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THE EFFECTIVENESS OF USING E-COLLABORATION TOOLS IN THE SUPPLY CHAIN. AN ASSESSMENT STUDY WITH SYSTEM DYNAMICS

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ABSTRACT

Developments in information technologies in recent years have enabled major advances in electronic commerce and e-commerce is growing at a very fast pace. Although business-to-consumer (B2C) e-commerce seems to be slowdown due to economic conditions, business-to-business (B2B) e-commerce still represents the next generation of business automation.

Taking advantage of new technologies, is nowadays an opportunity, but will be a must in the future. Internet e-collaboration tools show up in this new era, and besides playing a role of "value creation enabler", also generate a wide range of "new business and market complexities" that companies have to face.

This paper presents a classification of "managerial spaces" where multiple trading partners share critical information using e-collaboration tools and assesses the possible local and global impact on the supply chain (SC) performance. This is made by means of a conception of a supply chain model and a simulation study with System Dynamics.

Keywords: Supply Chain Management (SCM), Business Modeling, System Dynamics.

1. INTRODUCTION

In a traditional vision of the supply chain, demand flows up the chain (from each trading partner to its upstream trading partner) and products are moved in the opposite direction. Delay times, distorted demand signals and poor visibility of exceptional conditions result in critical information gaps and serious challenges for supply chain managers. It includes missing information and finally a lack of trust between buyers and suppliers. For example, when partners do lose faith in the forecast they receive, they typically respond by building up inventory buffers to guard against uncertainty demand. The disruption that results from suddenly dramatic changes in forecasted demand is amplified through the supply chain. This phenomena called "bullwhip effect" is responsible for much of the inefficiency in a supply chain (Lee et al. 1997, Chen et al. 1999). Researches agree that sharing critical information, has contributed to reduce dramatically inventories and to improve the performance of the total SC.

The need of certain co-ordination among partners in a SC, should be translated into process and function integration within the organizations and along the entire SC (Cooper et al. 1997). Several researchers agree that planning and control activities should be integrated (Jones and Riley 1985). Also, there is a important consensus of an idea that the integration of information systems is a must (Ellram and Cooper 1990, Houlihan 1985, Stevens 1989, Ellram 1991, Gavirneni et al. 1999).

On the other hand, Internet and the low costs of accessing applications, as well as the emerging standards for data exchange such as XML (extended markup language), allow systems to be shared within multiple organizations and facilitate the information flow from any source to all SC partners. The emergent e-collaboration tools enable the trading partners to exchange business information in supply chain operations, in a structured, agile (in real time), stable and leveraged way (Shore 2001, Raghunathan 1999, Bauknigh 2000). The opinion of most authors is that the benefits by closing the information gap to form collaborative partnerships far outweigh the risk (financial analysis suggests that collaborative planning can lead to inventory reductions of 10% to 50% for each of the supply chain members).

Although the term "supply chain automation and collaboration" has only gained attention in recent years, various forms of SCM information systems have been around for over 20 years. For example, Electronic Data Interchange (EDI) and Electronic Funds Transfer (EFT) technologies they were first introduced in the late 1970s (Adam et al. 1999).

Shore (2001) separates the evolution of information technologies in supply chain management into four stages. In the first stage, inter-organizational information exchanges traveled through the postal system or fax. Using EDI, the second stage is focused on the automation of information flows and the elimination of many labor-intensive data entry and re-entry processes between retailers and suppliers. The third stage emphasizes a more integrative strategy by implementing ERP systems. In the fourth stage, a supply chain is characterized by strategic supplier alliances with extensive two-way information flows. By studying the performance of the SC in the last stage, we see that it is the issue that concerns us.

In this paper we evaluate the impact of using Internet-based e-collaboration tools in the supply chain management, assuming they are different opportunities for collaboration. This assessment will be presented by a reasonable supply chain integration path by using the necessary e-collaboration tools, and using a system dynamics model which will be introduced in the following sections.

In the sequel, we first discuss the types of sharing information by using e-collaboration tools within a SC and, we review the main contributions in this topic. In Section 3 a generic model for the representation of the SC is introduced and then, how are formalized the different supply chain collaboration tools within that model. Section 4 is dedicated to the modeling of the cash requirements and other related financial variables of the SC. In Section 5 the model outputs are discussed to validate the behavior of the main variables. Finally after the validation, in Section 6 several model results are presented, helping to understand the potential implications of the integration process for the global SC and for each of its members. The conclusions are presented in Section 7.

2. TYPE OF INFORMATION SHARING AND E-COLLABORATION TOOLS

Collaboration by sharing information has joined the ranks of integration and automation as a hallmark of competitive advantage in the supply chains. Gartner (1999) describes c-commerce as achieving "...dynamic collaboration among of business partners employees and customers throughout a trading community or market...." The ability of businesses to "morph" into whatever the market needs them to be, in time, always, clearly means more than buy-sell transactions and auction events. The benefits of c-commerce are similar to those whose have been achieved in the 80s through concurrent engineering. Following benefits are shown: Reduced time to market, increased market share and faster response to changes in custom preferences. The big difference between c-commerce and in-house concurrent engineering is that c-commerce requires integrated processes, pervasive information sharing, co-operation, and trust between firms.

