SYSTEM DYNAMICS SIMULATION FOR ANALYSING 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.

Introduction
Novaes (2007) presents the typical formulation of a supply chain in terms of the material flows derived from inputs, components and goods. Historically, these flows among the participants of the supply chain present conflicts in the business channels. Each link of the chain seeks to minimise its individual costs, which does not usually correspond to the global optimum of the supply chain (Seifert, 2003). This fact is

becoming increasingly difficult to ignore, so to reduce costs, increase efficiency and obtain competitive advantages, enterprises are being forced to rethink their procedures, to use reengineering techniques and to redefine the relationships and the models of their supply chains.

The global concept CPFR (Collaborative Planning, Forecasting, and Replenishment) emerged within this context at the end of the 90s. This concept expresses the integration of several participants into the supply chain to ensure increases in sales, inter-organisational alignment, and operational and administrative efficiency. An application of CPFR occurs in the transportation area, under the name CTM (Collaborative Transportation Management). There is a consensus among specialists that this tool has a great potential for reducing costs and risks, for increasing service and capacity performance, and for obtaining a dynamic supply chain (Seifert, 2003; Tacla, 2003). This paper is composed of 6 sections, including this introductory section. Section 2 presents concepts on collaborative logistics and collaborative transportation management. Section 3 presents the mechanism for exporting manufactured goods by maritime transportation. Section 4 describes the proposed model for the collaborative transportation problem and section 5 presents the analysis results. In the last section some final considerations are discussed, along with suggestions for continuing this work.

Collaborative logistics and the Collaborative Transportation Management

Tacla (2003) explains that while few reports in the literature corroborate the emergence of a "collaborative logistic" phase, reports exist on a "new wave". Similar to CPFR, Collaborative Transportation involves the flow of information and processes from suppliers and buyers who collaborate with carriers or 3PLs to provide effective and efficient cargo delivery. Conceptually, enterprises can join the Collaborative Transportation system with or without using CPFR. However, Collaborative Transportation has been referred to as the "missing link" in the realisation of the collaborative supply chain. Although collaborative transportation is a relatively new concept, a considerable literature has been published on the subject, albeit in a relatively theoretical context. Few publications exists on more applied collaborative transportation methods, such as mathematical programming and simulations, Tacla (2003), Novaes *et al.* (2009) and Silva *et al.* (2010-a, 2010-b, 2011-a, 2011-b, 2011-c).

Maritime transportation mechanisms for the export of manufactured goods

Silva *et al.* (2011-b) have discussed that negotiations may be initiated by a manufacturing industry (1), which may act alone, being responsible for all the arrangements in the distribution chain (follow the blue-coloured flow in Figure 1). In this situation, the manufacturing industry hires a land carrier (4) (if the industry does not own a truck fleet) to transfer the manufactured goods from the industry to the port. There is also a possibility, or in many cases a necessity, of first transferring the manufactured goods to a warehouse (3) to maintain a stock which can be used to quickly solve delivery problems or of retaining the cargo up to the time that all the bureaucratic export issues are resolved. The industry also chooses the port of origin, at which time freight prices are negotiated with shipowners (7) and a shipowner is selected choosing one of them to transport the manufactured goods. At this stage, it is quite common to hire a NVOCC (6). This agent is responsible for managing the maritime transportation demands of several industries to negotiate with shipowners on freight prices and the availability of ships to the destinations of the industries' manufactured goods. The manufacturing industries also need to determine the most appropriate port of destination port (8) for delivering the goods to clients (11). To fulfil deliveries, the manufacturing industry must also hire land carriers (10) to transport the goods to intermediate warehouses (9) or to the final destinations in the relevant country. The red-coloured flow in Figure 1 is almost the same as the blue-coloured flow except for the presence of the freight forwarder (2). This agent is hired by the manufacturing industry to handle all the contracts and control all the stages in the distribution chain. This is typically practiced by small and medium industries that do not have expertise in these processes, such that the freight forwarder, who manages the transportation demand for several industries, can negotiate intelligently on their behalf.

