INDEPENDENT JOURNAL OF MANAGEMENT & PRODUCTION (IJM&P)
http://www.ijmp.jor.br v. 6, n. 3, July - September 2015
ISSN: 2236-269X
DOI: 10.14807/ijmp.v6i3.312

# THE LOGISTICS MANAGEMENT IN THE SIZING OF THE FLEET OF CONTAINERS PER SHIPS IN DEDICATED ROUTE - THE USE OF COMPUTER SIMULATION: A BRAZILIAN SHIPPING COMPANY CASE

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*Submission: 19/03/2015*
*Revision: 31/03/2015*
*Accept: 07/04/2015*

***ABSTRACT***

The aim of this paper is provide the use of the simulation in the discrete event to manage one important point in the logistics systems to shipping companies that is the imbalance of containers, movement of empty containers from surplus ports to deficit ports.

From a survey of data from a shipping company operating in Brazil, at various ports, it was possible to model and simulate the needs in six major domestic ports of empty and full containers and seek to meet demand in the shipping market, reducing storage of containers and maintaining the level of excellence in service.

Based on the discrete event simulation it was possible to analyze the problem of empty and full containers at the ports in the maritime transportation system. It was possible study the imbalance situation in the ports e provide one tool the companies to manage yours service.

The data are confined to one company located in São Paulo and operating in Brazil at maritime transportation.

The research shows that the imbalance problem between full and empty containers is a real case to all companies in the maritime transportation and can have effective solutions using discrete event simulation.

To have excellent supply chain management it is important to have also one effective transportation system. This paper contributes to research in the inbound and outbound part of the supply chain management.

**Keywords**: Full and empty containers, logistics system, sizing of the fleet of containers, simulation model.

## 1. INTRODUCTION

This work addresses a topic considered of great relevance to the shipping companies that operate in the ordinary market (liner) carrying laden and empty containers. It approaches the management of containers available to ships and customers, so that the expected cargo matrix on each port is fully answered. If there are no laden containers available and ready to be transported when a ship berths at one port of the route, the cargo matrix will not be accomplished due to the unavailability of containers in the system, causing loss of transport and hence revenue.

The raw material, parts, components or finished products will not feed the production line of business (inbound part), and there will not be products available to the consumer (outbound part). The Role of Supply Chain Management is to deliver products on time and in the correct amount to their customers. In addition, having a proper sizing of containers in maritime transportation system is essential for the effectiveness and efficiency of logistic system.

As the cargo matrices of cargo liners usually present imbalance between containers delivered and received by container ships, many ports end up accumulating many empty containers, while others suffer from a lack thereof. To mitigate the effects of "imbalance", shipping companies seek to accomplish the repositioning of empty containers, taking them from the surplus to the deficit ports. An efficient repositioning of empty spaces between the ports allows the company to have smaller fleets of containers, and avoid leasing costs and loss of transportation (OHAZULIKE, et al., 2013).

http://www.ijmp.jor.br v. 6, n. 3, July - September 2015
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The problem in the transport chain of maritime shipping service companies is crucial for an excellent logistics system, as far as most of the world transport occurs by maritime shipping. So, lack of containers in the system directly influences the efficiency of the logistics chain. If there are no empty containers to offer to customers of its maritime transport system, there may be a stop on the production line or the shortage in point of sales. Proper sizing of the fleet of containers for logistics providers is an essential condition to offer their services to the market, with levels considered good to excellent (GUAN; YANG, 2010).

The alternatives to accomplish the repositioning of those containers have been studied and are essential so that the total amount of containers inside the system is minimized, while the space available for the transport of laden containers should be maximized. The focus is to prevent a client to run out of container to transport its products, or have empty containers available at the port with no demand to use them, meanwhile in another port, need for empty containers to meet the market. Balancing the need for container is the core of the problem.

Thus, through a simulation model, this paper aims to scale a fleet in the system so that customers have containers to be loaded on land and shipped to ports to be boarded into vessels and then, fulfilling the cargo matrix planned by the shipping company, involving the repositioning of empty spaces between the ports that comprise the routes taken. Keeping the system balanced is a prerequisite for the logistics system of a shipping enterprise. The study was conducted in a shipping company established in Brazil and covers some of the main Brazilian ports (HARTMANN, 2013).

The presented simulation model was built in the ARENA software and it has the help of an interface built in a spreadsheet for data to be entered and then have the scenarios configured to be simulated. Through this interface has also been possible to obtain the results generated by the simulation in a clear and organized way, allowing even comparisons between scenarios and sensitivity analysis of design parameters.

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## 2. LITERATURE REVIEW

### 2.1. The problem with Empty Containers

Empty containers have been an issue in several works by different authors. This is due to the great importance and difficulty regarding planning their destination. Lam, Lee and Tang (2007) pointed out in his research that transporting a laden container results in at least one empty container movement. According to Di Francesco et al. (2009), the process of repositioning empty containers in a maritime system can be defined as the planning and distribution of those containers so that inventories are minimized as well as the cost of shipping and handling, while the demand is met in all ports.

Braekers, Janssens and Caris (2011) defined a route commonly performed by the container during a logistics loop. The containers available at a port are all the stored ones, those returning from customers, the unloaded and the ones which can be rented and reused. Braekers, Janssens and Caris (2011), empty containers generate costs when they are loaded and unloaded from vessels, stored, transported, and when they are rented.

Yun et al (2011) argue that companies often waste time repositioning empty containers between locations in which they are stored (ports, depots, etc..) and cite that effective management in this area can increase company productivity. The decisions that a company must take are basically how the demand for empty containers will be answered, which route should be drawn by an empty container, how and when the shipping will be performed. For those decisions, it is necessary to know the inventory of empty containers at all ports and existing depots and whether those can be used (ZOU et al. 2013; LI, 2013; NISHIMURA et al., 2009; ZHEN et al, 2011).

Those factors lead to uncertainty in the data used as input to a mathematical model that addresses the logistics of the empty container. Braekers, Janssens and Caris (2011) argue that containers availability in a liner service provider is subject to a number of uncertainties, including the demands of the ports, the time involved in returning an empty container and available capacity on ships to transport those containers. To face such uncertainties, the owners usually act with prudent conservatism.

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Due to that, the planning and management of a fleet of empty containers depends on supply and demand forecasts in all ports, which confirm the data uncertainty and the stochastic nature of the problem. What makes that problem difficult are the uncertainties in the system and the probability of events that interfere with the planning as, among other things, forecast errors, damage to equipment, strikes and delays in the return of containers (Lai et al. , 2013). Such uncertainties lead companies to use a safety stock, avoiding some freight to be lost. This practice leads to increased costs, since costs related to storage, rent and amortization of acquired new containers arise (ZOU et al., 2013; LI, 2013; LAI et al., 2013; IMAI, 2007; KONINGS, 2005; KOZAN; PRESTON, 2006).