The possible shared information includes inventory, sales, demand forecast, order status, product planning, logistics, production schedule, etc., and can be summarized into three types: product information, customer demand and transaction information, and inventory information.

- **Product information**

Original exchange of product information among the partners of the supply chain was done by paperwork, such as paper catalog, fax, etc. The problems caused by this, include delays of information sharing and miscommunications among the trading partners. To add the product information into its information systems, a retailer has to re-enter the data manually, which may or may not come along with the product. To keep the data updated is even a harder task. For example, if some information has been changed since its last release, all the retailers in the industry (if they are lucky enough) have to check the data individually. According to UCCnet, 30 percent of data which has been exchanged between suppliers and retailers doesn't match up due to the inefficiencies of manual data entry and convoluted processes (http://www.uccnet.org). This is an enormous problem for the industry, because bad data translates into a bad understanding of what retailers actually have on their shelves and what suppliers actually have in their warehouses. Bad data translates directly into huge costs, missed revenues and often enough, end-user dissatisfaction.

EDI was first introduced for data interchange. Although EDI was originally designed to process transactions, it has been extended to facilitate sharing of some information like POS and on-hand inventory (Sokol 1995). However, EDI has its own limitations. In addition, EDI does not verify data accurateness, it just transmits the data--"Garbage in, garbage out".

- **Customer Demand and Transaction Information**

Customer demand and transaction information serves as a critical source of information about future business, and is directly used for demand forecasting, manufacturing schedule, transportation planning, etc.

Lee and Whang (1998) provide an example of transaction information sharing in Seven-Eleven-Japan's (SEJ). In case of SEJ, POS data is transmitted to SEJ headquarters, wholesalers, and manufacturers to monitor stocking levels, shelf space organization, merchandizing, and new product development.

The recent developed Collaborative Forecasting and Replenishment (CFAR) is a new inter-organizational system that enables retailers and manufacturers jointly, to forecast demand and schedule production (Raghunathan, 1999).

- **Inventory Information**

Inventory information, including inventory status and inventory decision models, directly affects the amount of order placed to the immediate upper stream supply chain partners. However, inventory information seems to be more sensitive than customer demand and transaction information, additionally, trading partners are less willing to share it. For example, manufacturers may not be willing to divulge their true inventory situation or may portray false inventory levels to discourage competitors from producing additional products or building additional capacities and suppliers may use inventory and sales data to get a better bargaining leverage.

In practice, sharing of inventory information is implemented in different forms. CRP (Continuous Replenishment Programs) or Vendor-Managed Inventory (VMI) is a practice often employed by two neighboring partners in a supply chain. In a typical CRP relationship, the buyer shares its inventory data with vendor and asks the vendor to manage his inventory within a guideline. Wal-Mart's Retail Link program (Gill and Abend 1997) and Apple-Fritz Supplier Hub (Lee & Whang, 1998) are good examples of sharing inventory information.

VMI system lets the manufacturer maintain the retailers inventory levels. The manufacturer has access to the retailers inventory data and is responsible for generating purchase orders. (http://www.vendormanagedinventory.com/definition.htm) The major difference between VMI and regular information sharing is that under VMI, the manufacturer generates the purchase order, not the retailers.

3. MODELING THE SC COLLABORATION STEPS

The steps of collaboration are ways or processes in which firms can collaborate with their partners. The departure point of the supply chain is a lack of collaboration, "Non-Collaborative (NC)" SC, it means that the trade partners don't share critical information, e.g. they only transfer information about products, orders and orders state, and exclusively between each exact match supplier-customer. The most important point here is that, in this common practice a delay time exists in receiving and processing the ordering information in trading partners from the upstream customers, further, this delay time delays to know the true inventory levels every time.

In a first improvement step, "Collaborative Forecasting (CF)", this paper asserts that this collaborative partnership offers the possibility to speed up the information about final customer demand along the chain. This enables partners to make consensus-based forecasting and allows the orders in the supply chain to be visible in real time, and processed accordingly. The goal of consensus based forecasting is to consolidate the various forecasts into a common time serie to be used for further planning. Business partners can view each other's forecasts, make changes and agree on a consensus-based forecast using just an Internet Browser.

In a second improvement step, "Collaborative Planning (CP)", this paper asserts that the Internet allows the supply chain members to gain access to additional information that they do not control and use it in their planning process. In this paper we assumed that firms gain access to additional information about finished good inventories (FGI) and work in process inventory (WIP) of downstream supply chain members. This means that, CP is an aggregate of collaborative forecasting and collaborative inventories (VMI).

We first assume that this sequence of steps to improve the performance of the supply chain, is through collaboration. A reason for this is that analysts agree that VMI has been successful in many cases, but inaccurate forecasts and undependable shipments have been major obstacles so that the firms achieve higher performances.

