



# SELECTED PROCEEDINGS

## A SYSTEM DYNAMICS MODEL FOR ANALYZING THE COLLABORATIVE MARITIME TRANSPORTATION

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# **A SYSTEM DYNAMICS MODEL FOR ANALYZING THE COLLABORATIVE MARITIME TRANSPORTATION**

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## **ABSTRACT**

This paper aims to present a model to analyze the systemic effects arising from the collaboration policies among the manufacturing industries, which use the maritime transportation to execute the exportation. It was researched about the Collaborative Logistics era and the Collaborative Transportation Management and, in order to validate the study proposal and to obtain data to insert in the model. Some interviews were executed to entrepreneurs and specialists. Subsequently, it was performed a study about Agent Based Modeling and Simulation and System Dynamics. The proposed model using SD contributed to the analysis of the systemic effects arising from the collaboration policies among the manufacturing industries, which strengthen the bargain power if acting allied to each other, and have the power to influence the maritime freight rate reduction. This work contributed to the comprehension of the importance of adopting an interdisciplinary approach to deal with the maritime transportation problems.

*Keywords: Collaboration, Maritime transportation, Freight price, Manufacturing industries, System Dynamics.*

## **1. INTRODUCTION**

The supply chain management acts in the coordination of several relations occurring in the chain, in other words, in the organizations networks involved in creating services and products to the final consumer. According to Novaes (2007), when talking about supply chain automatically it is thought in the material flows derived by inputs, components and goods. These flows among the participants of the supply chain, historically, present conflicts in the

business channels. It is observed that each link of the chain seeks to minimize its individual costs, and it normally does not converge to the global optimum of the supply chain (Seifert, 2003). Thus, it is becoming increasingly difficult to ignore this fact and in order to reduce costs, increase efficiencies and obtain competitive advantages; it is observed that the enterprises are being forced to rethink their procedures, to use reengineering techniques and to redefine the relationships and the models of their supply chains. It is in this context that emerged the global concept CPFR – *Collaborative Planning, Forecasting, and Replenishment*, at the end of the 90s. This concept express the integration of the several participants in the supply chain in order to ensure the sales increase, inter-organizational alignment, operational and administrative efficiency. Considering it, one field of CPFR application occurs in the transportation area, receiving the nomination CTM - *Collaborative Transportation Management*. It is observed there is a consensus related to this tool among the specialists that it presents a great potential to help in costs and risks reduction, to increase the service and capacity performance, as well as to obtain a dynamic supply chain (Seifert, 2003; Tacla, 2003).

So far, however, there has been little discussion about the resolution of the collaborative maritime transportation problem by the manufacturing industries. Thus, this paper aims to present a model that analyses the systemic effects of the collaboration policy among the manufacturing industries that use the maritime transportation to perform the export, considering the main strategical and operational parameters involved in this operation.

## **1.1 Research method and the paper structure**

The method choice was initiated with an analysis of the different possible approaches to the proposed problem through a bibliographical review and with the determination of the study object. From this point, it was concluded that the most appropriated approach to the problem in study would be the experimentation through the modeling technique. After modeling the problem and performed some simulations, the study object was validated conducting to some conclusions and recommendations for future works.

This paper is composed by 6 sections, including this introductory section. Section 2 presents some concepts about the collaborative logistics and the collaborative transportation management. In section 3 it is presented the mechanism to perform manufactured goods export through the maritime transportation. Section 4 describes the proposed model to the collaborative transportation problem and section 5 presents some results from the analysis. The last section presents some final considerations and suggestions to the continuity of this work.

## **2. COLLABORATIVE LOGISTICS AND THE COLLABORATIVE TRANSPORTATION MANAGEMENT**

Since the introduction of the ECR (*Efficient Consumer Response*) concept, approximately in 1993, the participants of the chain have tried to look through their own business in a way to

transform the ECR concept, with all the participants involved, working together principally through the communications networks formed by EDI (*Electronic Data Interchange*) (Silva, *et al.*, 2009). According to Tacla (2003) research, there is not in the literature abundant documents that ratify the emergence of the “collaborative logistic” phase, but it is possible to find material naming it as the “new wave”. Initiatives and recent works presented in several known conferences, as POMS (Production and Operations Management Society) conference, in 2008, have already presented this approach as a forward step to the evolution of the SCM concept. The strongest initiative to classify the Collaborative Logistics is named “CPFR” (Collaborative Planning, Forecasting and Replenishment) and it can be seen as a tentative that aspires to increase the cash flow and to improve the return on investments, besides to improve the goods’ flow management from the producers to the final consumers.

Similar to CPFR, the Collaborative Transportation involves information and process flows from suppliers and buyers that collaborate jointly with the carriers or 3PL’s to provide effective and efficient cargo delivery. Conceptually, the enterprises can join the Collaborative Transportation system with or without the use of CPFR. However, the Collaborative Transportation has been referred as the “lost link” of the collaborative supply chain execution. With no ability to develop effective cargo forecasts, the order forecasts that were developed by the CPFR could be handled without accuracy; nevertheless, the Collaborative Transportation provides the next critical step after the order generation by the CPFR (Sutherland, 2003). See Silva *et al.* (2009) to major information about the ways to implement the CTM.

Despite the thematic about the collaborative transportation be relatively new, a considerable amount of literature has been published about it but in a more theoretical form (Gomber *et al.* (1997), Bloos and Kopfer (2009)). Concerning the applied form, using mathematical programming and simulations there are few publications (Carnieri *et al.* (1983), Tacla (2003), Novaes *et al.* (2009) and Silva *et al.* (2010-a, 2010-b, 2011-a, 2011-b, 2011-c).