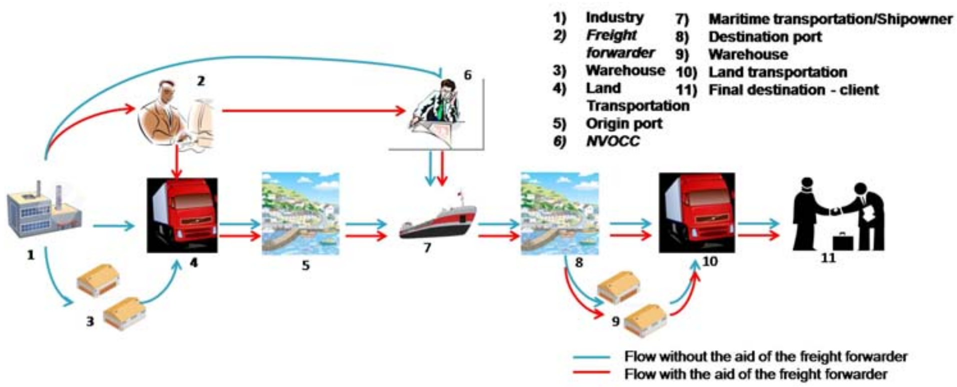

Figure 1 - Export mechanism stages
Fonte: Silva et al. (2011-a).

Modelling the Collaborative Transportation Problem

Modelling was selected as the experimental method in this study and simulation was used as the computational technique. Next, a systematic literature review was conducted on studies using the simulation method System Dynamics (SD). SD was developed to solve problems characterised by dynamical complexity, i.e., systems where the actions of a pre-determined agent cause reactions by other agents, which is also known as feedback (Sanches, 2009).

Behaviour of manufacturing industries

The starting point in the model is to understand the operation of manufacturing industries, as well as how collaborations form among industries based on the market freight price. Therefore, the behaviour of the industries was modelled using Vensim® software from Ventana Systems enterprise, Inc. (version DSS), using the stock-flow diagram. The number of industries considered in the analysis is modelled as a stock variable, Industries (*Ind*). This type of variable is an accumulation variable that characterises the state of the system, providing information with which the entrepreneurs can make decisions and take action. A stock variable is typically modelled by a rectangle (i.e., a container that stores stock). This type of variable is only changed by flow rates, inputs or outputs: ingress of new industries (*ini*) and abandonment of industries (*di*) are both stock variables.

Comparing with the stock-flow diagram proposed by Silva *et al.* (2010-b), 7 variables were eliminated by embedding them as equations in the remaining variables. Thus, the accumulated number of collaborating industries *(Ind)* is expressed as the initial number of industries *(*Ind*(*t_0*))* added to the integrated rate of change of the number of industries ($\dot{I}$) in time, as in equation **Error! Reference source not found.** :

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

The $\dot{I}$ variable represents the number of new industries that have ingressed into the collaboration (*ini*) and the number of industries that have been abandoned (*di*) at time *t*, as in equation **Error! Reference source not found.** :

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

The *ini* variable varies with the profit ratio (*ral*) obtained in a determinate time *t*.

The behaviour of ships

The accumulated number of ships in this analysis is modelled by the stock variable, *Ships* (*Nav*) and the flows are represented by the inflow, *ingress of new ships* (*inn*), and by the outflow, *abandonment of ships* (*dn*). Both flows are influenced by the auxiliary variable, *freight price* (*pref*), which is a function of the number of ships available on the market (*Nav*).

This diagram is modified from a diagram given by Silva *et al*. (2010-b), where the number of variables has been reduced to facilitate the analysis of the ships' behaviour. Thus, the number of ships (*Nav*) is given by the initial number of ships ($Nav(t_0)$) plus the integrated rate of change of ships ($\dot{J}$) with time, as in equation (3) :

$$Nav(t) = Nav(t_0) + \int_{t_0}^{t} \dot{J}\, dt. \quad (3)$$

The variable $\dot{J}$ denotes the number of new ships that ingress into the collaboration (*inn*) minus the number of abandoned ships (*dn*) at time *t*, as in equation **Error! Reference source not found.**:

$$\dot{J} = inn - dn. \quad (4)$$

Collaboration between industries and the availability of ships as a function of the maritime freight price