The notation that we have used for the model presented in this paper is as follows:

- Material flow variables:

P_t^i : pipeline from Firm i to the next Firm $i+1$, (includes work in process inventory in the Firm plus the inventory of parts in transportation to the warehouse of finished materials) in period t

Y_t^i : inventory of finished materials of the Firm i, on-hand inventory in period t,

S_t^i : amount of units finally shipped to the next Firm $i+1$,

O_t^i : output from the pipeline of Firm i in t,

I_t^i : input to the pipeline of the Firm i in t,

- Information flow variables

D_t^{i+1} : orders of material units, received in the Firm i in period t,

B_{t-1}^i : existing backlog of orders in Firm i in $t-1$,

S_t^i : amount of orders finally shipped to the next Firm $i+1$ (equivalent to units shipped to the next Firm) in t,

- Model parameters

L^i : lead time for a material unit in the pipeline to arrive to the inventory of finished materials

ss^i : desired time for a material unit to remain as on-hand inventory of Firm i (policy of each Firm),

a^i : Firm i forecast smoothing factor,

b_S : fractional adjustment coefficient for the on-hand inventory,

b_{SL} : fractional adjustment coefficient for the pipeline inventory,

$\hat{m}_t^i$: forecast of Firm i in period t,

ID^i : delay time in the sending of the orders information from some downstream trading partner and, received and processed by the respective upstream supplier.

Table 1 shows the equations of basic model, based in non-interchange of information among trading partners in the supply chain.

Table 1. Model equations in the Basic SC Model

Equation	No.
Final demand: OP_t^{cust}	
Incoming orders:	
From Firm *i+1* to Firm *i*: $D_t^{i+1} = OP_{t-ID^{i+1}}^{i+1}$ (delayed by the delay time ID^{i+1}),	(1)
From customers to final Firm: $D_t^{cust} = OP_t^{cust}$	
Desired shipments (in final Firm, backlog B_{t-1}^n are not included in equation 2, since they are considered lost sales):	
From Firm *i* to Firm *i+1*: $DS_t^i = B_{t-1}^i + D_t^{i+1}$, from final Firm: $DS_t^n = D_t^{cust}$	(2)
Shipment rate:	
From Firm *i* to Firm *i+1*: $S_t^i = MIN(TY_t^i, DS_t^i)$,	
From Firm n to final customers: $S_t^n = MIN(TY_t^n, OP_t^{cust})$	(3)
Total available inventory (in each Firm):	
$TY_t^i = Y_t^i + O_t^i$	(4)
Backlog (in each Firm):	
$B_t^i = B_{t-1}^i + D_t^{i+1} - DO_t^i$,	(5)
Finished good inventory (*FGI*) (in each Firm):	
$Y_t^i = Y_{t-1}^i + O_t^i - S_t^i$	(6)
Finally delivered orders (from each Firm):	
$DO_t^i = S_t^i$	(7)
Output from the WIP (completion rate in each Firm):	
$O_t^i = I_{t-L^i}^i$	(8)
Input to the WIP (procurement rate) of each Firm:	
$I_t^i = S_t^{i-1}$	(9)
Pipeline (WIP) from Firm *i* to the next Firm *i+1*:	
$P_t^i = P_{t-1}^i + I_t^i - O_t^i$	(10)
Forecast (in each Firm):	
$\hat{m}_t^i = a^i D_{t-1}^{i+1} + (1 - a^i)\hat{m}_{t-1}^i,\ 0 < a^i \leq 1, \forall i$ (Madridakis et al. 1998)	(11)
Desired production orders (from each Firm),	
$OP_t^i = Max\ (\hat{m}_t^i + b_S(\hat{m}_t^i ss^i - Y_t^i) + b_{SL}(\hat{m}_t^i L^i - P_t^i) - B_{t-1}^{i-1}, 0)$	(12)

Now we will explain how the equations are obtained.

The desired shipments to the firm *i+1* DS_t^i (equation 2) are calculated adding the incoming orders for the current time period, D_t^{i+1}, to the existing backlog of orders in *t-1*, B_{t-1}^i. It is assumed that the orders received in the firm i, D_t^{i+1}, are immediately shipped to the firm *i+1*. The amount of orders to deliver by firm *i* is the same amount of units per time period than the material flow to firm *i+1*, which is therefore in this model the build rate of the firm *i+1*. The finally delivered orders from firm *i*, S_t^i (equation 3), will depend on the desired shipments (for Firm *n* DS_t^i is assumed to be equal to final demand) and the total parts existing in the finished materials inventory of the firm, TY_t^i (includes current inventory constraints). In each period, TY_t^i (equation 4) is calculated accumulating the orders completed into current inventory.

When the inventory constraints limit the flow of materials from firm i to firm $i+1$, a portion of the orders of the firm cannot be fulfilled, this is the accumulated difference between incoming orders and delivered orders. Those orders will remain as backlog B_t^i in the firm (equation 5). The finished good inventory Y_t^i (equation 6), is calculated (assumed that initial conditions are known) subtracting the accumulated delivered orders from the accumulated available total inventory. The completion rate en each firm , O_t^i (equation 8) is equal to the output from the pipeline in t, $I_{t-L^i}^i$, which is the procurement rate of Firm i calculated as (equation 9) the shipment from the Firm i-1.

Therefore the pipeline P_t^i (equation 10) of each Firm is calculated (assumed also its initial conditions are known) subtracting the accumulated completed orders from the accumulated Input to the WIP (procurement rate).