In their study Yun et al. (2011) also cite the need for a policy solely for stock control that mitigates the interference of empty containers (LAI et al., 2013). The distribution of empty containers is very common among owners who choose to rent them or transfer them from one port to another to remedy any shortcomings in the system. The repositioning of empty containers takes into account data provided by the commercial sector of the company with the likely future demands and scheduling of each ship - Schedule (LAI et al., 2013).

According Di Francesco et al. (2009), it is common to have in large ports, specific areas for storage of empty containers, which can be maintained for a pre-set price by the time the shipping company deems necessary. Many companies choose to store their empty containers in depots outside the port area by cheaper stocking prices compared to those generally used by port companies. According to the authors, small ports do not have areas dedicated to the storage of containers, resulting in longer time to transport them.

## 2.2. Inventory Control and Repositioning Decisions

According to Imai and Rivera (2010), scaling the container fleet is a way to determine the quantities needed to meet future demands, while the problems of fleet management actions generate as repositioning or leasing of empty containers. In case a ship-owner has a wide fleet of own containers, this probably requires performing just a few movements with empty or rent of containers and, thus demonstrating the interdependence between strategic and operational decisions (LAI et al., 2013).

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According to Li et al. (2007), effective management of maritime transport includes coordinating the distribution of goods and materials between suppliers, industries, distributors and customers through a fleet of vessels. His work aims to determine a strategy for containers allocation in a set of ports and adjust supply and demand. The authors describe very well the effect of the imbalance of the difference between supply and demand in different ports and cite the container rental is an operation frequently used by shipping companies so there is no loss of customers due to lack of capacity.

The idea proposed by Li et al. (2007) part from a model for determining optimal inventory policy to a port for a policy that considers more than one port interconnected in a route. Their model provides the maximum and minimum inventory of empty containers at a port so that the costs are minimized. However, such inventory levels cannot be considered as optimum values when it is analyzed a set of ports, since the optimum amount of containers exported through a port may not be the same amount that needs to be imported by another port. Furthermore, Li et al. (2007) found that the minimum or maximum quantities of empty containers stored in a port converge to the same value in case the other stock policy is kept fixed. This enabled the development of a heuristic for determining the inventory policy that enables cost reduction (ZOU et al., 2013; LI, 2013; LAI et al., 2013).

Li et al. (2007) concluded that their model allows the analysis of the limits of stock in several scenarios and routing settings, and that the complexity of inventory policy is present in any state of the problem. Lagoudis et al. (2006) highlight approaches to the vehicles fleet sizing, routing in travel and repositioning of empty containers studies; and also attest to the lack of studies that address the containers fleet sizing. In their study, Lagoudis et al. (2006) seek to determine the container fleet that allows meeting demand in the ports of the Mediterranean route and minimize what they call the "idleness" of containers.

Imai and Rivera (2010) describe three models that address the problem of sizing the container fleet: an analytical model to treat a dry container fleet in a balanced market, an analytical model that studies the fleet of refrigerated containers in a scenario with imbalance and a simulation model. Noteworthy is the fact Imai and Rivera (2010) use calculations in their study that do not consider deterministic and

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random parameters. Also, they do not use linear programming techniques (LAI et al., 2013; LI et al., 2004).

Yun et al. (2011) based their study on the empty containers in inventory control and repositioning decisions, their rent and storage. They also considered statistical distributions to obtain supply and demand and storage costs, rent and repositioning of empty containers (ZOU et al. 2013; LI, 2013). From the assumptions, Yun et al. (2011) created a simulation model using ARENA software that could assist in a search process to obtain a policy that minimizes inventory costs.

About the possible approaches to the problem of repositioning empty containers, the authors also argue that deterministic formulations may be inefficient due to the uncertainty related to demand and future supply and therefore no differences between predicted data and the amounts moved. Di Francesco et al. (2009) emphasize that there are no studies that quantify the actual losses in profits and efficiency from the use of a deterministic model. Still, the authors chose to build a deterministic model for optimizing the reallocation of empty containers between different ports (LAI et al., 2013). Di Francesco et al. (2009) used the opinions collected in the shipping companies to determine the distributions of uncertain parameters and, from those, created different scenarios (multi-scenario approach).

Song and Dong (2011) treat the repositioning of empty containers as a major problem for shipping companies, representing many of the movements made with containers in the oceans. According to the authors, many factors contribute to the need for those movements. Among them, the lack of balance between supply and demand of containers (they cite the example of route Trans-Pacifica, in which the volume transported from Asia to the West is much larger and means that there is a need to transport empty containers in the opposite way). Thus, for Song and Dong (2011), the efficient repositioning of empty containers is a "key strategy" for the shipping companies to gain competitive advantages.

Song and Dong (2011) point out that many of the works on the shipping container use a deterministic approach, through classical formulations of linear programming. Studies that consider uncertainty and stochastic factors began to draw attention from the 1990s. For the authors, the mathematical models capture, often successfully, the stochastic and dynamic nature of the problem, but increase the

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concern that one should have some problems such as: Choosing an appropriate time horizon; computational complexity and difficulty of implementation of the model and robustness on handling of uncertainties present in the problem. It should also be noted that Song and Dong (2011) cite the interest in the development of the analysis of qualitative characteristics of optimal policies of repositioning of containers.

## 3. METHODOLOGY

The methodology of simulation was chosen because it is an alternative to the techniques used and provides a better detailing of processes that involve the movement of vessels, processes that occur on land and inventory management. Among all the work and research checked, any of them used the simulation as the main tool to determine the container fleet of a shipping company. Moreover, the problem has stochastic nature. So, discrete event simulation is the appropriate tool for that situation. The simulation techniques used allow the modeling of some constraints that are more difficult to be explained in an analytical modeling.

In the simulation model, it is possible to insert rules to decide how to reposition empty containers available at the port which can be transported to other ports of the route, specifically those having demand for empty. Setting the appropriate planning horizon will solve the problem of empty containers allocation, in order to obtain the lowest container fleet that suits the minimum requirements of attendance in the same period.

Processing the model several times, changing the initial condition of laden or empty containers at each port, it was obtained a configuration that meets the demand without any exaggeration in the number of containers stored at terminals. The model intends to obtain the optimal solution of the total cost of the system (from the point of view of the shipping company) through better composition among containers owned or leased and repositioning of empty ones (which can be used as a great ally in the quest for more economical inventories). It is important to highlight the fact that the model considers the transit of ships in ports to both directions (north and south). For example, instead of having a flow variable of laden containers to be shipped from a port i to port j, at a given time t, traveling towards a direction, there must be two different variables for transportation between those ports considering the two destinies.