### **3.MECHANISM TO PERFORM THE MARITIME TRANSPORTATION FOR THE MANUFACTURING GOODS’ EXPORT**

As presented by Silva *et al.* (2011-b), following the blue flow (Figure 1) the negotiation begins by the manufacturing industry (1) which can act alone being responsible for all the arrangement through the distribution chain. In this situation the manufacturing industry hires the land carrier (4) (in case the industry does not have its own truck fleet) to transfer the manufactured goods from the industry to the port. There is also a possibility or, in many cases, the necessity to firstly transfer the manufactured goods to a warehouse (3) to maintain a stock which can be useful to solve quick delivery problems or to retain the cargo up to the time that all the bureaucracies to export are solved. The industry is also responsible for choosing the origin port to be used and at the same time it should negotiate with shipowners (7) the freight prices, choosing one of them to carry the manufactured goods.

In this stage it is quite common to hire a NVOCC (6). This agent is responsible for managing several industries' maritime transportation demand in order to negotiate with shipowners the freight prices and the availability of ships to the destinations of the industries' manufactured goods. In the destination side, there is another necessity by the manufactured industries concerning the definition of the destination port (8), which should be the most appropriated in order to deliver its goods to the clients (11). To fulfill the deliveries the manufactured industries must also hire land carriers (10) to transport its goods to intermediaries warehouses (9) or to final destinations in the destination's country.

The red flow in Figure 1 is almost the same as the blue flow excepting by the fact of the freight forwarder presence (2). In this case the manufacturing industry hires this agent to be responsible for contracting and controlling all the stages in the distribution chain. It is normally a practice adopted by small and medium industries which do not have expertise in such process and then, the freight forwarder, who manages several industries' transportation demand, can be agile in the negotiation.

As a consequence of a good planning in the distributions' logistics it is possible to: reduce storage time and costs, reduce time in the course, and reduce problems in the delivery to better attend the sales contract. Regarding to the costs there are several stages of the distribution process where they can be reduced. One of them that Stopford (2009) presents as an influent key on supply and demand of maritime transportation mode is the freight prices definition.

For Silva (2011- b; 2012) it is worth to mention the real practice adopted by the shipowners in the freight prices formation. Normally, the shipowners define in a *Freight Conference* the prices to be practiced in the regular liner of maritime transportation. It means the conference maintain a full apparently monopoly on the trade routes. In such situation if the manufacturing industries negotiate individually the freight prices with the shipowners, they do not have bargain power to attain better prices. This is the point where the collaboration can be applied in order to create groups of industries with the same goal. These groups can negotiate with shipowners in order to depress the monopoly created by them and get economies of scale as well as other benefits like major time to execute the payment of the freight and free time on shipping.

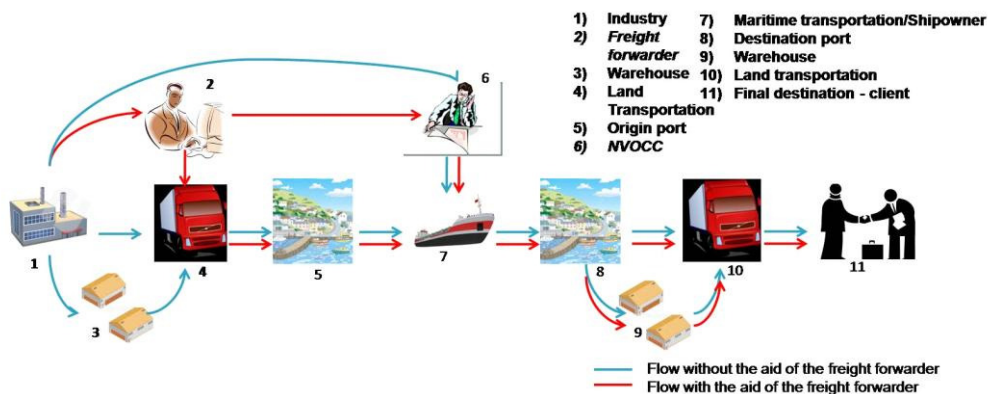


Figure 1: Stages of the export mechanism

Fonte: Silva et al. (2011-a).

## **4.MODELING THE COLLABORATIVE TRANSPORTATION PROBLEM**

Among the experimental methodologies, modeling was chosen for this work and the adopted computational technique was the simulation. After it, a systematic literature review was conducted of studies about the simulation method *Agent based Modeling and Simulation* (ABMS). Its main characteristics and application were analyzed as well as it was initiated the modeling process for the problem in study. Posteriorly, it was performed some discussions with specialists and researchers and it was mentioned the hypothesis of using the simulation method *System Dynamics* (SD) for modeling the collaborative transportation problem. Then, a new bibliographical review was conducted as well as analyzed the possible applications and limitations of it. These works resulted in the publication of several papers in well-known periodic, book chapter and conferences (see Silva *et al.* (2010 -a, 2010 -b; 2011 -a; 2011 -b; 2011 -c; 2012).

Thereby, based on the preliminary results of the study already done with both methods by the authors above mentioned, it was opted to continue modeling the collaborative transportation problem by SD method. The choice of SD method use in detriment of ABMS method was a consequence of two main factors. The first one was the fact that the problem in study be defined by the dynamic complexity where the actions of some agents generate reactions in other agents. The second factor was the necessity of quantitatively simulating the proposed policies to evaluate their impacts in the goals of the involved agents.

