CHALLENGES ON ORE PORT SIMULATION

Marcelo Moretti Fioroni [(a)], Caio Eduardo Zanin [(b)], José Alexandre Sereno Quintáns [(c)] Lúcia Dini Pereira [(d)] , Isac Reis de Santana [(e)] , Paulo Savastano [(f)] , Luiz Augusto G. Franzese [(g)] , Vítor Luciano de Almeida Benevides [(h)]

[(a)(b)(c)(d)(e)(f)(g)]Paragon Tecnologia – R. Clodomiro Amazonas, 1435 5th floor – São Paulo, SP – Brazil - 04537-012
[(h)] Anglo Ferrous Brazil - Av Inf Henrique, 345 – Rio de Janeiro, RJ – Brazil - 20021-140

[(a)]marcelo@paragon.com.br, [(b)]caio@paragon.com.br, [(c)]alexandre@paragon.com.br, [(d)]lucia@paragon.com.br, [(e)]isac@paragon.com.br, [(f)]paulo@paragon.com.br, [(g)]augusto@paragon.com.br, [(h)]vitor.benevides@angloferrous.com.br

ABSTRACT
There are several challenges involving the representation or an ore loading port system on a simulation package. This kind of port handles bulky material, much more adequately represented by continuous flow then discrete flow, as in opposite to the case of a container-handling port. This paper addresses some challenges faced such as the navigation restrictions to enter/leave the berth, the stacker/reclaimer position in the ore pile, the impact of meeting product mix requirements in the delivery and the loading plan for the ships. When these aspects are not represented under the correct level of detail, the model can present poor results. Also, results reporting challenges are addressed in this paper. The modeling approach of each of these aspects is presented, and the experimentation in the case of Porto do Açu, located at Rio de Janeiro, is addressed with the purpose of evaluating the efficiency of the solutions proposed.

Keywords: simulation, port, iron ore, ore pile

1. INTRODUCTION

Some of the most favorable applications of simulation studies are port projects. Ports involve expensive equipment, large scale cargo movement and heavy fines for delays. Also, the efficient use of ports is critical to countries, since they are the most important structure demanded to drain the export production.

This kind of simulation study becomes even more important if the port is not yet constructed, and is in the design phase. The simulation of the chosen design can help find problems or improve performance. It can save millions only by avoiding some design or operation mistakes that would be much more difficult to correct with an operating port.

Countries that are great commodities producers and exporters have ports specially designed to load bulky products like grains or coal into ships that are also specially designed to carry these types of products.

An ore loading port system presents characteristics that differentiate it from other kinds of ports:

- The product to be loaded is bulk material. Thus, a very specific system is needed move the material from one place to another. Usually, this is done by conveyor belts.
- The bulk material must be stored in piles. These piles must be handled by equipment specially designed for this purpose: stackers, that store material and build the pile, and reclaimers, that remove material from it.
- Specially designed equipment is necessary to load ships: the shiploader. It is fed by a conveyor belt that transports ore from the pile into one of the ship's compartments.

Also, bulk material ports present other usual problems that are common to regular ports:

- Ship arrivals must follow traffic rules involving weather, channel occupation and tide variations.
- There must be balance between product arrivals and ship arrivals, or the storage space might not be enough.

To simulate this kind of system some techniques and modeling approaches were applied to face each challenge, and they are all presented in the following sections of this paper. These techniques were validated over a real case, which presents all the characteristics listed above.

2. MAJOR CHALLENGES

First of all, the simulation of an ore handling port is very different from other kinds of ports, at which discrete cargo like containers are received, stored and loaded. This class of problem has been extensively studied, and some reference work is that of Meisel & Bierwirth (2009) and Karlaftis, Kepaptsoglou and

Sambracos (2009). The solutions and algorithms proposed in these studies do not apply to a continuous cargo flow port. These being the case, new developments were required to achieve a correct process representation.

2.1. Rules for Ships Entering or Leaving the Port

When approaching or leaving the port, ships follow certain rules or restrictions. Some of these rules apply to any port, while others apply only to bulk material ports. The list below details a worst-case scenario for these rules and restrictions:

- There is only one waterway channel. Thus, it is not possible to have more than one ship entering or leaving the port at the same time. In this case the priority is for ships leaving the port.
- There are a limited number of berths. A berth must be free before the ship enters the channel.
- The weather conditions must be good enough to allow ship mooring.
- Large loaded ships must wait for the correct tide to leave the port.
- A ship may not enter the channel if there are not enough products on stock to allow loading.