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The decision variables of the model refer to the system as a whole, the handling of laden or empty containers (owned and leased) and vessels. In the objective function (which is the sum of all costs involved resulting from the decisions of their own fleets, the rental of containers and repositioning of empty containers) are considered three situations to ensure that the resolution of the problem does not depend on a lot of information from the previous period: a) the container fleet must be loaded, b) full, awaiting shipment, or c) empty, at the terminals of shipping company.

Mathematically, the objective function (total cost) to be minimized is composed of four different cost factors, which are: The portion relating to the cost of the company's own fleet; The portion relating to the rental of containers; The portion of the cost for the transportation of their own empty containers between two ports in any direction; The portion relating to the costs associated with the hosting of laden containers in ports.

The inventory policy is composed of a minimum stock (s1 in periods of low demand and s2 in periods of high demand) and a ceiling (S1 in periods of low demand and S2 in periods of high demand). If the inventory level is less than s, the request of empty containers is made until the level reaches the value S. If there is a need to reposition empty containers, but those are not available, the model seeks to rent those containers returning to the amount of containers leased in a given period. As the costs of each operation are linked to the simulation model, they seek to reduce the amount spent by the end of the simulated period and, therefore, Yun et al. (2011) used a tool for finding the best solution ARENA, called OptQuest.

Many sensitivity analyzes are made possible by the use of the model, including the variation limits of inventory level (s and S) and the best inventory policy to be implemented in the terminal analysed. So as to achieve optimum inventory policy, it has to be found values of s1, s2, S1 and S2 that minimizes the cost of the terminal. OptQuest ARENA performs simulations and modifies the decision variables iteratively until the stopping conditions are met.

## 4. INTRODUCTION TO SIMULATION MODELING

A model was created to simulate a route for shipping containers between ports in a closed loop with a given fleet of ships. For this simulation, some assumptions are

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considered, as the availability of a berth in each terminal in the simulated scenario and the possibility of system configuration, varying the number of visited ports, the fleet size and cargo matrices to be met. The simulation model comprises two interconnected sub-models: the sub model movement of ships and sub model movement of containers in the land.

The first sub model that comprises a simulation of the transport container in a closed loop represents the travel of the ship and port operations according to the routes and matrices predetermined. Matrices of cargo have been established in a planning phase in order to ensure that the owner has profitability, at least, if he complies with the cargos represented in the matrices. In this sub model the vessels are firstly created in quantity set in the data input interface. About those ships, should be informed (in the interface data entry) some features like the speed and capacity, and the matrix of loads to be served between ports and by each ship allocated on the route.

Once created the ships of the fleet under consideration, the model assigns the specific characteristics of each, as the identification number, the number of the trip (in this case, the first trip of each vessel) and the sequenced list of ports, which will be visited on established routes. The vessels are then placed in ports and defined as initial vessel in each pair of ship-trip. At the beginning of the construction of the model, it was adopted the premise that all ships start their trips at port 1, and must begin with an interval within the relationship between the cycle time and the estimated fleet size (headway) in hours. From this and on, the model considers the entities ships separately.

Once defined the first port of the sequenced list for each ship, it is also recorded the initial instant of operations in order to facilitate the collection of statistics of the model. Then, the first port is allocated and there should take place port operations, according to the productivity inserted into the data input interface. The input data are also used to determine the initial condition for all ports: initial stock of empty containers, initial inventory of laden containers to be loaded on ships (out) and initial inventory of laden containers to be shipped to customers on land (in).

Among the operations that the model performs each time a port is allocated by a ship, it is considered initially unloading shipping containers bound for that port.

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Then, it is considered the loading (having enough stock of laden containers at the port) and the decision on whether or not repositioning the empty containers from the verification performed in the interface data entry, if a port has supply or demand for containers empty. This check considers ship cargo matrices to determine if the ports present imbalance between supply and demand for container and a simple calculation predicts whether there will be excess or lack of empties in each port.

Logically, during operation in ports, an update of inventories of laden or empty containers is carried out according to the cargo matrices corresponding to the ship in operation. The logic of loading ships traverses the specific sequence and array loads, performing the sum that indicates how many containers shall be unloaded in the next port to be visited. Thereafter, an attribute loading is created for each of the next ports in sequence with the amount of containers shipped on that vessel and to be unloaded further.

In the procedure of loading containers for subsequent ports of the list, two situations may occur: there is stock of laden containers (out) enough to supply the cargo matrix or containers are insufficient, in which case shall be proportionately apportioned in the containers available with the cargo matrix. For the latter situation, the loss of container transport is also calculated, given by the difference between the amount that should be loaded and the amount that will actually be carried by ship. Since this value can be a decimal number (due to the calculation performed), is added logic to correct such amounts (a container is an indivisible object), in which the mass balance model is maintained.

When operations are completed at the port, it is recorded the instant of departure of the ship. Now this port can receive the next ship, while the ship which had just been serviced follows its journey to the next port in sequence. The seaborne travel time to the next port is determined by the speed of the ship and the distance matrix between ports. Those data filled in data entry interface.

In case the port is not the last in the sequence, the ship should proceed to the next port and repeat all procedures from resource allocation at the port until the end of all operations. On the other hand, if the port in question is the last in the sequence, the vessel returns to the first port of the cycle and the model will register every input and output to each terminal. In addition, there are updates to inventory throughout

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the simulation that are recorded in the results interface, thus generating a very useful log for checking the results.

It is updated, then, the number of the next trip and the ship will repeat the sequence, still unloading in the sequence, containers that were loaded at previous ports (for example, if there is demand from port 2 to port 1, and the sequence of travel considers visits to ports in ascending order, when the ship starts the second voyage into port 1, the demand from port 2 will be unloaded). Finally, to determine the amount of travel (cycles) of each vessel, the model calculates, first, the duration of a round trip, recording the time elapsed since the first port of the sequence is allocated until the time when the vessel returns to this port.

After that, it is calculated the ratio between the duration of the simulation and the duration of a journey, obtaining the number of round trips and the number of cycles for each vessel simulated. Repositioning of containers is subject of specific studies within the shipping companies. Considering this reposition increases the complexity existing in container shipping, due to the large number of variables that relate. Proper logistic planning of empty containers has great potential to reduce the company's costs and enable higher profits due to increased containers availability and reducing the loss on transport.

The ability to reposition empty containers between ports is considered in the sub model of circulation of ships, as previously reported. For this, the model recognizes whether a particular port of a sequence has characteristics of a surplus or deficit port for empty containers. Such recognition is performed also in the input interface from a calculation carried out with the data reported in cargo matrices of the ships in the fleet.