The appearance of SD occurred due to its treatment with problems characterized by the dynamic complexity; in other words, systems where the actions of a determined agent generate reactions in other agents, also called as *feedbacks* (Sanches, 2009). Conceptually, the *feedback* is the *System Dynamics* core approach. Intuitively, a *feedback loop* occurs when an information resulting from an action goes through the system and eventually returns in any way to its origin point, potentially influencing a future action. If the loop trend is to reinforce the initial action, it is named *positive loop* or *reinforcing loop*; if the trend is to oppose to the initial action, it is named *negative loop* or *balancing loop*. The loop sign is named, *polarity* (Sterman, 2000).

For this work continuity, during the years 2010 and 2011 some interviews were performed with Brazilian managers, from diverse areas (Weg, Votorantim, Stanley Black & Decker, Tigre, Tupy, Brasmar, Log-In, among others). The main objective of this contact was to obtain information about the export mechanism performed by them, verifying which are the main agents involved in this process and to speculate if there was already evidences of collaboration in the maritime transportation execution. It was also analyzed how the Brazilian entrepreneurs evaluate the possibility of CTM adoption in their operations. Beyond it, it was intentioned to comprehend the best practices adopted in the market for later modeling the problem in study, similarly to the real adopted practices.

#### 4.1 The industries behavior

The starting point to model the problem was defined as the comprehension of the manufacturing industries operation, as well as the collaboration formation among them based on the market freight price. According to Mankiw (2011), the product price represents the main factor in determining its demand. Therefore, using Vensim® software from Ventana Systems enterprise, Inc. (version DSS), it was modeled the industries behavior through a stock-flow diagram as depicted in Figure 2.

The number of industries considered in the analysis was modeled as a stock variable, *Industries (Ind)*. This kind of variable is an accumulation variable and characterizes the system state, generating information to the entrepreneurs make decisions and actions. The common way to model a stock variable is through a rectangle (as a container that stores a stock). This kind of variable is changed only by its flow rates, inputs or outputs: *new industries ingress (ini)* and *industries abandonment (di)*, respectively.

Comparing Figure 2 with the stock-flow diagram proposed by Silva et al. (2010-b) it is possible to realize that in Figure 2, it was eliminated 7 variables and they were embedded as equations in the remaining variables. Thus, the accumulated number of industries in collaboration (*Ind*) is expressed by the initial number of industries (*Ind(t<sub>0</sub>)*) added to the integration rate of industries change (*İ*) in the time, as equation (1):

$$Ind(t) = Ind(t_0) + \int_{t_0}^t \dot{I} dt. \quad (1)$$

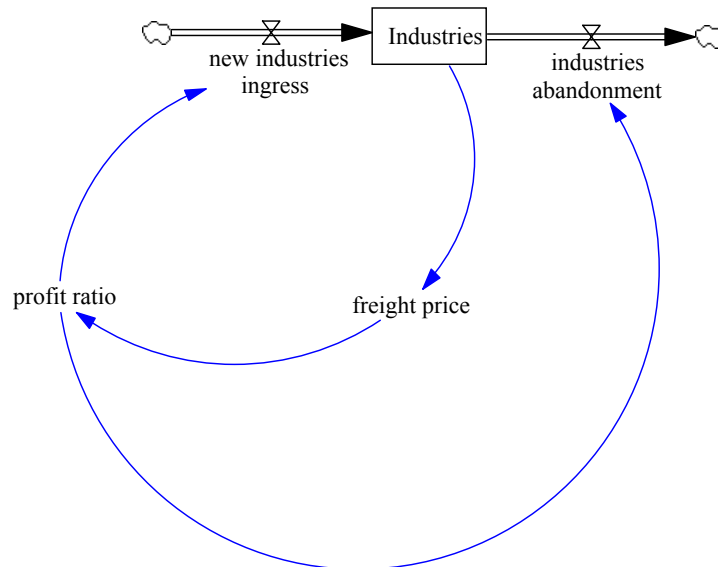


Figure 2 – Stock-flow diagram of the industries behavior

Source: the author.

The *İ* variable express the number of new industries that ingress in the collaboration (*ini*) and the number of industries in abandonment (*di*) at time *t*, as equation (2) :

$$\dot{I} = ini - di. \quad (2)$$

The *ini* variable varies according to the profit ratio (*ral*) obtained in a determinate time *t*. By *ral* it is understood the ratio between the obtained collaborative freight price (*Pref*) and the market maritime freight value for individual negotiation (assuming the value of \$ 100,00):

$$ral = pref / 100. \quad (3)$$

Thus, it is assumed:

$$ini = \begin{cases} 0, & ral > 1 \\ 8,1079 \cdot \exp(-2,179 \cdot ral), & ral \leq 1 \end{cases} \quad (4)$$

in other words, if the profit ratio is greater than 1, the collaboration freight price is greater to the individual freight price to be obtained by the industry and, then, it is not viable the ingress of a new industry into the collaboration.

The demand curve has not a simple definition; therefore, it was opted to use an exponential curve to represent the quantity variation in relation to the practiced freight price variation. According to the contacted specialists, it is quite common in the real market practices. For Warren (2002), adopting data close to real data is a common practice and it is efficient to analyze the variables behavior. Moreover, the needed effort to get exact data does not justify the low obtained gain with it, considering that an approximate behavior also allows an effective analysis.

The expected number of *di* varies also in function of *ral*: if  $ral \leq 0.58$  then  $di = 0$  else,

$$di = 0,0801 \cdot \exp(2,1502 \cdot ral), \quad (5)$$

in other words, the greater the *ral* it becomes impracticable to the industries to be in the collaboration, then, it becomes greater the abandonment number of industries. Following the principle that the practiced prices do not increase immeasurably, for  $Ind > 100$ ,  $Pref = 55$ , and in the opposite it will be changed as equation (6):

$$Pref = 100,38 \cdot \exp(-0,006 \cdot Ind). \quad (6)$$

## 4.2 The ships behavior

In order to better comprehend the shipowners behavior, who are responsible for making available the ships to the maritime transportation, it was modeled a stock-flow diagram to facilitate the ships offer mechanism related to the market freight price, as depicted in Figure 3.