These relationships are expressed in Figure 1 (causal loop diagram), figure 2 (feedback loops) and figure 3 (stock and flow diagram), where the connection between the information and the material flows can be clearly appreciated. In Figure 1, it is also appreciated the cause-effect relationships to obtain the orders to place to the firm upstream. This amount is obtained based on the local (assumed no supply chain collaboration) firm forecast (equation 11), which in this model is assumed to be a weighted average of the previous demand and previous period's demand forecast (demand smoothing with factor a):

Once the forecast is obtained, the orders OP_t^i (equation 12) are calculated (assuming no collaboration in the supply chain) by means of anchoring and adjustment heuristic (Tversky and Kahneman 1974, Davis 1986) with fractional adjustments coefficients (b_S , b_{SL}) for the FGI and the WIP, not allowing negative values of quantity to request (Sterman 1989). Furthermore, the backlog of the upstream Firm at the end of last period $t-1$ is included in the equation 12, where it is assumed that there is only one period between two consecutive orders of firm i.

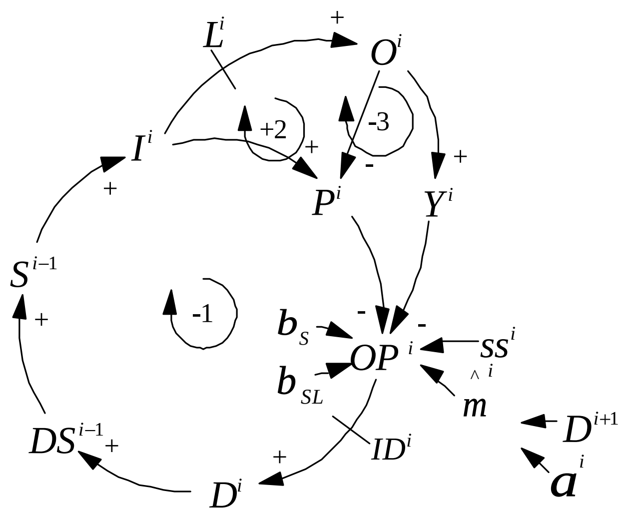


Figure 1. Causal Loop Diagram of the Basic Structure Model

In the causal loop diagram, where we can detect three feedback loops.

The WIP production control loop (first negative feedback loop in figure 2) shows that, a flow of information exists with delay time (ID^i) among the Firm *i* and the Firm *i-1* in whose interaction, an increase in the placed by Firm *i* and received orders by Firm *i+1* respectively, leads to increase the desired shipments of the Firm *i-1* ($+OP^i \rightarrow +D^i \rightarrow +DS^{i-1}$), this effect is transmitted so that, the biggest number of units sent by the Firm i-1, increases the units that its customer processes ($DS^{i-1} \rightarrow +S^{i-1} \rightarrow +P^i$). Finally, an increment in the work in process causes that the firm i requires smaller quantity of materials for the next period ($+P^i \rightarrow -OP^i$).

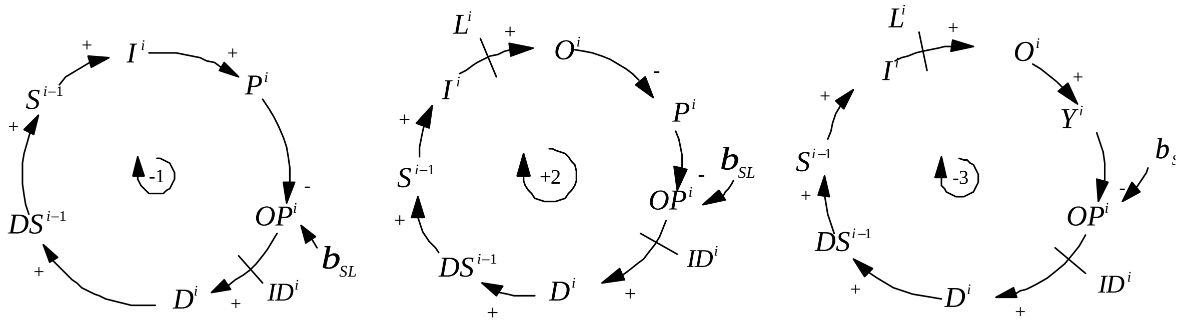


Figure 2. Feedback loops detected in the Basic Structure

A positive feedback loop can be detected, the WIP output production loop (second feedback loop in figure 2), in which, the increase in received units from the Firm i-1, favors a bigger number of units to be processed in the Firm i, and this in turn, a smaller work in process in the same Firm ($+S^{i-1} \rightarrow +I^i \rightarrow +O^i \rightarrow -P^i$). Finally, an decrement in the work in process causes that the firm i requires bigger quantity of materials for the next period ($-P^i \rightarrow +OP^i$). This loop acts in parallel to the loop number 3, which is a negative feedback loop. This indicates that, its performance won't lead to a pure growth, but it causes oscillations that could impede the adjustment of the flows when the demand varies.

The FGI production control loop (the third one), is a negative feedback loop. In this case the completion rate of the Firm *i* performs increasing the inventory of finished products of the same Firm. Likely, the subsequent increase in FGI, is used by the system for self-regulating and controlling its evolution by the decrease of the ordered quantities ($+O^i \rightarrow +Y^i \rightarrow -OP^i$).

Figure 3 shows the stock and flow diagram, where the connection between the information (dotted lines) and the material flows (continuous lines) can be clearly indicated.