With the values reported in the cargo matrices, it is calculated the amount of laden containers to be removed from a port, and the amount to be unloaded in the same port during a trip of the ship. Thereafter, the amount of containers unloaded is subtracted from the number of containers removed; obtaining the balance of containers that must remain in the vessel after the port completes its operation. This balance determines to the model if the port has surplus or deficit for empty containers. In ports where the balance is positive, the interface recognizes a surplus port. Otherwise, if the balance is negative, it will be a deficient port.

http://www.ijmp.jor.br v. 6, n. 3, July - September 2015
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From an order of priority determined by comparing the average quantities demanded at all ports of the route (balance), are recognized ports of which empty containers can be removed and those who should receive those objects. Note that this balance would accumulate over time if there were no repositioning (in surplus ports, container inventories would grow. Meanwhile the deficit ports would accumulate losses due to lack of containers). Checked which ports are surplus and which ones are deficient for empty containers, is the time to determine the amounts to be withdrawn or unloaded at each port. Such amounts are calculated taking into account three factors: the sequence of ports visited, the balances of empty containers at the end of a cycle and flows between the balances.

After the ports being ordered according to the sequence of visits, they should be divided into groups that begin with surplus ports. From those groups are removed from the provider ports the maximum amount to be left in a cycle, that is, it is withdrawn from the surplus ports a quantity equal the overplus of that port. It is estimated, then, the percentage of the balance that must be unloaded in the ports that follow this surplus port until the ship reaches another provider port. Besides movement of ships sub-model presented earlier, a sub-model was built to represent the movement of containers on land. This sub-model deals with transactions with empty containers that are shipped for loading in customers, returning filled for shipment and transport, and with containers that are unloaded filled in ports and are sent to recipients which empty and return them to the harbor depots that are located in regions close to the ports used in the simulation.

The entities generated at the beginning of the simulation through this sub-model are called entities of circulation in ports, while the number of "circulation" generated is equal to the number of ports that comprise the route indicated in the input interface data. Once created such entities, the model names each with the number of the respective port to which it refers, and those will be submitted to the events that may occur in the movement of containers on land. The entities head to a module of random decision, in which there are two different logics that can be treated as follows: drawing the daily demand of empty containers from the port concerned which will result the generation of laden containers to be sent to the terminal to be aboard (from a statistical distribution that takes into account the data from the cargo

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matrix); and the logic that should handle the containers that come full from ports to customers on land and are emptied and return to depots at ports.

In the first approach, which is to determine the daily demand for empty ports, the model checks if the stock of empty containers in port at that point of time is considered enough to meet the demand requested, by checking if there is still a balance of containers that was not attended previously. In case there is not sufficient containers, there will be an increase of an attribute named "balance to meet" specific to each port. Such empty containers become laden containers to be loaded at ports and, after an interval of time, the model updates the inventory of laden containers *out* in ports. Such transactions occur daily in the model.

This time interval for updating the inventory represents the retention time of containers on land and incorporates the duration of all events occurring since the withdrawal of an empty container deposits until the moment it is delivered filled for shipment. The model under consideration for this retention time, a triangular distribution, according to the suggestion of the shipping company consulted. The other logic in this sub-model of containers movement on land concerns the landing of containers that arrive full to ports under consideration.

The entity of movement awaits a "sign" that occurs in the sub-model of ships movement and informs the arrival of laden containers to ports. With this sign, the sub-model of land movement causes the variable of laden containers *in* (filled containers arriving at the ports from the vessels) to be retained during the time interval that represents the retention of the containers on land, and after that period, to become an increment variable of stock of empty containers in warehouses located near the ports under consideration.

It is worth noting again that the events held by the entities created in this sub-model of land movement repeat daily in the model. The simulations of both processes occur simultaneously and are dependent only on which refers to container availability inventories as occurs in reality. The transport of containers between the clients and the terminals where they are loaded or unloaded is the interface between the two phases, causing supplies at a location to be modified by other's interference. In other words, the demands used in each stage must be synchronized and updated

ISSN: 2236-269X
*DOI: 10.14807/ijmp.v6i3.312*

as soon as necessary, which shows the relation between the two logics that make up the model.

The sub-model of land movement turns empty containers into empty containers *out* (those that will be shipped filled) and laden containers *in* to become empty containers, always respecting the time indicated as the retention time on land, which includes travel between ports and warehouses, the time for loading and unloading and a possible waiting time.

To illustrate the dependence between the sub-models, the sub-model of ships movement sends a signal to the sub-model of land movement each time new containers are unloaded in ports, indicating that there must be, then, the "withdrawal" of laden containers and their emptying. As previously mentioned, the simulation model proposed in this paper considers two distinct stages: the movement of the fleet of ships predetermined between the ports that compose the system and the handling of containers, laden or empty, on land, representing transport between clients and the terminals in its area of influence. Each one of the steps has its peculiarities and independent rules, although linked. This generated the need to create the logics separately within a simulation model, based on different concepts.

The first logic presented is the movement of vessels between the ports that make up the system. The main rules adopted for the creation of the conceptual model of this logic are: Ships at the beginning of the simulation are inserted into a certain port to fulfill, from that moment, the activities of unloading, loading and travel according to a predefined sequence of ports, in a closed cycle. The vessels may have sequences of different ports, which make the model more flexible. The introduction of the fleet and ports sequence is shown in the data input interface; Each ship enters a queue when arrives in a port, unloads the laden and the empty containers and loads other laden and empty ones, since they available in the corresponding stocks, to be bounded to other ports of the route.

Those actions occur according to a cargo matrix that will appear on the data input interface; The model examines whether the port is surplus or deficient to perform repositioning of empties as efficiently as possible; If there are not sufficient empty or laden containers to fulfill what has been programmed into the cargo matrix, the model computes the deficit as loss of the ship's cargo; The total number of

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ISSN: 2236-269X
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containers moved by the fleet is obtained when it is inserted initially in the model a number of laden and empty containers in inventories in ports, large enough in order to the fleet to meet the planning of cargo matrix. From this number, it will be extracted the number of containers to be placed in the stocks in ports which minimizes the loss of transport with the fleet of containers inserted in inventories (objective function);

The second stage of the proposed simulation model represents the movement of containers on land. The rules adopted to implement this logic in the model are: The laden containers unloaded from ships over time are shipped to customers following a triangular distribution of retention time, which includes: customer journey, emptying and return to the stock of empty containers at the port; Daily, a demand for empty containers to suit export customers in the area of influence of each port is drawn. The stock of empty containers is checked and the total requested (or what is available) is sent to customers, clearing, this way, the stock of empties in the harbor; It was adopted that the balance of empty containers, not responded, is accumulated for the next day; The retention time of empty containers, which follows a triangular distribution, includes travel, carry and return to the port to be added to the inventory of laden containers, which are available to be loaded on ships (containers "out").