These restrictions must be cautiously implemented, since they can cause either deadlocks or wrong behavior. An example situation is when one ship leaves the berth at the same time that a queued ship, which was waiting for berth availability, goes ahead and seizes the channel. Since the first ship did not leave the port yet, it needs the channel. When the second ship arrives to the berth, the model will be representing an impossible situation: two ships at the same berth.

Many of these rules and restrictions are dependent from each other, and the implementation of some of them requires the use of information from other parts of the system (yard, weather, etc.). All of this must be remembered when modeling.

2.1.1. Modeling Approach for the Ships

To implement the circulation of ships at the port, separated algorithms for arriving and departing ships were developed.

Arriving ships must check:

a. If the weather is good to sail.
b. If there is enough product in the yard to load this ship.
c. If one berth AND the channel are free.

Departing ships must check:

a. If the weather is good to sail.
b. If the tide variation allows circulation of a ship of this particular size.
c. If the channel is free.

2.2. Ore Pile Slot Division

The ore is stored in piles and handled by equipments named stackers and reclaimers (some are stacker and reclaimer at the same time). This kind of equipment works connected to the conveyor network, so it can remove/store the material directly to/from the conveyor belt.

These piles are normally long, and the stackers/reclaimers are normally located at one or both sides of the pile. The stackers and reclaimers move over an axis parallel to “b”. Any position of the pile can be reached by these equipments, which move over a track system. To store different products on the same yard, different piles may be formed. Figure 1 shows the main parameters of a pile and its aspect.

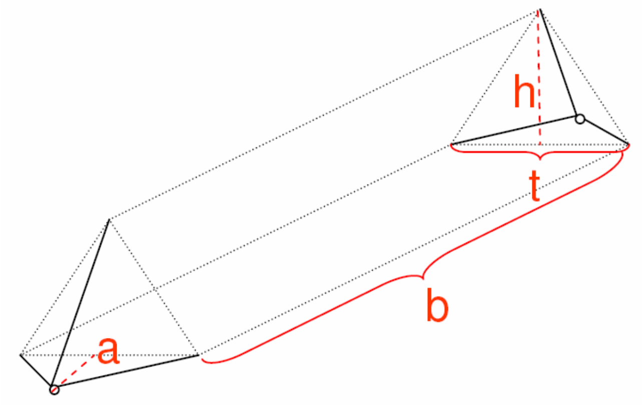

Figure 1: Parameters and aspect of an ore pile

Dimensions a, b, t and h define the pile’s geometry, and depend on the kind of ore being stored. The “b” axis is divided into “slots” of 5 meters each, so that a record of each pile’s position can be kept.

The challenge is to model the ore stored at each slot, and the stacker or reclaimer movements over the “b” axis. The movements and ore storage/consumption must be synchronized, and follow the company’s policy for handling the ore.

2.2.1. Modeling Approach for the Pile

In this case, the most important aspect is to represent the storage of ore at the correct position in the pile. This can be done by using a variable with as many lines as the number of slots in the pile. In fact, the ore position will rule the stacker/reclaimer position. Therefore, once the pile is modeled, the stackers and reclaimers are impelled to reach the correct slot.

Every time the system needs to recover or store the ore, it follows the algorithm:

a. Check if the stacker/reclaimer is in the first slot to be handled in the pile.
    a. If the equipment is not there, move it to that slot.
b. Begin the storage/consumption of the ore on this slot.

c. If the material batch was accomplished, finish the operation.
d. When the slot is full (if storing) or empty (if recovering), change the first slot to the next one.
e. Go back to step a.

By doing this, the equipment movements will be considered in the simulation, conferring it with a high level of detail. Other ore yard studies, like Fioroni et. al. (2007) and Coelho et.al. (2005), do not go further on that detail level.

2.3. Balance between Ship Arrival and the Production

One of the problems when representing a sub-system of a much larger system, is the impact of the other sub-systems on the one represented.