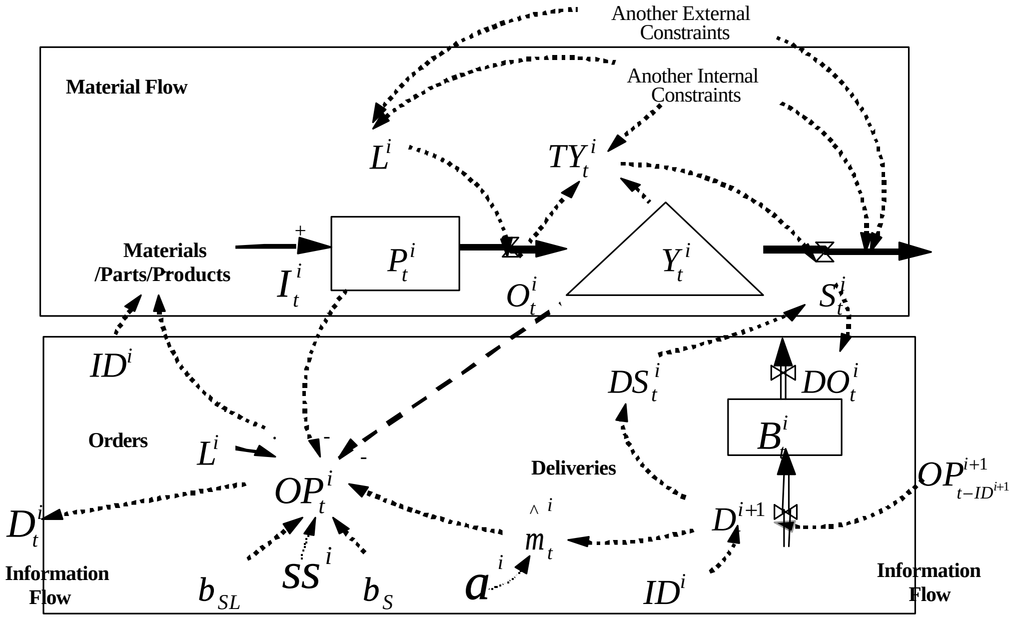


Figure 3. Stock and Flow Diagram of Basic Structure Model

Explanation for modeling the different supply chain collaboration steps, based on e-collaboration tools is as follows:

Non-Collaborative Supply Chain

When collaboration does not exist in the supply chain, an inventory manager only has operative information about the order placed by its direct downstream partner(s). The desired order rate to the previous Firm depends on the local Firm forecast and on local inventories according to the equation (11) and (12) in table 1. Each Firm will make their own forecast and it will order accordingly.

Collaborative Forecasting

In this way of collaboration, trading partners share the final customer's information in order to obtain a consensus and to use the same forecast to place their orders. The chain now collaborates on meeting end-customer demand, discusses issues and sales expectations (on a time period /weekly basis). Therefore equation (11) is replaced with the following formulation

$$\hat{m}_t^i = \hat{m}_t^n, \forall i = 1,.. n \tag{13}$$

this is,

$$\hat{m}_t^i = a^n D_{t-1}^{cust} + (1 - a^n) \hat{m}_{t-1}^n \quad \text{with} \quad 0 < a^n \le 1, \forall i \tag{14}$$

and D_{t-1}^{cust} is the last time period demand for the final customer of the chain. Once the new Firm forecast is obtained, the orders are calculated as in (12).

In the new relationships generated by this collaboration way, we do not detect new feedback loops; this can be observed in figure 4, which shows the unique modification to the causal loop and the stock and flow diagrams.

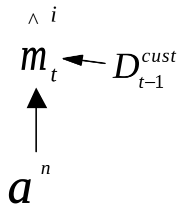


Figure 4. Firms Forecast in the Collaborative Forecasting Process

An additional modification in diagrams consists of removing the variable ID^i, which represents the delay time in sending, receiving and processing the information of orders. In this way the information of forecast and orders is known in real time along the chain.

Collaborative Planning

The Collaborative Planning structure assumes that the collaborative partnership extends to collaborative inventories and ordering in the entire network. That means that there is no need for local forecasts, all supply chain partners will be provided through the Internet with real-time forecast, demand information, and they will have visibility of the inventory and capacity utilization along the chain. With that purpose, in this "full" collaborative structure is assuming that an "information backbone" (common shared information system) has been totally developed in the chain. In practice, this is where VMI (Vendor-Managed Inventory) and CFAR (Collaborative Forecasting and Replenishment) fit in.

For the Collaborative Planning, (13) and (14) are still applicable but the following formulation (15) is introduced, replacing (12) (table 2):

Table 2. Obtained characteristic equations for the Collaborative planning structure Model

Equation	**No.**
Orders:	
$OP_t^i = Max\ (\hat{m}_t^i + \hat{m}_t^i(ss_t^i + L^i) - (P_t^i + Y_t^i) - B_{t-1}^{i-1} + ib_t^i, 0)$	[15]
Where ib_t^i is a variable expressing the information provided to the Firm *i* through the information backbone in time t, includes the inventory value of all down stream Firms.	
$ib_t^i = \hat{m}_t^i(ss^{i+1} + L^{i+1}) - (P_t^{i+1} + Y_t^{i+1}) + ib_t^{i+1}$	[16]

These new relationships are included in the causal loop diagram (figure 5), where we can detect eight feedback loops. Note that no delay time exists between the variables OP^i and D^i.