The accumulated number of ships in this analysis was modeled as a stock variable, Ships (*Nav*), and the flows are represented by the inflow, new ships ingress (*inn*) and by the outflow, ships abandonment (*dn*). Both of them are influentiated by the auxiliary variable freight price (*Pref*), which varies as a function of the ships' number (*Nav*) available in the market.



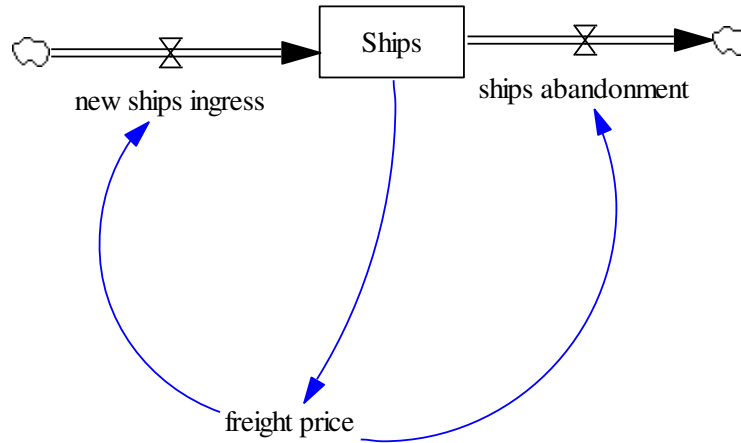


Figure 3 – Stock-flow diagram of the ships behavior

Source: the author.

This diagram was elaborated from the proposed diagram by Silva et al. (2010-b), reducing the variables number in order to facilitate the analysis of the ships' mechanism. Thus, the ships number ( $Nav$ ) is expressed by the initial ships number ( $Nav(t_0)$ ) added to the integration rate of ships change ( $\dot{J}$ ) in the time, as equation (7):

$$Nav(t) = Nav(t_0) + \int_{t_0}^t \dot{J} dt. \quad (7)$$

The variable  $\dot{J}$  is expressed by the number of new ships that ingress in the collaboration ( $inn$ ) and the number of ships in abandonment ( $dn$ ) at time  $t$ , as equation (8):

$$\dot{J} = inn - dn. \quad (8)$$

The variable  $inn$  varies according to  $Pref$ . In this way, if  $Pref < 30$  (a randomly adopted value), then  $inn = 0$ , in other words, no ships have interest to ingress into the system; but when  $Pref \geq 30$ , the number of ships that ingress into the system will occur according to equation (9):

$$inn = 0,0669 \cdot \exp(0,0441 \cdot Pref). \quad (9)$$

The expected value of  $dn$  will be null when  $Pref > 80$  and it will increase as  $Pref$  is reduced, considering the shipowner (representing the offer side) will be less interested to remain in the market as the freight is reduced, therefore, influencing the abandonment or reduction on the available ships on the market, in order to reduce the offer and to increase the freight price again. Thus, the equation (10) represents the expected value of  $dn$ :

$$dn = 8,6679 \cdot \exp(-0,043 \cdot Pref). \quad (10)$$

Lastly, the offer curve is defined from the freight price that is resultant from the number of ships offered in the market. Thus, for  $Nav < 1$ ,  $Pref = 50$ , else:

$$Pref = 55,206 \cdot \exp(0,006 \cdot Nav), \quad (11)$$

### 4.3 Industries' collaboration and the ships availability as a function of the maritime freight price

As a continuity of Silva *et al.* (2011-b) work, that considers in isolation the industries behavior and also the behavior of the ships availability, it was modeled a stock-flow diagram that allows to simultaneously analyze the behavior of the offer-demand system influencing the collaboration among the manufacturing industries, as Figure 4.

To model this diagram, it was used the diagrams depicted in Figure 2 and Figure 3, but both of them were changed in the definition of the variable *Pref*. This variable was an auxiliary variable, but now it was changed to a stock variable. Such consideration was adopted due the price does not be momentarily changed. According to Whelan and Msefer (1996), people do not have exact and quick information about a product offer and demand. Additionally, when an information becomes available it takes some time until someone makes a decision about a change in the price.

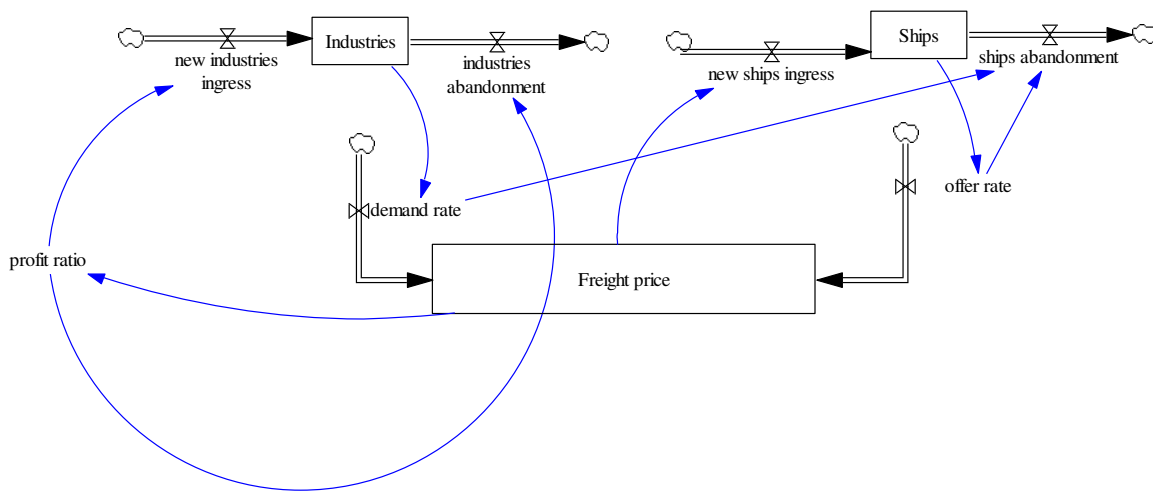


Figure 4 – Stock-flow diagram of the industries and ships

Source: the author.