Note that is the balance of laden and empty containers in ports that allows customer service on land (clients which need empty containers) and service to ships passing in each port, which need to be loaded according to the cargo matrix pre-defined. The conceptual models presented served as the basis for encoding the simulation model, ensuring that the logic used contains all existing events, and that they follow the sequence appropriately for future validation.

## 5. APPLICATION OF THE SIMULATION MODEL AND THE RESULTS OBTAINED

In order to build a base scenario, the starting point for sensitivity analysis and validation of the simulation model, data were requested for a large shipping company that operates in Brazil, whose identity will be kept confidential at the request of the company. The demands used and presented here, were multiplied by a conversion factor to be adjusted and thus remain confidential, keeping the same order of magnitude and enabling realistic analysis of the results obtained.

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*DOI: 10.14807/ijmp.v6i3.312*

The database provided by the shipping company was analyzed and it was extracted the necessary information for the construction of an initial simulation scenario. The chosen data comprise information of a cabotage route in which ships visit six ports along the Brazilian coast: Santos (SSZ), Sepetiba (Itaguaí) (SPB), Suape (SUA), Fortaleza (FOR), Pecém (PEC) and Manaus (MAO). To facilitate the reading of data in the model, the ports were numbered and all related information refers to the corresponding number. The numbers adopted were: Port 1: SSZ (Santos); Port 2: SPB (Sepetiba-Itaguaí); Port 3: SUA (Suape); Port 4: FOR (Fortaleza); Port 5: PEC (Pecém) and Port 6: MAO (Manaus).

Among the data provided by the company, are the demands of laden containers that exist between the ports visited. Such information has been processed and then, the cargo matrices have been obtained, considered equal for all vessels. In this cargo matrix there are quantities of laden containers to be removed from a port bound to each other to make up the route for each trip. The cargo matrix for each ship is desired by the shipping company to maintain profitability levels for this type of transport project. Thus, the proposed simulation model tries to determine which container fleet is required to meet the cargo matrix desired by the company. Actually, this carriage is subject to changes in demand, which can overcome or not the minimum cargo matrix required.

Once known the cargo matrix wanted, as expected, it is presented an "imbalance" between the ports. So, it is calculated which ports are the surplus and which ones are the deficient for empty containers. The cargo matrix considered by ships is presented in Table 1**.**

Table 1: Cargo matrix of vessels - baseline scenario

| | **PORT 1** | **PORT 2** | **PORT 3** | **PORT4** | **PORT 5** | **PORT 6** |
|---|---|---|---|---|---|---|
| **PORT 1** | 0 | 7 | 503 | 39 | 303 | 332 |
| **PORT 2** | 15 | 0 | 221 | 9 | 51 | 300 |
| **PORT 3** | 61 | 10 | 0 | 5 | 9 | 400 |
| **PORT 4** | 20 | 11 | 100 | 0 | 5 | 18 |
| **PORT 5** | 128 | 15 | 273 | 50 | 0 | 299 |
| **PORT 6** | 1,388 | 177 | 206 | 12 | 35 | 0 |

It is noteworthy, observing Table 1, the large amount of container that depart from port 6 to port 1, and the large amount of containers that are unloaded at port 6.

ISSN: 2236-269X
DOI: 10.14807/ijmp.v6i3.312

By filling the cargo matrices, one also obtains the balances of empty containers in ports, presented in Figure 1. Therefore, the model uses the proportions calculated to determine the amount of empty containers that should be removed from the surplus ports and how many containers would be unloaded at each port in a sequence.

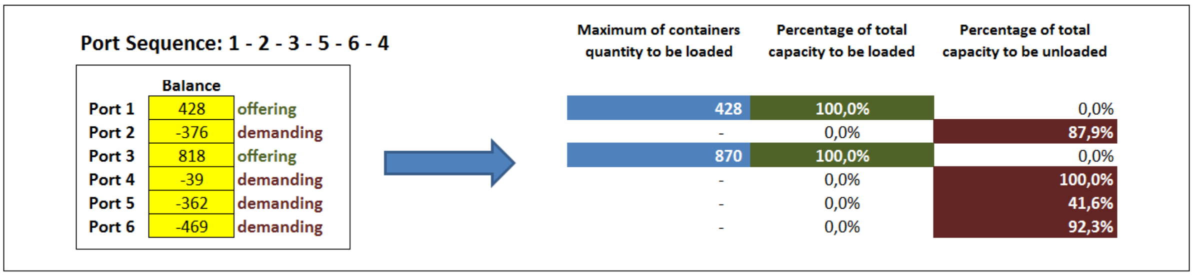


Figure 1: Representation of the repositioning of empty containers mechanism

In a route designed for a 15-knot speed, four identical vessels were considered in the simulation. The capacity of those ships (3,500 TEU) is enough to carry the container load and reposition empty containers. Figure 2 shows the amounts of laden containers on board at each part of the trip. Note that the maximum number of laden containers on board is 2.462, which also allows it to have 1,038 empty containers on the same vessel.