In this case, the arriving ships must load ore that comes from a mine, passes through a beneficiation plant, a mining duct and a filtering process, a railroad or other sub-systems. The problem is that the type of ore sent from the mine must match the type of ore to be loaded into the arriving ship, days later. Lack of product type matching may cause an excess of an unrequired product type at the yard, while the system may be out of stock for the required product type.

In the worst situation, this can cause a deadlock in the simulation model. For example, there could be a situation where a ship has arrived to the port but cannot enter the berth because it needs product A, and there is only product B in stock. Product A is being received by the port but the yard is full, so product A cannot be stored. In the meantime, a second ship that needs product B has arrived, but remains in the queue because the first ship is on delay. In a real situation such as this one, the operational managers could decide on a number of alternatives to solve the problem. Hence, the simulation model must be prepared to respond to such cases.

2.3.1. Modeling Approach for Production and Dispatch Balance

In this case, the weakness of the model can become its strong point: the model lacks the representation of the entire production line of the real system, but it “knows” which ship will arrive, and when, and what product will be loaded into it. With this information, the product arrival at the yards can follow the ship arrivals, balancing the storage area.

It is important to note that this approach is based on the premise that the commercial team does not make mistakes, and the production of the entire system worked as expected, which is not always true, but valid to check the sub-system’s maximum capacity.

2.4. Loading Plan for Different Types of Ships

Ships that transport ore are loaded by certain equipment, the shiploader. This equipment drops ore continuously into the ship’s compartments, one by one, until the ship is completely loaded. However, the loading process cannot access the different compartments at any random order. If all compartments in one side of the ship are loaded in sequence, the weight of the material and the impact of its fall is likely to sink the ship to the side. There is also a risk of breaking the ship’s structure in two parts due to excess weight in the middle section.

In order to avoid these and other operational risks, the ships are loaded in a sequence of steps called loading plan. Each step of the loading plan is determined by a compartment to be accessed and a quantity of ore to be loaded.

The key challenge here is to account for the movements of the shiploader accessing each compartment, which are part of the loading process, but consist in a time spent with no actual ore dropping into the ship.

2.4.1. Modeling Approach for the Loading Plan

The loading plan can be controlled in the simulation model through the use of a matrix variable that represents the compartments and the sequence of loading steps.

The incoming ships vary in terms of their capacity. Since the difference of loading procedure can be significant between a very small or a very large ship, two or more loading plans can be inputted to the model, each one to be applicable to a different category of ship size. Thus, the idea developed is to minimize the number of different loading plans inputted to the model, as opposed to inputting as many loading plans as there are ships to it.

Furthermore, in the approach designed, the compartments are to be filled with a fixed quantity of ore at each step of the loading plan. As the ships vary in terms of capacity, the number of steps will also vary according to the ship capacity.

Both the minimized number of different loading plans and the fixed quantity per step approaches are simplifications that accurately represent the loading process in the ore port, but allow reducing the amount of data inputted to the simulation model.

3. CONCEPT APPLICATION

3.1. The Case of Porto do Açu, LLX

LLX is a company that belongs to the Brazilian holding EBX, which administrates a portfolio of businesses in mining, logistics, oil and gas, real estate, traditional and renewable energy and entertainment. LLX focuses on the development of logistic infra-structure, especially in the portuary area. Porto do Açu is an LLX port, currently in the design and construction phase, developed to receive very large ships and to handle several different types of cargo, including containers and also ore from MMX / Anglo Ferrous mines in the state of Minas Gerais.

The focus of the simulation developed for the case of LLX was:

- Validating the designed conditions for the equipments and operational rules of the port, verifying if the volume loaded is in accordance with what is being budgeted. The operational times of ships are also object of validation.
- Verifying the impact on the overall indicators of operating two different products and not only one.
- Verifying the possibility of, in a longer future, increasing the port's capacity only by installing larger shiploader equipment.
- Verifying the impact on the overall indicators of operating larger ships vs. smaller ones.

3.2. The Major Challenges Emerge From the Objectives of the Simulation

The major challenges that have emerged from the simulation of Porto do Açu are all results of the need to represent operational rules and details that have a significant impact on the overall indicators that are the main object of the simulation.