As a stock variable is changed only by the inflows and outflows (Sterman, 2000), it was considered as inflow, the *demand rate* (*tdem*) and the *offer rate* (*tof*), representing the demand and offer, respectively. The *tdem* express the number of industries (*Ind*) that exist in a given time, but this value is converted in the number of ships (*Nav*), in order to use the same unity in the analysis. In this way,  $tdem = Ind/3,33$  and  $tof = Nav$ . In this proposed diagram the variable *dn* assumes the following values, as the equation (12):

$$dn(tof, tdem) = \begin{cases} 2, & tof / tdem \geq 1, \\ 1, & tof / tdem < 1 \end{cases} \quad (12)$$

This ratio indicates that if the offer rate is greater or equal to the demand rate in a given time  $t$ , 2 unities of ships leave the system, in order to try to reduce the freight price. Else, when the demand rate is greater than the offer rate, only 1 ship leaves the system (it is considered that always a ship can leave the system, even when the business is viable).

Besides such considerations,  $Pref$  is expressed by the initial value of the freight price ( $Pref(t_0)$ ) added to the integration rate of freight value change ( $\dot{M}$ ) in the time, as equation (13):

$$Pref(t) = Pref(t_0) + \int_{t_0}^t \dot{M} dt \quad (13)$$

where, the variable  $\dot{M}$  is regulated by  $tof$  and  $tdem$ , as equation (14):

$$\dot{M} = \begin{cases} -((tof - tdem) \cdot 0,3), & tof > tdem \\ ((tdem - tof) \cdot 0,3), & tof \leq tdem \end{cases} \quad (14)$$

In this way, if the offer is greater than the demand in a given time  $t$ , the freight price will be reduced, else the freight price will be increased, in order to equilibrate the market, looking for a condition where  $tof = tdem$ .

#### 4.4 Hinterland capacity

According to Novaes *et al.* (2012) the port areas suffer with several critical problems that contribute to generate high logistics costs and one of these problems is the lack of port capacity. Thus, considering that maritime transportation operations involve also the need of an area available to container reception and storage, known as hinterland, it was included such variable in the model, as depicted in the Figure 5.

Thus, *Hinterland capacity*, was modeled as being a stock variable, identified as  $CapHin$ , that represents the accumulated capacity of container storage whose unity is containers. This variable is changed through the inflow named *expansion area* ( $amp$ ) that represent the additional capacity that the system receives in a given time. This additional part of capacity occurs when the hinterland managers, per example, realize a trend in the space demand growth and then they anticipate a new construction or yard availability.

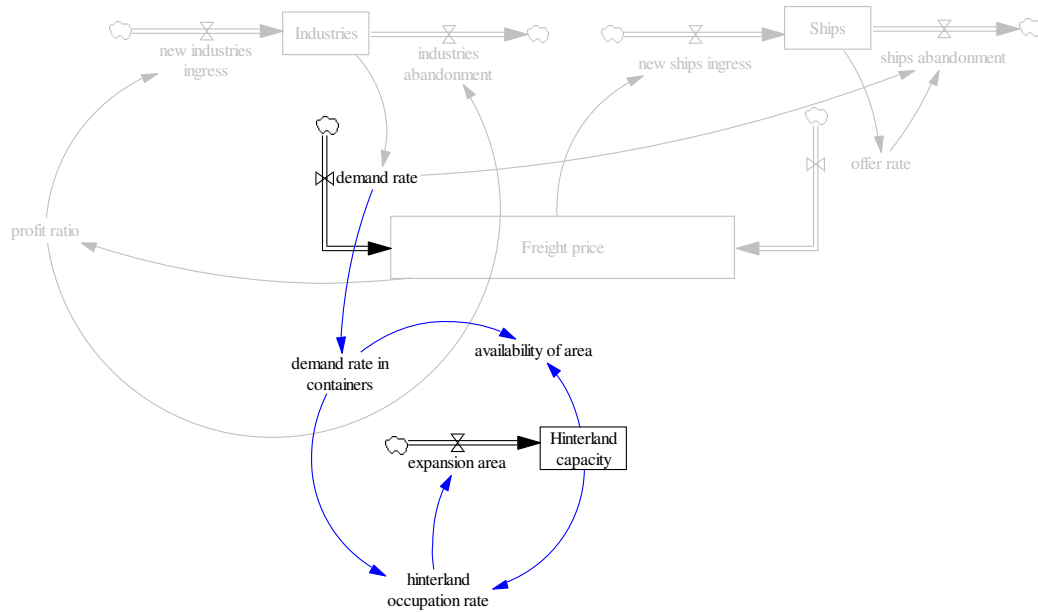


Figure 5 – Stock-flow diagram of the hinterland capacity

Source: the author.