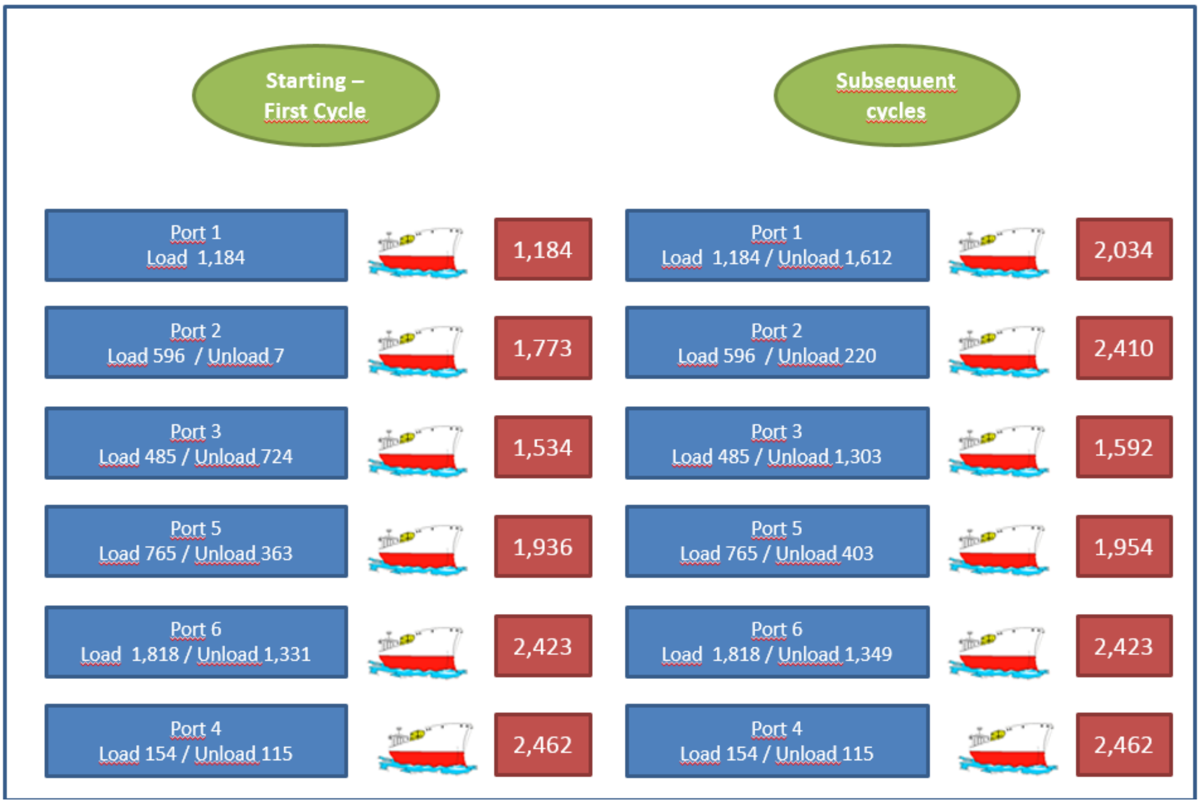


Figure 2: Amounts of laden containers on board at each part of the trip

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The sequence of visits to ports is the same for the four ships of the fleet. The sequence of visits: port 1 – port 2 – port 3 – port 5 – port 6 – port 4. It is worth highlighting that at the end of the sequence all vessels must return to the original port and repeat the cycle. Figure 3 illustrates the basic cycle trip on the route in question.

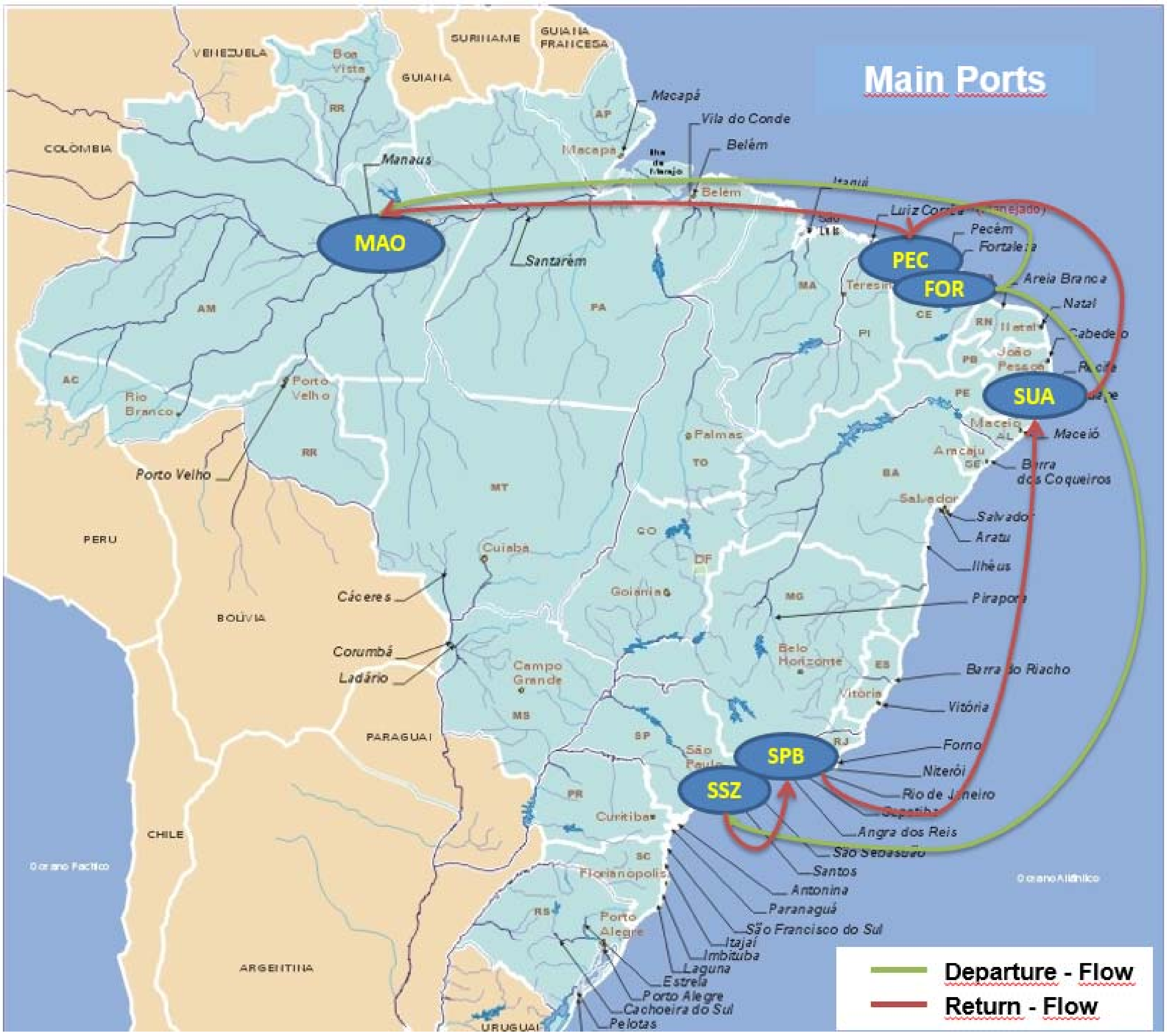


Figure 3: Representation of ships' routeing

As the speed of the ship is 15 knots (27,8 km/h), through the distance matrix, the durations of trips are obtained. Table 2 shows the distances, in km, between 6 ports under consideration in the routes of ships.

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Table 2: Distance matrix between the ports under consideration (kilometer)

| | PORT 1 | PORT 2 | PORT 3 | PORT 4 | PORT 5 | PORT 6 |
|---|---|---|---|---|---|---|
| **PORT 1** | 0 | 83.4 | 695.7 | 921.7 | 1,083.7 | 1,990.8 |
| **PORT 2** | 83.4 | 0 | 612.3 | 838.3 | 1,000.3 | 1.907.4 |
| **PORT 3** | 695.7 | 612.3 | 0 | 226.0 | 388.0 | 1,457.1 |
| **PORT 4** | 921.7 | 838.3 | 226.0 | 0 | 162.0 | 1,069.1 |
| **PORT 5** | 1,083.7 | 1,000.3 | 388.0 | 162.0 | 0 | 907.1 |
| **PORT 6** | 1,990.8 | 1,907.4 | 1,457.1 | 1,069.1 | 907.1 | 0 |

Other data provided by the shipping company refers to productivity in the ports analyzed. It is considered the average duration of the operations of containers at each port, given the berthing and unberthing of vessels. For the values, it is used a statistical triangular distribution (with 30% variation from the average, that is, the lowest value is 30% lower than the average value, and the highest, 30% larger than the same average) which, according to the company that supplied the data, adheres to the actual data. The average values were adopted: Port 1: 14 hours; Port 2: 30 hours; Port 3: 48 hours; Port 4: 50 hours; Port 5: 48 hours; Port 6: 30 hours.