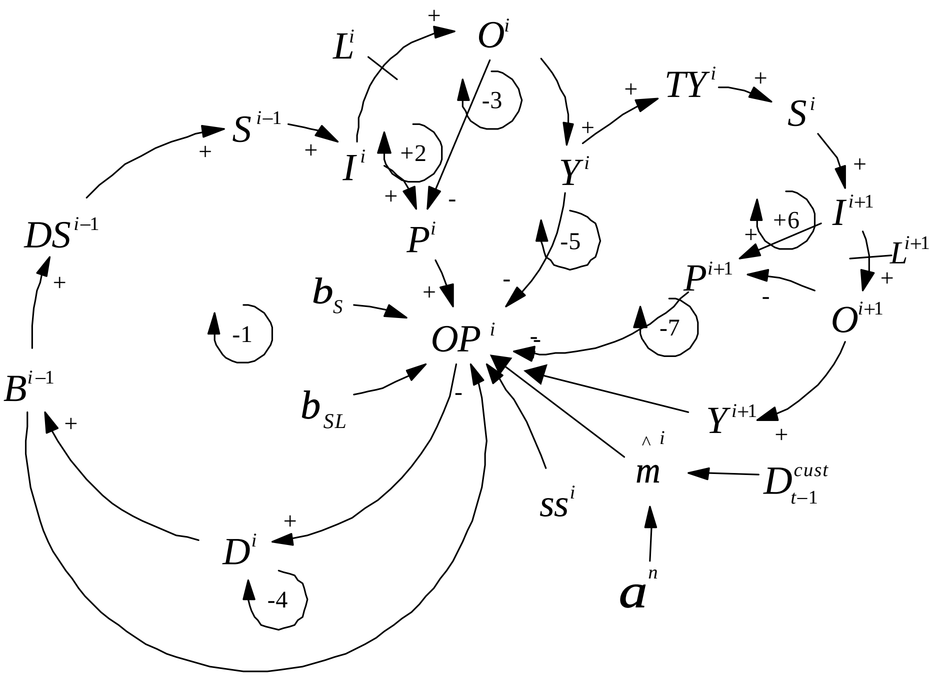


Figure 5. Causal Loop Diagram of the Collaborative Planning structure

The first three feedback loops are the same three feedback loops of the non-collaborative (and collaborative forecasting) structure, therefore, they perform in similar way. Figure 6 shows the additional feedback loops which act in the collaborative planning structure.

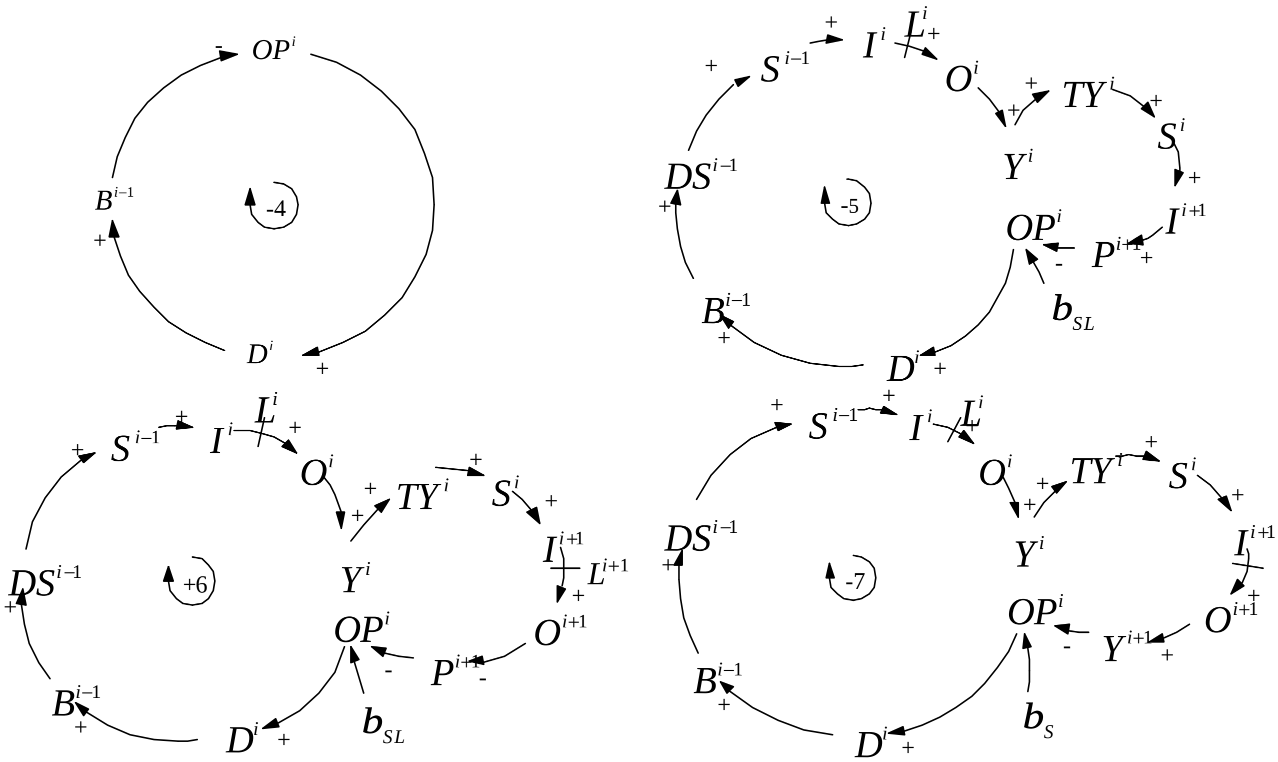


Figure 6. Additional Feedback loops detected in the Collaborative Planning Structure

