Handling seasonal uncertainty in a fertilizer inbound maritime terminal

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ABSTRACT

Big and stable logistics systems fail to fast respond to market change given the necessity to coordinate a large number of departments with different skills and different objective. For some types of supply chains such effort is crucial to guarantee the success of an operation. This paper presents one of those effort applied in a maritime inbound terminal, it was developed a simulation model representing a fertilizer importing system with its unloading berths, warehouse, and railroad subsystems. Beyond several complex behavior such as maneuverability constraints, and the different types of rates (commercial, bare, and effective) to have a realistic OEE output, it was included the seasonality of the demand. This last element capable the model to derive accurate conclusions in terms of capacity, service level, inventory and queue dynamic over the seasonal period (one year). In this study it was recommended two main policy changes: (1) the harsh imposed by the seasonality; (2) the capability of the terminal to operate a different product during the low season.

1 INTRODUCTION

A simulation model is a mathematical representation of a system with the objective of evaluation operational impacts by a significant modification. The configuration of the system under study may represent a new equipment acquisition, improvement efforts, or even personal training. The study described in this paper simulates a maritime bulk handling terminal called “Terminal de Produtos Diversos” (TPD) operated by VALE S.A., a commodity multi-national company situated in Brazil. To create this model it was used the discrete event simulation technique ARENA, form Rockwell Automation. Particularly this study is focused on TPD4, which is responsible on fertilizer handling.

One particular challenge to model this system was its seasonal behavior of the operation. The fertilizer operations occurs mainly between August and December. This characteristic requires, from the model builder perspective, extra care in the use of statistics concepts, and regular mathematical techniques. The main reason for such care is the wrong impression that the system is not efficient given the low demand. Classical questions like: (1) the identifications of the bottleneck; (2) the capacity of the terminal; (3) the dwell time of the product; (3) the service level, and (4) how the neighborhood terminals impacts the TPD4 operations; needed to be very carefully analyzed to not take wrong conclusions. Such risk is remarkably high if it was used an oversimplified model. The seasonality issue in the fertilizer business is critical since the operations is concentrated in the second semester of the year. Hence infra-structure needs to be accordingly dimensioned, and operations should be precise to avoid idle time.

In a model perspective, not only several states of the system should be capable to change in monthly basis, but also the capacity and the offer of products should follow the market demand. Moreover, the
output of the model should be tracked in the same manner, in order to have it valid and reliable enough to derive recommendations.

According to (Ludolfo 2011) Brazil figures out as one of the major agricultural exporters, and the majority of its cargo is shipped through maritime ports. To make grain operations internationally competitive, it is necessary to have an adequate infra-structure, modern operations with specialized terminals that contributes to have an efficient harvest. Consequently, the plantations requires the farmers to have enough fertilizer on hand to prepare the soil with proper nutrients. Unfortunately, Brazilian infra-structure for producing fertilizers is not adequate to fulfill its necessity. Hence, according to (Agrosoft 2008), Brazil imports about 60% of its fertilizers necessary for agribusiness industry. In such context, V ALE S.A. has been exploring such market successfully with the benchmark operation of TPD4. Some historical aspects, this maritime complex was started at 1966, initially only handling iron ore. In 1983 they started to handle coke, coal and manganese. After three years they started to operate bulk liquid (oil and gas). Finally, by 1998 they started to operate grain and fertilizer (VALE 2008). The figure below can show the TPD 4 location among the complex (Figure 1).

![Figure 1: Aereal view of Tubarão Portuary Complex - Details of TPD 4.](image)

Located in Tubarão Port Complex, TPD4 is situated in the state of Espírito Santo, at the southern of Brazil. This state accounts for about 3.5 Million inhabitants. The biggest player in this complex is VALE. The complex is served by a railway system called "Vitoria-Minas", based on a metric gage (1 meter of distance in the axis) this railroad has about 900 km of extension, and connects the state of Espírito Santo
with Minas Gerais. Minas is an important ore exporter in Brazil, and it is closer to the center-west region, where the majority of plantation is located.

With such business importance, the objective of this study was to develop a simulation model where the most important constraints were analyzed in order to have a reliable analysis of the capacity of the terminal. Such analysis needed to consider the strong seasonality of the system otherwise the system would be dimensioned to the peak of the operations, which is not the most economical decision. To explain how those objective were reach, this paper is organized as follows: (1) A brief introduction about the problem, and in which context it was analyzed; (2) The literature review of the fertilizer context, previous initiatives to tackle such problem, and similar researches; (3) A description of the methodology applied in this study, with the main points of the conceptual model and assumptions used in the research; (4) Data and parameters of the experiments used in the study to validate the model, as well as, to run exploratory scenarios; and finally (5) the conclusion and discussion of the study, indicating room for future work and relaxations of this system to be investigated in the following years.