The navigation restrictions have a direct impact on the time that each ship spends in each phase of the process in the port. This has an impact not only over the total time spent by each ship in the system, but also over the occupation rates of resources such as berths and the total volume loaded annually at the port.

Furthermore, the correct representation of the movements of stackers, reclaimers and shiploaders across yards and ship compartments is essential for the correct assessment of the real hourly capacity of these equipments. Had the time spent on these movements been very few, they would be irrelevant. However, these movements have consumed up to 15% of certain equipments available time in some simulated scenarios, which has a clear impact on the annual loading capacity of the port, as well as in these equipments´ occupation rates.

Moreover, the need to test the ports indicators in situations where more than one product is being handled makes it inevitable for the simulation analyst to deal with the problem of meeting required product mix. While this aspect had not yet been effectively taken in hand, in the model validation phase, the simulation developed for LLX presented several scenarios of deadlock results due to the excess of one type of product and the lack of another. It is also important to note that although the stocking areas capacities were represented in the model, the goal was not to check if the stocking area had been correctly sized. If this was so, there might have been necessary to face the product mix challenge in a different way.

In short, it must be said that the approach chosen to represent the process at Porto do Açu allowed the correct assessment of the main indicators of the simulation.

Since the port is not on duty yet, and are being built while this paper is written, the regular validation process was not used since there is no real data to be compared with the simulation results. So all results was evaluated by the port designers, whose experience on the process was used to criticize the results and detect wrong behaviors.

4. RESULTS

Having adequately represented key issues in the process at the ore loading port, there are still some challenges to be faced on the reporting of the results obtained by a simulation model, built in the ARENA discrete-event simulation tool. The adequate reporting of the simulation results allows the interpretation and analysis of the simulation model and leads to the answers of the questions primarily asked in the project.

This simulation study followed the process proposed by Valentin et.al. (2005) to simulate maritime infrastructure, were a simulation expert builds the model and perform the experiments. Then, the results are analyzed by the port expert.

4.1. Result Reporting Challenges

The main challenges on the reporting of the results obtained by the ore loading port simulation are a result of two circumstances:

- When one rule is composed of several sub-rules or conditions, it may occur that the behavior of a system in a certain point in time cannot be explained by the occurrence of non-occurrence of one of these conditions but by an ensemble of them. In the case of the port, the navigation rules of the ships leaving the system state that three conditions must be met at the same time: The tide must be adequate, the weather must be good and the channel must be free. In a certain point in time, if both the channel is occupied and the weather is bad, a ship is retained in the berth, but the time retained can be attributed neither to the channel not to the weather.
- When a simulation model takes in consideration the preparatory movements of equipments (to begin a task), such as it is the case for the stackers, reclaimers and shiploaders, the total time spent in an operation cannot be attributed solely to equipments capacities to process a given material, but also to equipments capacities to prepare to process a given material. Thus, the equipments capacities must be described as a pair of

capacities: the processing and the preparation capacities.

The solutions adopted to solve these reporting challenges were as described below.

4.1.1. Reporting Results of Navigation Conditions

Navigation rules at ports are, as stated before, a combination of different conditions that must be met. To report results related to navigation conditions, the approach used started by the determination of an hierarchy of conditions, from the strongest condition to the faintest. The strongest conditions are the ones which are very unlikely to be altered by process managers. In opposition, a faint condition is one that can be suppressed by a change in infrastructure.

In the case of ports, a good example of a strong condition would be the climate restriction for ship navigation, since humans have, we can say, no control over the weather. On the other hand, the channel restriction is quite faint, since there is always the possibility of excavating a second channel for a port.

The logic adopted is to attribute all of the time when the strongest condition was present directly to it. Since it is the strongest condition, it should be very hard to get back this time. In the opposite situation, the time attributed to the faintest condition will be the time when only this condition was present, which could be gained if the condition could be suppressed.

To illustrate this principle once again the example of the port outbound navigation is applicable. In this case, the conditions are: The weather must be good (strongest), the tide must be adequate (middle), and the channel must be freed (faintest). Thus, the waiting time to leave the port is reported according to the diagrams that follow.