The fourth feedback loop, backlog production control loop, performs regulating the orders to place by firm i by the control action of the backlog variable B^{i-1} of the firm $i-1$ ($+B^{i-1} \rightarrow - OP^{i}$). The fifth feedback loop is a negative feedback loop, analogous to the first feedback loop, is a WIP production control loop which acts regulating the orders place by firm *i* by means of the action of the WIP of the Firm *i+1*. This means that, an increment in the WIP of the Firm *i+1* causes that the firm *i* requires smaller quantity of materials for the next period ($P^{i+1} \rightarrow -OP^{i}$). In the same way, the sixth (positive) and seventh (negative) feedback loops perform similarly to the second (self-reinforced behavior of the orders placed, this is, $-O^{i+1} \rightarrow -P^{i+1} \rightarrow +OP^{i}$) and third (regulating the orders placed by FGI, this is, $+O^{i+1} \rightarrow +Y^{i+1} \rightarrow -OP^{i}$) feedback loops respectively. In this case the sixth loop neither leads to a pure growth, since it acts parallel to the seventh one loop.

Figure 7 presents the corresponding stock and flow diagram.

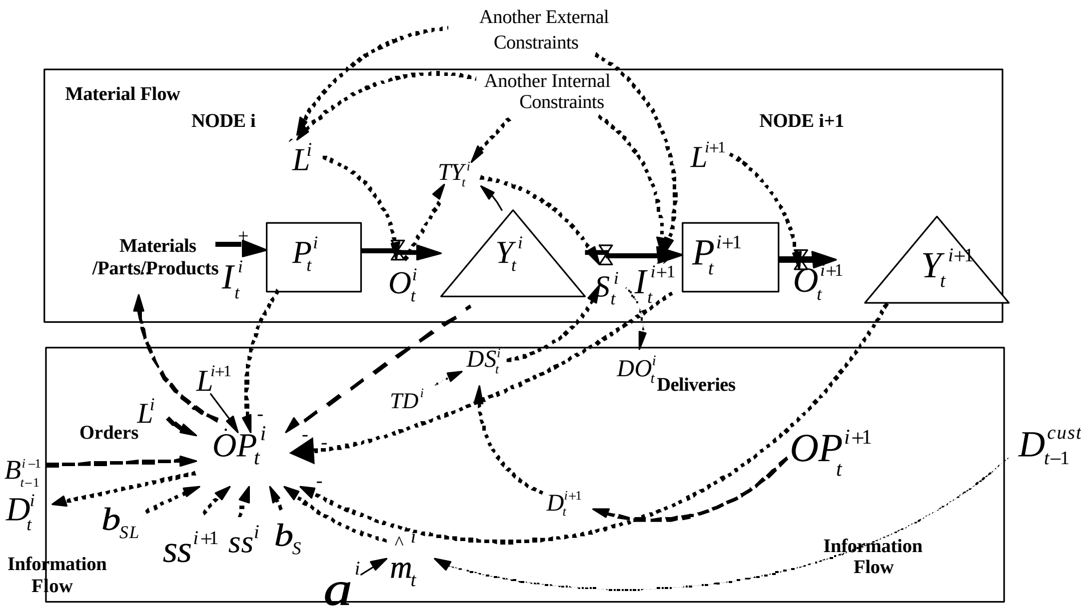


Figure 7. Stock and Flow Diagram of Collaborative Planning structure

We have proposed a sequence (Figure 8) to improve the performance of the SC through a gradual increment in the collaboration.

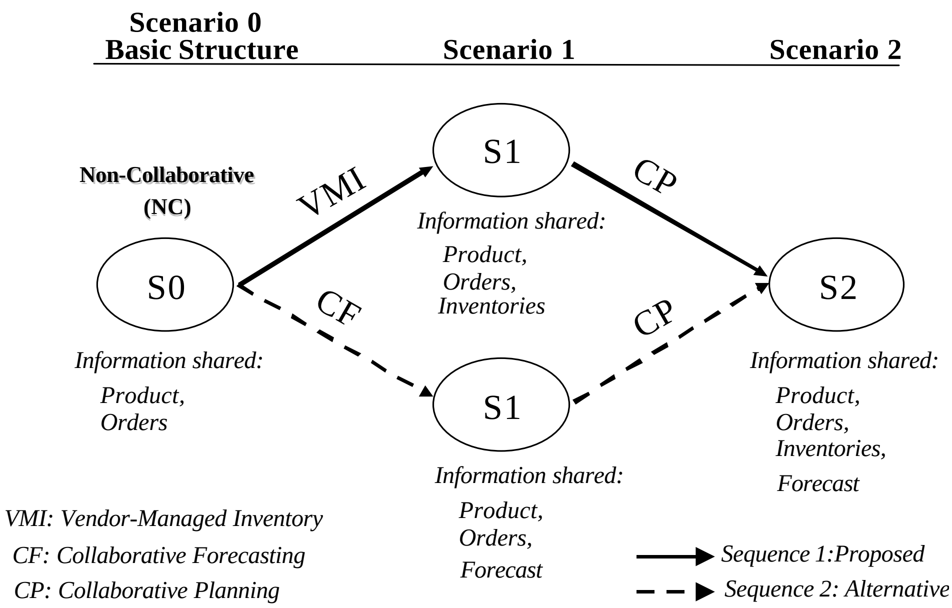


Figure 8. Steps in the Expansion of the Collaboration and Information sharing Scenarios in the Supply Chain