Considering such information  $CapHin$  is expressed by the initial value of the hinterland capacity ( $CapHin(t_0)$ ) added to the integration rate of rate  $amp$  in time  $t$ , as equation(15):

$$CapHin(t) = CapHin(t_0) + \int_{t_0}^t amp dt, \quad (15)$$

where the variable  $amp$  is expressed in a first moment as:

$$amp = \begin{cases} 300.000, & toc \geq 0.75 \\ 0, & toc < 0.75 \end{cases}, \quad (16)$$

In other words, if the hinterland capacity occupation rate ( $toc$ ) is greater or equal to 75% of the used capacity, it is enlarged the capacity in 300.000 containers (a randomly adopted value) else, nothing is done due the demand be attended by the available capacity. Considering that  $toc$  must be measured in containers, it was transformed the demand rate ( $tdem$ ), which unity was ships/month to containers/month. For it, it was considered for a ship an allocation capacity of 10.000 containers and, therefore, the new demand rate measured in containers, is given by:

$$tdemc = tdem \cdot 10.000, \quad (17)$$

and in this manner, the  $toc$  is expressed by the ratio between  $tdemc$  and  $CapHin$ , as equation (18):

$$toc = \frac{(tdemc)}{CapHin} . \quad (18)$$

If there is interest to analyze, during the running time, the availability of area in the hinterland, it was inserted in the model an auxiliary variable, *disp*, given by:

$$disp = CapHin - tdemc. \quad (19)$$

Capacity expansion is the process of adding facilities over time in order to satisfy rising demand (Manne, 1961; 1967). Capacity expansion decisions generally add up to a massive commitment of capital. The efficient investment of capital depends on making appropriate decisions in expansion undertakings, in such a way the demand remains satisfied over an extended time period, with a minimum discounted lifespan cost.

The basic way to economically minimize a project lifespan cost is to compute its Net Present Value (NPV), where investments and costs are discounted using a continuous interest rate *r*. According to Casarotto and Kopittke (2010), the classic manner to calculate the NPV considers that the future monetary values with unknown risks are summarized by their expected values, and they can be expressed following the equation (20):

$$VPL = \sum_{j=1}^n \frac{R_j - C_j}{(1+r)^j} - I_0, \quad (20)$$

where:

$R_j$ : revenue obtained in period  $j$

$C_j$ : cost generated in period  $j$

$I_0$ : initial investment

$r$ : monthly interest rate

To calculate the generated revenue it was considered the monthly gain per container in storage in the hinterland area. Then:

$$R_j = tdemc_j \cdot prearmaz, \quad (21)$$

where *prearmaz* represents the monthly price paid for the storage of a container in the hinterland area. For the calculus of the incident cost in period  $j$ , it was considered the costs from the investments of the hinterland area capacity expansion.

According to Novaes *et al.* (2012) an important characteristic of most capacity problems is the recognition of economies of scale, i.e. large installations usually cost less per produced unit than small ones. But, if the demand level is continuously rising on the long run and demand backlogging is not permitted, excess capacity will occur. Thus, there is a trade-off between scale economies and excess capacity cost, leading to a compromised optimal solution.

The term “learning curve” effect (Couto & Teixeira, 2005) states that the more time a task is performed, the less time it will be necessary to workers do each subsequent iteration. Learning curve theory states that as the quantity of units produced doubles, labor costs will decrease at a predictable rate. The experience curve, on the other hand, is broader in scope, since it encompasses far more than just labor cost. Now, each time cumulative volume doubles, value added costs (including construction, administration, logistics, etc.) fall by a constant and predictable percentage. Mathematically the experience curve is described by a power law function:

$$I^{(m)} = I^{(1)} \cdot m^{-\theta}, \quad (22)$$

where  $I^{(1)}$  is the value of the building cost of the first unit,  $I^{(m)}$  is the value of the investment on the  $m^{\text{th}}$  unit, and  $\theta$  is the elasticity of building cost with regard to the number of units built in sequence. A experience curve that depicts a 25% cost reduction for every doubling of the number of built units is called a “75% experience curve” indicating that unit cost drops to 75% of its original level when installing the second item of the series, and so on. Let  $\delta$  be the experience factor, obtained via (23) as:

$$\delta = I^{(2)} / I^{(1)} = 2^{-\theta}. \quad (23)$$

Applying logarithms to (23) one has

$$\theta = -\ln \delta / \ln 2, \quad (24)$$

and the total investment related to the installation of  $m$  units in series is:

$$I^{(m)} = I^{(1)} \cdot \sum_{j=1}^m j^{-\theta}. \quad (25)$$

#### 4.5 Export incentive

In Brazil, the international business has been little used as a pro active factor of the development strategy and few actions have been done in order to expand the manufactured products export. Thus, conscious of the expansion importance for the Brazilian manufactured products, it was opted to include in the proposed model an auxiliary variable that represents the incentive to the export increase, named *export incentive (incexp)*, in order to evaluate the impact generated by the industries that ingress in the collaborative transportation system.

For this analysis it was not considered the manner how this incentive occurs (it can be through R&D, expansion of the manufactured industries, incentives of investments in high technology production, costs reduction, besides other policies), but only considered the generated impact. The variable *incexp* was modeled as a “PULSE” function (Vensim® language). This function (dimensionless) expressed as PULSE(initial time, duration) returns value 1, at the programmed time and remains with it for the programmed duration of time; adopting value 0 for all the other instants. Thus, it is considered:

$$incexp = \{60, t = 130\}, \quad (26)$$

in other words, at instant  $t = 130$  (randomly chosen), there is an ingress of 60 additional industries to the collaborative transportation system, due to the export incentive contributing with the industries. In this way, the variable *incexp* insertion affects the *ini* variable, expressed by the equation (27), which in turn becomes:

$$ini = 8,1079 \cdot \exp(-2,179 \cdot ral) + incexp. \quad (27)$$

#### 4.6 Maritime industry impact

When modeling the collaborative behavior of the industries into the maritime transportation system, it cannot be forgotten to consider the impact that the maritime industry can generate upon such system. According to Stopford (2009), the maritime industry market in the world involves the freight market, the ships construction, the second hand ships commerce and also de ships demolition. In this way, it was included in the model a new block of variables that represent this mechanism in a simplified manner.