2 LITERATURE REVIEW

2.1 Fertilizer operations

According to Mr. Shah and Mr. Balken (International 2008), the fertilizer industry is a global and large tonnage, requiring shipments of large quantities of raw materials and finished products across continents. This occurs because fertilizers are essential for crop production and agriculture, and the source materials for the three main plant nutrients: (1) nitrogen; (2) phosphate; and (3) potassium. And most of them are not available naturally in many regions.

In modern manufacturing process nitrogen is obtained from air to produce ammonia, the process requiring natural gas or other similar hydrocarbons as the main raw material. Ammonia is then used to produce ammonium nitrate (AN) and urea, which are widely used main nitrogen fertilizers. The main source of phosphate (commonly expressed as $P_2O_5$) is rock phosphate mineral (or simply rock), which is processed to produce phosphoric acid. Ammoniation of phosphoric acid enables production of mono-ammonium phosphate (MAP) and di-ammonium phosphate (DAP). Even though acidification of the rock can give single super-phosphate (SSP) and triple super-phosphate (TSP). These materials are the common sources of $P_2O_5$. Lastly, potassium (expressed as $K_2O$) is mainly sourced from potassium chloride, described in the industry as potash, which is mined. Other source materials are also used for the above nutrients, for example, ammonium sulphate (AS), potassium nitrate, potassium sulphate, calcium nitrate, and sodium nitrate. The main types of fertilizer operated in this terminal are Ammonium Sulphate (locally called SAMO), urea, potassium chloride (KCl).

2.2 Seasonality in simulation models

Not many literature about the use of seasonality in a maritime simulation model is available. Given the complexity, modelers tends to simplify this characteristic of the system by averaging the demand. Seasonality impacts were widely modeled by biological researchers due to the investigation of crop growth during the rainy season (Ichii, Hashimoto, White, Potter, Hutyra, Huete, Myneni, and Nemani 2007). In this work, it was modeled the dynamic impact of carbon, water and energy in tropical forests.

Under the same topic, (Duguay and Chetouane 2007) incorporated the seasonal component in a health-care system, by defining a patient arrival pattern over 24 hs period. Given the short period horizon of this system, this type of seasonality could be easily tackled by allocating a higher personal effort during the peak periods. This decision differs from the one proposed in this paper due to the long decision horizon a maritime terminal needs to face. Following the same path, (Gunal and Pidd 2010) also simulated a health-care system including some seasonal aspects.

Finally, (Ding, Benyoucef, and Xie 2005), investigated the impact of high seasonality in a supply chain to verify the demand variability impact in the system profitability, efficiency, and service level. Those approach
can be considered close to this research because of the logistic system under investigation. However they are extremely different in terms of the objective because our work has operational components, with a short simulation horizon. Hence, when Ding is interested in strategic and broad questions, we are looking specific questions like the number of equipment should be purchased, or maintenance policy impacts in the port routine.

3 METHODOLOGY

3.1 Conceptual Model

To model such system it was considered the following diagram as the scope of the model built (Figure 2).

![Figure 2: Schematic representation of the fertilizer terminal - TPD4.](image)

In this figure according to (Churchman 1979), it can be identified the terminal as a complete system, and its traditional elements of a bulk terminal as subsystems: (1) Pier; (2) Warehouse; (3) Railroads.

As the material flows from 1 to 3, it is extremely important to have a dimensioned asset to transport the cargo inbound. In order to maintain the randomness of the ship arrival within the seasonality imposed by the system, fertilizer ships fully loaded with importing products are generated according to an exponential distribution, where its parameter (arrival rate) can vary in monthly basis following the algorithm proposed by Kelton (Kelton, Sadowski, and Sadowski 2002), seen in (Figure 3). The following algorithm indicates the idea behind the stochastic seasonality proposed in this system.

3.2 Overall equipment efficiency

One important disruption considered in the conceptual model was the rain impact in the operations, since this type of load (fertilizer) is very sensitive to water, at a slight signal of rain, the operations has to be interrupted to avoid any kind of damage. Hence, all the blockages were considered in the model.

Beyond the natural stops due to the rain, there are several maintenance aspects which was considered in the model. Equipments like: (1) ship-unloader; (2) train-loader; (3) hoppers; and (4) conveyor belts; among others had its natural schedule of preventive and corrective maintenance.