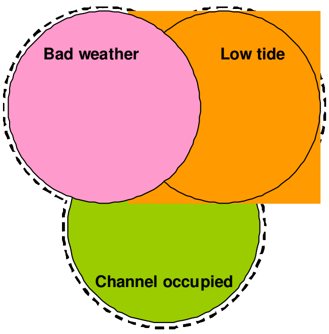

Figure 2: Outbound navigation waiting time reporting for ore handling ports

Table 1: Outbound navigation waiting times reporting for ore handling ports

Time reported	Colors
Total time	Total time
Bad weather time	Bad weather
Low tide AND good weather ->> Time that could be spared in case the surface of the ocean is dredged: useful to analyse the benefit of dredging the surface of the ocean.	Low tide AND good weather
Time of occupied channel only ->> Time that could be spared in case other channels are dredged: useful to analyse the benefit of dredging other channels.	ONLY occupied channel

4.1.2. Reporting Equipment Occupation

Equipment occupation, in a situation where the preparatory equipment movements are considered, must be reported separating these movements from the main equipment material processing. This separation allows the assessment of the impact of the two different classes of capacities of the equipments: the preparatory capacity and the processing capacity. Henceforth, it is possible to understand weather a better overall performance of equipment can be attained by increasing one or the other capacity.

In the ore handling ports, this difference becomes clear when we imagine a situation where 30% of the time of equipment is occupied with processing and 20% with preparatory movements, in an overall 50% occupation. In this case, if the processing capacity is doubled, a probable outcome would be a 15% occupation with processing and 20% with preparatory movements, summing up a global 35%. Although the processing capacity was doubled, the occupation did not drop by half. The analyst may explore, in these cases the possibility of increasing not only one of two capacities to obtain a better overall performance.

4.2. Results Obtained With the Simulation

The results obtained with the simulation showed that the overcome of the modeling challenges described in this paper were essential to the validation and the experimentation over the model of the ore handling port.

First of all, the complete treatment of the mixed product handling situation given to the model allowed a comparison of two extreme scenarios: a first scenario with only one product flow and a second scenario with a two product-demand for all ships. The demand of two products for a ship causes the shiploader equipment to perform additional preparatory movements, which increase dramatically the occupation of this resource. The chart that follows illustrates the occupation of resources in both scenarios.

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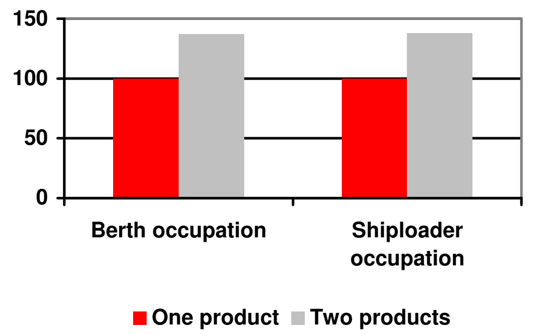

Figure 3: Occupation of resources in scenarios with one and two products per ship (indexed)

Also, the treatment given to preparatory movements allowed the comparison between two scenarios with different shiploader processing capacities. The comparison showed that a 30% increase in shiploader capacity provoked a 13% increase in maximum volume loaded annually.

Finally, the impact of operating larger ships vs smaller ones was the object of an assessment using the simulation model. The results showed that the use of larger ships in the port has very little impact on the volume of material that can be loaded annually. As ships get larger, the time spent by each ship in the port gets bigger, and the number of ships loaded per year gets smaller. In this situation, the occupation of berths does not grow significantly, and nor does the occupation of other resources such as shiploaders. Another way to read these results is to say that the variation of time spent by each ship at the port vs the size of the ships is fairly linear. In other words, the fixed time spent by ships in the port, which involves activities such as channel transit and docking, represents a very small percentage of the total operating time of each ship in the port.

5. CONCLUSIONS

In this paper the main challenges faced to simulate an ore handling port are described. These challenges consist of the development of an innovative approach for modeling certain situations, and may also apply to other simulation cases that present similar challenges.

The development of this approach has allowed an adequate representation of the operations of an ore port and the evaluation of several questions related to the port project.