This new block is composed by some already presented variables, as *tdem*, *tof*, *Pref*, that will influence the maritime industry system and also by *Nav*, that will be influenced by the system. Besides these variables other variables were modeled.

The discrepancy value existing in the maritime fleet, *discrep*, can be seen as the difference between *tdem* and *tof*:

$$discrep = tdem - tof. \quad (28)$$

The *discrep* variable should inform the value of the ships orders number (*encnav*) to be performed per time period. Therefore,

$$encnav = \text{Max} \{0, discrep\}. \quad (29)$$

The *encnav* variable is defined as being an inflow to the *Cartec* variable. This one, as a stock variable, represents the existing construction and order charter; in other words, it represents the accumulated number of ships that are in construction each time; and it is also influenced by the outflow *ships delivery* (*entnav*). Equation (30) defines *Cartec*:

$$Cartec(t) = Cartec(t_0) + \int_{t_0}^t \dot{Z} dt, \quad (30)$$

being  $Cartec(t_0)$ , the initial value of this charter and  $\dot{Z}$ , the variation rate (in time) of the ships on construction. The  $\dot{Z}$  variable is expressed by the difference between the ships order charter and the number of delivery ships in time  $t$ , as equation (31):

$$\dot{Z} = encnav - entnav. \quad (31)$$

When talking about ship construction, a hard work, it must be considered a delay existence between the ship order moment and the delivery time moment. This delay is modeled in Vensim® language, through a DELAY11(input value, duration, initial value) function, which returns an exponential delay of the input value. According to a Montgomery published paper in 1995, the average time to construct a ship is 16,7 months (approximately 1,4 years). This value will be adopted to the variable named *tmc* (average time construction) and then *entnav* can be equated as:

$$entnav = \frac{encnav}{tmc}. \quad (32)$$

this one, besides an outflow of *Cartec* is also recognized as an inflow to the variable *Nav*, previously defined. This last one is also influenced by the outflow *ships demolition* (*demnav*), which represents the rate of ship demolition at each time period *t*. For a simplification, it is not considered the demolition reasons and it is adopted  $demnav = Nav * 0.05$ ; in other words, the adopted demolition rate is 5% of the existing ships values. Then, the new value for *Nav*, previously expressed by equation (7), is given by:

$$Nav = \text{Max} \{ (entnav + inn - dn - demnav), 0 \}, \quad (33)$$

in other words, the greatest value between 0 and the difference among the delivery, ingress, abandonment and demolition of ships.

## 5. RESULTS

In this section will be presented the obtained results (through computational simulation). The results contributed to the comprehension of the collaborative maritime transportation mechanism.

### 5.1 Analysis of the industries behavior

At the beginning of the analysis it was considered as initial value,  $Ind(t_0) = 20$  and that *Pref* is high (around \$90,00). With this situation, initially the rate *di* is relatively high (it is not attractive to the industries ingress in the collaboration system due the collaboration cost be higher than the individual cost), whereas the rate *ini* is relatively low (they are inversely proportional).

When *Pref* is reduced, it becomes interesting to the industries ingress in the collaboration system, therefore, the rate *ini* is high, exponentially growing and increasing the number of industries *Ind*, which reduces the value of the variable *Pref*, closing a *Balance Looping*. Whereas the business is favorable for them, it is reduced the rate *di*.



## 5.2 Analysis the ships behavior

Initially  $dn$  is high because at low freight prices the shipowners offer low ships. When the freight price receives an increase, it is also increased the new ships ingress flow and, consequently, the number of available ships on market, closing a *Reinforce Looping*. Thus, the flow of ships on abandonment is also reduced.

## 5.3 Industries and ships behavior as a function of the maritime freight price

At the beginning, when the freight price is low, it is not attractive to the shipowners offer new ships on the market, therefore, the offer remains constant, until the time the freight price starts increasing, and it becomes favorable the new ships ingress on the market. This situation remains until the freight price reaches its maximum value (approximately at time 20), where the offer is greater than the demand, and the reduction process is started. This action stops the new ships ingress (approximately at time 30).

When analyzing the demand (industries in collaboration demanding ships), it has initially a growing behavior but at a low rate ( $ini$ ). When the flow decreases, the stock increase rate also decreases. Even when the flow  $ini$  is decreasing, the stock level of  $Ind$  is also increasing and when exists positive flow acting in the stock, the stock value will be increased. As verified, the flow  $ini$  indicates the stock  $Ind$  slope, at each instant of time. During the time 0-20, the incident flow in the stock is decreasing, therefore the increment in the stock value is decreased, but during the time 20-45 the incident flow is increasing, and it makes a raise in the stock. Thus, it is assumed the stock slope in an specific instant of time is equal to the resulting flow (input-output) in this time. In other words, the stock slope in a certain instant of time is equal to the tangent line slope in this instant of time.

After the maximum value of the variable  $Pref$ , as the freight value decreases, the number of industries acting in the collaboration system increases, and the new industries ingress rate in this situation is positive, due the lower the freight price, the greater is the attraction of new industries ingress in the collaboration.