Those figures represent the total time of operation since the berthing to the departure of each ship and includes loading and unloading of containers. It can be seen that the efficiency in port 1 (SSZ - Santos) is higher than the efficiency of other container yards, and the operation takes less than half the time it takes ports 2 and 6, for example. To meet the cargo matrix of containers that each vessel has to pull out of each port, there will be the need for daily generation of empty containers compatible with the matrix, which will be shipped to customers in order to be loaded. Those containers will return to port after a retention period and normally, should not cause a continuous increase in the stock of laden containers available for the vessels. This is, then, a principle of the containers balance flow in the system.

On the other hand, as the containers are unloaded in the ports, they will be sent to customers, and after a retention time, they will return to stock of empty containers. If it is a surplus port of empty containers, this amount will be enough to serve customers in the region as mentioned above, and also the balance of empties may be shipped to the deficit ports of the route. This should be configured directly on the model, with a variable that determines the average daily demand of customers for empty containers in ports (which will return full).

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The company also provided the average retention time of containers on land. This is the time it takes a container from the moment it is sent to the customer (whether to load or unload) until the moment that returns to the terminal (empty or laden). This retention time includes loading, unloading and transport of the containers. Also, can include possible delays due to customs procedures, inspection and cleaning of the containers

The average retention time was set at 15 days, also considering the statistical triangular distribution with 30% variation in accordance with the informed by the shipping company. The initial inventory of laden and empty containers in ports are the decision variables of the problem of searching for the best solution (minimization of container fleet), because they relate to the container fleet size of the navigation company required to meet the cargo matrix.

At the interface it has to be filled, for each port, at the beginning of the simulation, the number of laden containers that can be shipped to customers on land to be emptied, the amount of empty containers and the amount of laden containers to be removed by the next ship to visit the port. Note that the sum of those stocks in each port and the sum of all ports is the fleet of containers needed to meet the required cargo matrix. It was necessary to divide the total stock, in each port, in those three initial stocks (full "in" full "out" and empties), so that the simulation did not have a long transitional period until a balance.

This total initial inventory of containers make up a part of the objective function one wants to minimize. An objective function is an equation for optimization problems to represent the focus of the problem, for example, minimization of cost or maximization of income. The other part of this function to be considered is the loss of shipment due to lack of laden containers at the port over time and lack of empty containers, causing the non-compliance of the loading of cargo to a certain ship (not comply the cargo matrix at each visit of a vessel to a port). It is sought a fleet of containers that meet the required cargo matrix for each of the ships in the fleet. In principle, the loss of cargo (no cargo matrix services) should be zero and the fleet of containers as small as possible.

There could be situations where a loss of cargo was solved by rental of containers (leasing) per trip, so that the required fleet of containers would be even

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lower. However, this option was not implemented in the simulation model because it would increase complexity of the problem and a demand to generate information not provided by the shipping company.

The responses obtained with each round of the simulation model are: Objective function: sum of initial inventory of containers inserted in the model plus the amount of containers not shipped (unmet demand) over time. As one search for optimization (or best solution) of the responses obtained, it is suitable the use of the term "objective function" in this simulation study; Mass balance of containers handled for each port: demands for laden and empty containers are loaded and unloaded from ships and the number of containers that circulate on land; Inventory of laden containers (in and out) and empty at all ports; Number of containers repositioned (deficit and surplus); Operational indicators: cycle time of vessels, time of berthing in ports, number of cycles of each vessel.

From the results, it stands out the loss of transport (unmet cargo matrix), one of the factors that compose the objective function to be minimized by an appropriate amount of containers in initial inventory (container fleet). Therefore, changing the initial condition of laden and empty containers in ports will enable the evaluation of the behavior of the objective function you want to minimize.

The interface for Excel is also used to produce other results obtained with simulations of different scenarios. Through a worksheet called "Log of ships", it is possible to fully map all travel and operations performed by each of the ships, including instant of operations, the quantities of containers loaded and unloaded at each stop of each vessel and inventories in ports. This tab allows extraction of various results and allows the creation of statistics that help to interpret the results, assist in the comparison between scenarios and validate the simulation model.

You can also check the performance of stocks every trip and examine the operation of the model, making sure that the sequences each ship follows confer with the ones that were entered in the input interface. This first scenario was the starting point for the simulation of scenarios for the search of the container fleet sizing and subsequent sensitivity analyzes according to relevant parameters.

The initial scenario is constructed from the input data and assumptions presented in **section 5**, representing a regular operation of the entire system that

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includes the six ports of the route and all four ships. As previously mentioned, the initial inventories of containers are the decision variables that meet the objective of this work, which is the sizing of the shipping company container fleet. Processing the model with different levels of initial inventory at ports, aims to achieve the minimum fleet of containers and manages a reduced loss in transport.

For this baseline scenario it was used an initial inventory of containers (container fleet) large enough for the system to operate, ensuring that no loss occurs due to lack of containers. This initial inventory of containers (total sum of the stocks of laden containers "in" stocks of containers "out" and stocks of empties on all ports of the route in question) was determined from initial tests with the model.

This allowed finding a preliminary solution with zero loss of containers, where it was also possible to evaluate what size the transport capacity of the fleet is, once the cargo matrix is inserted. Based on this cargo matrix, it was then calibrated the daily amount of empty containers that customers need. The quantities of containers in initial stocks used for the simulation of this scenario are presented in Table 3.