The variable *Pref* was an auxiliary variable, but has been changed to a stock variable. This change is made because the price does not change instantaneously. As a stock variable is changed only by the inflows and outflows (Sterman, 2000), the *demand rate* (*tdem*) and the *offer rate* (*tof*), representing the demand and offer, respectively, are both considered to be inflows. The variable *tdem* denotes the number of industries (*Ind*) that exist at a given time, but this value is converted into the number of ships (*Nav*), to unify the analysis. Thus, $tdem = Ind/3,33$ and $tof = Nav$. In the proposed diagram, the variable *dn* assumes the values in equation **Error! Reference source not found.**:

$$dn(tof, tdem) = \begin{cases} 2, & tof/tdem \geq 1, \\ 1, & tof/tdem < 1 \end{cases}. \quad (5)$$

This ratio indicates that if the offer rate is greater or equal to the demand rate at a given time *t*, 2 units of ships leave the system to try to reduce the freight price. Otherwise, when the demand rate is greater than the offer rate, only 1 ship leaves the system (it is assumed that a ship can always leave the system, even when business is viable).

Apart from such considerations, $Pref$ is expressed by the initial value of the freight price ($Pref(t_0)$) plus the integrated rate of change of the freight value ($\dot{M}$) over time, as in equation **Error! Reference source not found.**:

$$Pref(t) = Pref(t_0) + \int_{t_0}^{t} \dot{M}\, dt \qquad (6)$$

where the variable $\dot{M}$ is determined by tof and $tdem$ as given by equation **Error! Reference source not found.**:

$$\dot{M} = \begin{cases} -((tof - tdem) \cdot 0,3), & tof > tdem \\ ((tdem - tof) \cdot 0,3), & tof \le tdem \end{cases}. \qquad (7)$$

Thus, if the offer is greater than the demand at a given time t, the freight price will be reduced, otherwise the freight price will increase to equilibrate the market such that $tof = tdem$.

Hinterland capacity

Thus, the *hinterland capacity* was modelled as a stock variable, $CapHin$, representing the accumulated container storage capacity in units of containers. This variable is affected by the inflow known as *expansion area* (amp), which represents the additional capacity that the system receives at a given time. This additional capacity may occur, for example, when the hinterland managers, recognise a trend in the growing demand for space and consequently anticipate new construction or yard availability.

Based on this information, $CapHin$ is expressed as the initial value of the hinterland capacity ($CapHin(t_0)$) plus the integrated rate of change of amp over the time t, as in equation **Error! Reference source not found.**:

$$CapHin(t) = CapHin(t_0) + \int_{t_0}^{t} amp\, dt, \qquad (8)$$

where the variable amp is expressed initially n a first moment as:

$$amp = \begin{cases} 300.000, & toc \ge 0.75 \\ 0, & toc < 0.75 \end{cases}, \qquad (9)$$

Results

The computational simulation results are presented in this section. These results helped to elucidate the mechanism for collaborative maritime transportation.

Analysis of the behaviour of industries

As $Pref$ is reduced, it becomes worthwhile for industries to ingress into the collaboration system: therefore, the rate ini is high, exhibiting exponential growth and increasing the number of industries Ind, which in turn reduces $Pref$, closing a *Balance Looping*. While the collaboration is favourable for industries, the rate di is reduced.

Analysis of the behaviour of ships

Initially *dn* is high because shipowners offer a small number of ships at low freight prices. As the freight price increases, the new ships ingress flow also increases, which in turn increases the number of available ships on the market, closing a *Reinforce Looping.* Thus, the flow of abandoned ships is also reduced.

Behaviour of industries and ships as a function of the maritime freight price

When the freight price is initially low, it is not worthwhile for the shipowners to put new ships on the market: therefore, the number of ship offers remains constant until the freight price starts to increase and it becomes favourable for new ships to ingress into the market. This situation continues until the freight price reaches a maximum, when the offer is greater than the demand, which starts the reduction process. This action stops the ingress of new ships.

