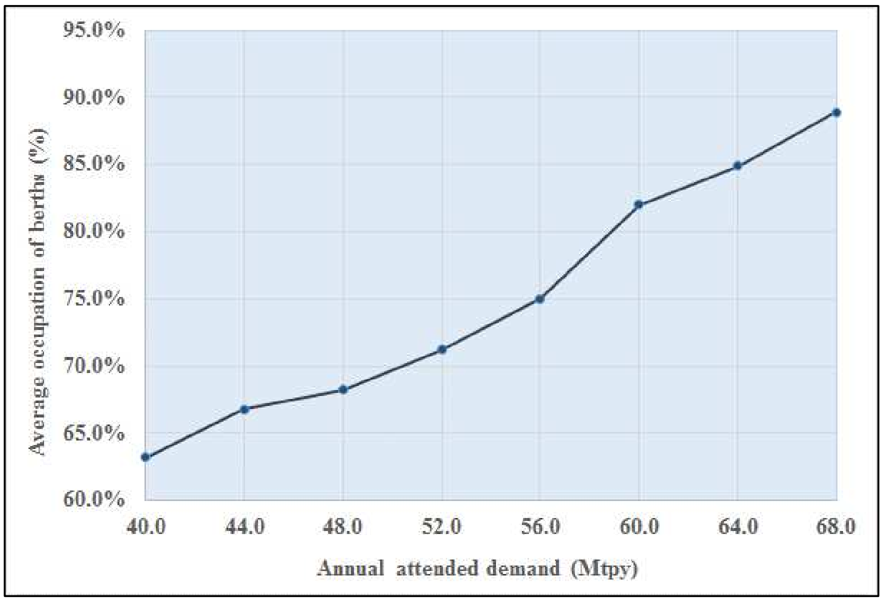

Figure 6: Graphic: Average occupation of berths (%) x Annual attended demand (Mt/year).

7 CONCLUSIONS

This paper had the objective of, using concepts of systemic approach and capacity associated to service levels, propose an analysis of results obtained through a simulation model and determine the capacity of movement of products in a port terminal.

The first step after the construction of the simulation model was the validation of it from data given by the company that own the port operations of the terminal, which handled 39.5 million t of iron ore in 2013. After that, it can be considered able to give results that enable the determination of maximum capacity of exportation of the terminal, analyzing such results in function of service levels considered for the operation So, it was obtained the maximum capacity of the terminal with increases: 64.2 Mt/year, an increase of 24.7 Mt/year, and the identified bottleneck was the loading subsystem, since the service level limited the increase of demand due to the average occupation of mooring berths.

On expansion of terminal, the berths are the only resources that would achieve the 85% utilization threshold, all the other resources were below. In 2013, the average occupation of berths (%) it was of 86.1%.

The concept of capacity associated to the service level is, so, a really important and useful tool to execute projects that considerate implantation and improvements or expansion of terminals, such the studied ore port, allied to systemic approach that considerate different subsystems that compose a terminal, making it possible to determine the maximum capacity of movement of products and also what should be the next step of this project. This is because we know what is the bottleneck of the system, making it possible to look for an increase of capacity through other actions executed directly to the identified restriction.

As recommendation for future works is proposed that an analysis of the operation described and modeled in this paper be done from modeling the handling of the iron ore at the port continuously (using loading & unloading rates) and the arrivals of trains and departures of ships, discretely, adopting a combined simulation approach.

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