Table 3: Initial inventory of containers in the initial scenario

| | |
|---|---|
| Initial inventory of laden containers "*in*" at PORT 1 | 1,600 |
| Initial inventory of laden containers "*in*" at PORT 2 | 250 |
| Initial inventory of laden containers "*in*" at PORT 3 | 1,400 |
| Initial inventory of laden containers "*in*" at PORT 4 | 200 |
| Initial inventory of laden containers "*in*" at PORT 5 | 400 |
| Initial inventory of laden containers "*in*" at PORT 6 | 1,300 |
| Initial inventory of laden containers "*out*" at PORT 1 | 8,400 |
| Initial inventory of laden containers "*out*" at PORT 2 | 5,400 |
| Initial inventory of laden containers "*out*" at PORT 3 | 4,200 |
| Initial inventory of laden containers "*out*" at PORT 4 | 3,000 |
| Initial inventory of laden containers "*out*" at PORT 5 | 4,800 |
| Initial inventory of laden containers "*out*" at PORT 6 | 8,400 |
| Initial inventory of empty containers at PORT 1 | 9,000 |
| Initial inventory of empty containers at PORT 2 | 8,700 |
| Initial inventory of empty containers at PORT 3 | 4,200 |
| Initial inventory of empty containers at PORT 4 | 1,800 |
| Initial inventory of empty containers at PORT 5 | 3,600 |
| Initial inventory of empty containers at PORT 6 | 9,600 |
| TOTAL Initial inventory of containers | **76,250** |

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With those initial stocks of Table 3, it was simulated the initial scenario and quantities of laden containers unloaded on the six ports of the route were obtained, plus the total containers generated from the cargo matrices for one year. Table 4 shows the daily and annual quantities of laden containers required to meet the cargo matrix in ports as well as the amount of laden containers which were unloaded at each port, showing, therefore, the "imbalance" between received and shipped.

Table 4: Daily and annual quantities of containers required or unloaded at each port

| | ANNUAL | DAILY |
|---|---|---|
| Laden containers required to PORT 1 | 114,848 | **315** |
| Laden containers required to PORT 2 | 57,216 | **157** |
| Laden containers required to PORT 3 | 46,560 | **128** |
| Laden containers required to PORT 4 | 14,322 | **39** |
| Laden containers required to PORT 5 | 71,910 | **197** |
| Laden containers required to PORT 6 | 170,892 | **468** |
| Laden containers unloaded at PORT 1 | 149,916 | **411** |
| Laden containers unloaded at PORT 2 | 20,268 | **56** |
| Laden containers unloaded at PORT 3 | 122,772 | **336** |
| Laden containers unloaded at PORT 4 | 10,695 | **29** |
| Laden containers unloaded at PORT 5 | 37,722 | **103** |
| Laden containers unloaded at PORT 6 | 126,734 | **347** |

Also, the average cycle time of vessels was obtained in this simulation that, divided by the fleet size (four ships), provided the average interval to which vessels can be inserted at the beginning of the simulation process. Note that at the beginning of the simulation, each ship is empty and begins cycle by the first port of the sequence. The average cycle is 365 hours. As the fleet is composed of four vessels, the range is 91 hours.

The results obtained in the initial scenario of the simulation are presented in Table 5: Results obtained in the initial scenario of the simulation.

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Table 5: Results obtained in the initial scenario of the simulation

| | PORT 1 | PORT 2 | PORT 3 | PORT 4 | PORT5 | PORT 6 |
|---|---|---|---|---|---|---|
| 1. Quantity of containers unloaded | 149,916 | 20,268 | 122,772 | 10,695 | 37,722 | 126,734 |
| 2. Quantity of laden containers shipped inland | 151,516 | 20,518 | 124,172 | 10,895 | 38,122 | 128,034 |
| 3. Quantity of empty containers shipped to ports | 145,068 | 19,638 | 118,960 | 10,435 | 36,510 | 122,638 |
| 4. Quantity of empty containers reposit. to the port | 0 | 32,954 | 0 | 3,454 | 32,430 | 42,016 |
| 5. Final inventory of empty containers at ports | 2,176 | 5,528 | 1,748 | 1,730 | 0 | 0 |
| 6. Quantity of empty containers reposit. to other ports | 37,062 | 0 | 75,999 | 0 | 0 | 0 |
| 7. Quantity of empty containers generated at ports | 114,830 | 55,764 | 45,413 | 13,959 | 73,717 | 176,939 |
| 8. Quantity of empty containers withdrawn from ports | 114,830 | 55,764 | 45,413 | 13,959 | 72,540 | 174,254 |
| 9. Quantity of laden containers delivered at portos | 110,608 | 53,648 | 43,634 | 13,451 | 69,883 | 166,982 |
| 10. Final invent. of laden containers to depart at ports | 4,160 | 1,832 | 1,274 | 2,129 | 2,773 | 4,490 |
| 11. Loss of transport by port | 0 | 0 | 0 | 0 | 0 | 0 |
| 12. Quantity of containers generated at the port | 114,848 | 57,216 | 46,560 | 14,322 | 71,910 | 170,892 |
| 13. Quantity of containers departed at the port | 114,848 | 57,216 | 46,560 | 14,322 | 71,910 | 170,892 |

From the results obtained, it is noted that the repositioning of empty containers from the ports occurred from ports 1 and 3 (surplus) to ports 2, 4, 5 and 6 (deficit) according to the data presented in section 5. Moreover, the initial inventory (fleet) used was absolutely sufficient, so that there was no loss of demand in ports. With the simulation of this initial scenario, it could also be observed that Ship 1 made 24 complete cycles, while the other three ships performed 23 cycles (due to the gap between the positions of the ship at the first port of the sequence, which caused the ship 1 to perform one more complete journey). The average cycle time was 364.5 hours. It is also important to visualize the behavior of stocks of laden containers ("in" and "out") and empty containers over the 365 days simulated, presented in graphs.

## 6. CONCLUSIONS

The conclusion is that the discrete event simulation is a tool that allows to treat the problem of container fleet sizing in order to meet a fleet of ships operating efficiently in closed loop and obtaining satisfactory results. Moreover, with the simulation model and the aid of the search engine OptQuest, the processing time of the proposed scenarios was considered appropriate, which turns that into a simulator tool able to be used in management of large shipping companies, as well as in generation of new scenarios due to changes in the initial assumptions adopted.

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The models proposed by the theoretical framework provided apply the knowledge needed to determine a theoretical model that could meet the need for a shipping company to manage its container fleet.

The initial inventory of containers in ports (container fleet) in all scenarios specified was obtained and the simulation model was validated. The results show consistency of sizing in the sensitivity analysis performed. Note that the most important parameter is the container retention time on land, which increases the required fleet size more than the change in the ship speed, when both parameters are high. It was also possible to notice the importance that repositioning of containers has in system operations.

It was also presented a way to use the model for annual planning in a shipping company using the variation of two impacting parameters for that planning: the fleet of ships used and the load matrix to be served (demand for containers). The model allows variation and combination of these parameters to obtain the containers fleet required to avoid loss of transport. Another contribution of this work was to obtain values that relate the number of containers to be handled and the size of the containers fleet required according to the load matrix and amount of vessels used in the route.

The practical contribution of this study was to verify the importance of repositioning containers for proper operation of shipping operations. Therefore, it was possible to use the annual planning model of a shipping company considering two essential parameters, the fleet of ships and loading matrix (container demand).

The model contributed to be an additional way to approach the problem of repositioning empty containers, besides sizing of containers fleet.

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