The ships offer and the ships demand (by the export manufacturing industries), tend to reduce the gap existing between their volumes and therefore there is a reduction in the freight price oscillation, reaching a market equilibrium, around time 130, when  $tof = tdem \approx 75$  unities and,  $Pref \approx 71$ \$. Besides the price stabilization always will exists oscillations and this fact impacts  $tdem$ ,  $tof$ ,  $ini$ ,  $di$ ,  $inn$  and  $di$  that continue acting independently of the stabilized price. It demonstrates the collaboration power acting in the system and influencing  $tdem$  and  $tof$  growth. The behaviour of the industries in collaboration as a function of  $Pref$  can impact the *new industries ingress* ( $ini$ ) and the *industries abandonment* ( $di$ ).

It is verified  $di$  rate is proportional to  $Pref$ . In other words, as  $Pref$  is increased,  $di$  is also increased, because it is economically viable the industries act individually. If  $Pref$  is reduced,

$di$  value is also reduced. The *new industries ingress* is inversely proportional to the freight price: if  $Pref$  increases,  $ini$  decreases; and when  $Pref$  decreases, the  $ini$  value increases.

The behavior of  $tof$  is also commanded by  $Pref$  and it varies through two flows: the *new industries ingress* ( $inn$ ) and the *abandonment ships* ( $dn$ ). As  $Pref$  increases, it is increased the rate  $inn$  considering the shipowners aim to maximize their profits and therefore as equation (12),  $dn=1$ . Only 1 unity of ship abandons the system per time period. When  $t=22$ ,  $Pref$  reaches its maximum value of \$93,82, and from this point, as  $tof/tdem \geq 1$ , the ships abandonment rate becomes  $dn=2$  ships per time period. The excess of ship offer in the market generates the freight price reduction considering the industries in collaboration have greater power in the negotiation of it. The freight price is reduced until the ship offer is low, around time 46 when  $tof/tdem < 1$ , and then, the shipowners start to increase the freight price one more time. The cycle is repeated through the time until it reaches the equilibrium point (around time 140).

#### 5.4 Analysis of the hinterland capacity behavior

When  $CapHin(t_0) > tdemc$ , a low capacity occupation ( $toc$ ) will exist,  $toc=0,20$ . As  $tdemc$  increases,  $toc$  also increases. In this situation the *hinterland capacity* starts to receive greater occupation until the moment ( $t=36$ ),  $toc=0,75$ ; in other words 75% of the hinterland capacity is used and therefore, in the next step a capacity expansion occurs with 300.000 containers. Then, the new available capacity is  $CapHin=600.000$ . At this moment, the occupation rate is reduced to  $toc=0,39$ . This procedure is repeated through the time and at  $t=73$ ,  $t=119$  and  $t=177$ , the new occupation rates are  $toc=0,50$ ,  $toc=0,56$  e  $toc=0,60$ , respectively. In a long term  $amp=300.000$  containers will not be enough and a new expansion strategy will be necessary. For this scenario, the NPV was calculated and according to Bashyam (1996), the capacity investment anticipation is a good strategy. So, there exist a special period of time where the investment is indicated in order to reduce cost and increase the capacity occupation.

#### 5.5 Analysis of the export incentive

During a project analysis exogenous variables can emerge and most of these situations deregulate the system. In the proposed model, the variable *export incentive* contributes to the *new industries ingress*, increasing the demand rate. It makes the gap between the demand rate and the offer rate to increase, and this increases the freight price. Besides it, an export incentive generates a congestion in the hinterland area and then it is necessary a new capacity expansion which was not considered in the original project.

#### 5.6 Analysis of the maritime industry impact

The maritime industry tries to reduce the fleet discrepancy when covering the existing demand for ships. Some construction orders are made through the time and some deliveries

are also made. As the adopted construction time for a ship is 16,7 months, there exists a delay between the construction order time and the delivery time. The delivered ships become part of the available ship stock and they directly influence the offer rate.

When the offer rate is greater than the demand rate, there is a reduction in the freight price and basically the new ships ingress stops. The freight price reduction is the ideal condition for new industries ingress in the collaboration, increasing the demand rate over the offer rate. Such condition increases the freight price and also the new ships ingress besides to start the maritime industry again.

## **6. FINAL CONSIDERATIONS**

From a simplification of the problem in study it was possible to perform several simulations (despite the empiric adopted relations) and to comprehend how the collaborative maritime transportation dynamic system works. One of the more significant findings to emerge from this study is the comprehension of the importance of each variable in isolation besides the generated impact in the system after a change in these variables. This change was done using sensibility analysis. After a bibliographical review, a research with some entrepreneurs, modeling the problem and analyzing the numerical results of the system behavior it was identified, explicitly and implicitly, the benefits arising from the collaborative maritime transportation system: shared administrative costs, reduced maritime freights, greater free-time on shipment, greater time to pay the freight, greater influence over the carriers, import and export constant flows, greater service offer by the shipowners and ports, improvement in the hinterland, among others.

The results of this study indicate that collaboration is a good opportunity for industries and a variety of subjects related to the theme of this paper was not mentioned. Therefore, there are several opportunities for expanding this work: to expand the proposed model including all the other agents involved in the maritime export chain, as presented in Figure 1, as well as improve the details of the agents behavior, repeat the study after obtaining more quantitative real data, to effectuate the same study in other industry segment in Brazil in order to compare them, to propose a collaboration index, to improve the SD study in order to generate better analysis of the collaboration formation models. Thus, it is desired to consolidate the collaborative network formation in order to improve the logistics efficiency and the enterprises profits, as proposed the collaborative transportation approach.

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