The lessons learned on this study were:

- To simulate the process in high detail is not ever the best option. The ore piles representation considering every single slot of the yard and the pile geometry, gave a nice improvement on the precision. But at the cost of a hard work on coding the model. And, for a strategic study, the additional precision was not relevant. It would have better use on a tactical or operation study.
- When simulating a “non existing” system, the participation of specialists on the process is critical. In this case, the port designers were very experienced on other ports, ore yards, belt operations, ship queues and so on. It helped a lot to reach a reasonable conclusion for the study.
- The use of a good simulation tool is very important in these studies, when there is a phase of frequently updating the model code, while the port specialists pointed problems on the results. The flexibility and very nice documentation capabilities of the chosen tool, the Rockwell Software ARENA, was critical for the successful ending of the study.

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REFERENCES

Karlaftis, M. G., Kepaptsoglou, K., Sambracos, E. 2009. Containership Routing with time deadlines and simultaneous deliveries and pick-ups. In *Transportation Research Part E*, n.45, p210-221. ed. Elsevier.

Meisel, F., Bierwirth, C. 2009. Heuristics for the integrationof crane productivity in the berth allocation problem. In *Transportation Research Part E*, n.45, p196-209. ed. Elsevier.

Coelho, R.J.; Fioroni, M. M. 2005. Estudo de expansão do sistema de manuseio de matérias-primas da CST através de simulação. In: 60° Annual ABM Congress. Belo Horizonte, MG, 25 - 28 jul., 2005.

Fioroni, M. M., Franzese, L. A. G., Fúria, J., Perfetti, L. T., Silva, N. L. 2007. Simulation of Continuous Behavior Using Discrete Tools: Ore Conveyor Transport. In: Winter Simulation Conference, 2007, Washington DC.

Valentin, E. C., Steijaert, S, Bijlsma, R. A., Silva, P. 2005. Approach for Modeling of Large Maritime Infrastructure Systems. In: Winter Simulation Conference, 2005, Orlando FL.

AUTHORS BIOGRAPHY

MARCELO MORETTI FIORONI is a simulation consultant with an Electrical Engineering degree, MSc. in Manufacturing and PhD in Logistics at University of São Paulo (USP). Has participated in almost 150 successful projects with simulation. Co-founder of PARAGON Tecnologia in 1992, the pioneer and leading consulting company in simulation in South America. Teaches Simulation at Faculdades Metropolitanas Unidas (FMU) in São Paulo, Brazil. Has trained more than 1,200 professionals in simulation. He

can be contacted by email at <marcelo@paragon.com.br>

CAIO EDUARDO ZANIN is a simulation consultant with an Electrical Engineering degree. Has participated in almost 10 successful projects with simulation and teaches simulation in Paragon. He can be contacted by email at <caio@paragon.com.br>

LUIZ AUGUSTO G. FRANZESE is a simulation consultant with a Production Engineering degree and MSc. in Logistics, who has completed almost 150 successful projects with simulation. Founded PARAGON Tecnologia in 1992, the pioneer and leading consulting company in simulation in South America. Has trained more than 1,200 professionals in simulation. He can be contacted by email at <augusto@paragon.com.br>

LUCIA DINI PEREIRA is a simulation analyst with a Production Engineering degree from the University of São Paulo (USP) and a diploma for specialized Logistics studies from École Centrale de Lyon, in France. Her background is in decision-making analysis and mathematical modeling in several organizations in Brazil. She can be contacted at <lucia@paragon.com.br>

JOSÉ ALEXANDRE SERENO QUINTÁNS is a simulation consultant. He has participated in almost 10 successful projects with simulation and teaches simulation in Paragon. He can be contacted by email at <alexandre@paragon.com.br>

ISAC REIS DE SANTANA is a simulation consultant. With Technical Degree, he has participated in almost 10 successful projects with simulation and teaches simulation in Paragon. He can be contacted by email at <isac@paragon.com.br>

PAULO SAVASTANO is a simulation consultant. He has participated in almost 10 successful projects with simulation and teaches simulation in Paragon. He can be contacted by email at <paulo@paragon.com.br>

VITOR LUCIANO DE ALMEIDA BENEVIDES Coordinator for the project of implantation of Porto do Açu. Mechanical Engineer degree from Universidade Federal do Espírito Santo – UFES. Doing masters degree in Management at the Fundação Getulio Vargas – RJ. Specialist in Internationl Commerce and Logistics by the same university. He can be contacted by email at < vitor.benevides@angloferrous.com.br>