All those maintenance interferes in the loading rates. For that reason, it was considered three different type of rates: (1) Bare rate which is measured by the ratio between the total of load handled and the total operational time. This rate includes all types of disruption in the operation practice; (2) Effective rate which considers only the operations events, so it accounts for the ratio between the total of load handled
Data: Current month arrival rate, demand
Result: Arrival event for a specific month initialization;
while n do not reach the final of the simulation period do
    u = uniform random number from 0 to 1;
    Next arrival event = Last arrival event + a function of u;
    while Next arrival event is greater than the end of the current arrival do
        increment k
    end
    Next arrival event = last arrival event + the remaining time to finish the period divided by the arrival rate in the current period;
    Output Next arrival event;
    increment period;
end

Algorithm 1: Exponential distribution with seasonality

Figure 3: Width of a channel parameters to be considered vessels crossing.

and the operating time (not considering the idle time due to maintenance, or any other type of interruption); finally (3) Nominal rate which is the rate an equipment is designed for.

All those rates are input of the system so that it should figure out in the simulation model. As an output it is measured the occupancy rate, or the overall equipment efficiency (OEE) which, in this case, is the ratio between the time the equipment remains operating and the total time the equipment is available to be seized. This time includes the corrective maintenance, breaks, and setups. Remarks that this time do not considers the preventive maintenance, since it can be scheduled for the most appropriate period (with low demand). The appropriate scope of the rates mentioned can be seen in the following diagram (Figure 4).

3.3 Maneuverability conditions

Another important aspect of the model is the consideration of maneuverability conditions. In order to berth or unberth in TPD4, there are some conditions to be respected, otherwise the ship will necessarily be put in hold at a queue until there are free space for it to move. Such conditions can be observed in the following figure (Figure 5). A ship can only berth at Pier 4 if there is no ship at Pier 1 - South, and Pier 3. Even
though the size of fertilizers ships tends to be smaller, there is not enough room for it to maneuver if there are ships moored in front of it.

There is a particular case where such movement can be done: if there are two small ships in both Piers (Pier 3, and Pier 1 - South). As mentioned in previous work, (Mota, Pereira, Botter, and Medina 2013) physical constraints of a system if not evaluated properly can lead into extremely conservative conclusions. In this case, the limitation is attributed to the vessel beam.

Satisfied all conditions, the ship is free to move and berth in the appropriate pier. The constraint generated by the warehouse management is out of scope in this research, leaving room for further investigation.

4 EXPERIMENTS

It order to validate the model, the system was configured to simulate the operations of 2009, where TPD4 reported to have produced about 0.7 Million tons. The seasonal behavior of the system can be noticed by the inventory level at the top part of the chart (Figure 6)(small lines), at the same time, the queue level to identify the service level can be analyzed at the same chart, but now at the lower bars. It is important to mention that such chart represents a 5 replication experiment, and the seasonality capability were built in the model.

Additionally, the ship-unloaders has high variability because the use of effective rates associated with a large occurrence of corrective maintenance can lead this equipment into such behavior. The low season
can hide such inefficiency, however during the second semester, it can be noticed by the chart (Figure 7) how the equipment is highly demanded. Consequently it generates more corrective events. Another important consideration is the simultaneity. Since the terminal can count with two ship-unloader, it was important to know when both equipment are operating simultaneously. In this occasion, the rest of the system (like conveyor belt, hopper, and warehouse) are more demanded putting the system into risk (but the most efficient situation as well). Such situation can be observed in the same figure, at the right hand side. The operational occupancy rates can be observed in the table at the top right hand side of the figure. As an output of the system, this table shows that only about 13% of the time the simultaneity were observed.

Finally, it can be observed the seasonal output of the system where it can be indeed identified the bottleneck of the system (Figure 7). Such chart became extremely informative for the decision maker of the terminal because at the top it can be observed the inventory level of the berth every month, reaching a peak at September. Additionally, still at the top portion of the chart, it can be noticed the average queue time of the vessels. It was clear that most of the ships which arrived at August were held in the queue due to capacity constraint to berth at September, where the inventory reached the peak. Whereas, at the bottom of the same chart, it can be observed the OEE of the berth, as well as the railroad subsystem. Hence, it can be seen that March and April, the system has low occupation, but at this time the operational team takes advantage to realize long maintenance and machine repairs. Of course such policy is, operationally speaking, much conservative and proactive, it is not profitable, because there is a huge asset which is not being used. This trade-off will be discussed in the next section.

5 DISCUSSION

By the observation of the results presented, it was possible to realize the powerful of such tool developed using simple concepts of discrete event simulation. After validating with real demand level, several simulations were successfully conducted to identify policies that increases the port capacity. The most relevant deliverable were the negative impact of the seasonality. Despite it was crystal clear for the operation labors, it was not much clear for strategic team before this study. Such alignment generated synergy among different departments to tackle this problem. Sales was involved trying to mitigate this jeopardy by adjusting contracts.

Another important recommendation delivered by this study is the necessity of finding complementary loads to take advantage of the infra-structure during the low season. This decision involves several areas
as well and the avoidance of having an idle terminal from January to August would increase the surplus of the system.

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