The demand for ships by industries in collaboration initially grows at a low rate (*ini*). As the flow decreases, the rate of increase of the stock also decreases. This is because the stock level of *Ind* is also increasing even while the flow *ini* is decreasing, so that the positive flow of stock results in an increase in the stock value. As the freight value decreases beyond the *Pref* maximum, the number of industries in the collaborative system increases: the rate of ingress of new industries is positive in this case because new industries are more attracted to the collaboration as the freight price is lowered.

The number of ships offered and the demand for ships (by the export manufacturing industries) tend to reduce the gap between the volumes of these variables, reducing the oscillation of the freight price so that a market equilibrium is reached. Oscillations always exist around the stabilised price, which impacts the variables *tdem*, *tof*, *ini*, *di*, *inn* and *di* that continue to act independent of the stabilised price. This demonstrates the power of collaboration in the system, which affects the growth of $tdem$ and tof . The behaviour of the industries in collaboration as a function of *Pref* can impact the *new industries ingress* (*ini*) and the *industries abandonment* (*di*).

The *di* rate was found to be proportional to *Pref*, i.e., as *Pref* increases, *di* also increases because it is economically viable for industries to act individually. If *Pref* is reduced, *di* is also reduced. The *new industries ingress* is inversely proportional to the freight price: when *Pref* increases, *ini* decreases and when *Pref* decreases, *ini* increases.

The variable *tof* is also controlled by *Pref* and changes with two flows: *new industries ingress* (*inn*) and *abandonment ships* (*dn*). As *Pref* increases, the rate *inn* also increases as the shipowners try to maximise their profits, so that $dn = 1$ as in equation **Error! Reference source not found.**. Only 1 ship unit is abandoned by the system per time period. The excess ship offers in the market reduce freight prices because the collaborating industries have greater negotiating power. The freight price continues to drop until the number of ships offers is low, which occurs around time 46 when $tof / tdem < 1$: the shipowners then start to increase the freight price again. The cycle repeats in time until an equilibrium is reached.

Analysis of the behaviour of the hinterland capacity

For $CapHin(t_0) > tdemc$, a low occupation capacity (*toc*) exists, $toc = 0,20$. As $tdemc$ increases, toc also increases. In this case, the *hinterland capacity* starts to be used up until, $toc = 0.75$, i.e., 75% of the hinterland capacity is used resulting in the capacity is being expanded to 300.000 containers. The new available capacity is

$CapHin = 600.000$. Over the long term, $amp = 300.000$ containers will not be sufficient, necessitating a new expansion strategy. The NPV for this scenario has been calculated scenario by Bashyam (1996), showing that the anticipation of capacity investment is a good strategy. Thus, there is a particular time period where investment can reduce cost and increase capacity utilisation.

Final considerations

The problem under consideration needed to be simplified (despite the use of empirical relations) to perform several simulations and to understand the workings of a collaborative maritime transportation dynamical system. One of the more significant findings to emerge from this study is the importance of each variable in isolation, in addition to the impact on the system following a change in these variables. This change was made using sensibility analysis. Following a literature review, consultation with entrepreneurs, modelling the problem and analysing the numerical results of the system behaviour, the explicit and implicit benefits of the collaborative maritime transportation system were identified: shared administrative costs, reduced maritime freights, greater *free-time* on shipment, greater time to pay the freight, greater influence over carriers, import and export constant flows, increased offers of service by the shipowners and ports, and improvement in the hinterland, among others.

The results of this study show that collaboration presents a good opportunity for industries and a variety of subjects related to the theme of this paper have not been mentioned. Therefore, there are several options for extending this work: expanding the proposed model to include all the agents involved in the maritime export chain shown in Figure 1, as well as improving the details of the agents behaviour; repeating the study after obtaining more quantitative actual data; performing the same study in a different industrial sector in Brazil for comparison; proposing a collaboration index; and improving the SD study to better analyse the models for collaboration formation. Thus, the formation of a collaborative network should be consolidated to improve the efficiency of the logistics and enterprise profits, as proposed in the collaborative transportation approach.

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