Further important analysis regarding this point could be done. That is, exploring and checking what would happen if in the first step, firms use the Vendor-Managed Inventory process, and then, Collaborative Forecasting is added. This is analyzed evaluating several metrics in the validation of the structures in section 5. Figure 8 illustrates the sequence proposed in order to expand the collaboration, and the alternative sequence.

4. MODELING THE FINANCIAL FLOWS AND THE WORKING CAPITAL

Through the material flow variables, the financial flow variables can be obtained just by attaching the materials value to the inventory movements along the chain. Once the financial flow variables are estimated, the delay times for payments existing in the trade partners will condition the working capital of each Firm, and therefore, its cash requirements Lyneis (1980). Taking into account that, in this paper only the relationship between the main financial variables for each Firm are presented, using the following notation:

CR_t^i : Cash requirements (working capital) of the Firm i in time t,

ICR_t^i : inventory value of the Firm i in time t, includes cash requirements to fund the materials in the pipeline plus those in the finished inventory.

R_t^i : Firm i account receivable in time t,

Py_t^i : Firm i account payable in time t,

Pm_t^i : price of a unit of product shipped from Firm i in time t,

$Pwip_t^i$: average value of a work in process unit in Firm i in time t,

mr_t^i : profit margin in a product in Firm i in time t,

$dso(i)$: weeks of sales outstanding of Firm i,

$CumP_t^i$: cumulative profit of Firm i, in time t,

The main variable relationship is as follows:

$$CR_t^i = ICR_t^i + R_t^i - Py_t^i - CumP_t^i \qquad (17)$$

Where the elements of the right hand side of the equation (14) are computed as follows:

$$Py_t^i = Py_{t-1}^i + S_t^{i-1} Pm_t^{i-1} - S_{t-dso(i-1)}^{i-1} Pm_{t-dso(i-1)}^{i-1} \qquad (18)$$

$$R_t^i = R_{t-1}^i + S_t^i Pm_t^i - S_{t-dso(i)}^i Pm_{t-dso(i)}^i \qquad (19)$$

$$ICR_t^i = P_t^i Pwip_t^i + Y_t^i (Pm_t^i - mr_t^i) \qquad (20)$$

$$CumP_t^i = \sum_{k=1}^{k=t} S_k^i mr_k^i \qquad (21)$$

5. VALIDATION OF THE BEHAVIOR PATTERNS FOR THE MAIN MODEL VARIABLES

For the validation of the behavior patterns of the model main variables, the following example was built gathering operational data (lead times, delay times, etc,..) from a real supply chain in the PC components business. The supply chain consists of four main trade partners (Figure 9) in a row: a supplier, a first (1st) manufacturer, and a second (2nd) manufacturer, after which the chain delivers to the distribution channels. The behavior pattern results are mainly presented for the two first (upstream) trade partners: the supplier and the first manufacturer. The reason for this is to appreciate better the differences upstream, where the information flows may cause a higher impact. Some more details of this example are: customers demand is assumed (which was not the original case for the model validation) to be 4 units/week – constant -, until there is a pulse in this demand signal in week number 5, increasing its value to 8 units/week. There is no capacity constraint for any Firm, and the safety stocks are estimated to reach service levels (% of orders delivered in time) near the 95% for each Firm. Initial conditions for WIP and FGI in firms are, *WIP*: $P_0^{\ i} = 8$ beer cases *and FGI*: $Y_0^{\ i} = 12$ beer cases, for $i = 1$ to n. These values were chosen for validating that the model previously reproduces the results obtained by authors like Sterman (1989) and Lee et al. (1997). The following graphs show the pulse impact in the orders, material and financial flows variables and in some measures of the system financial performance.

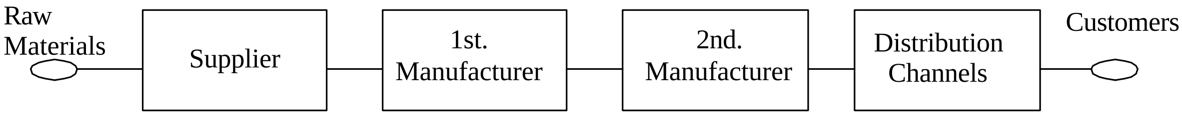


Figure 9. Sample SC selected for variables behavior validation

Our analysis by means of System Dynamics allows to see in figure 10, how the inventory in front of the first manufacturer Firm is highly vulnerable in the NC structure. The late reaction of the supplier when ordering in the NC SC (see section 6) may lead to oscillations in its finished materials inventory. This behavior is, which typical of non-collaborative supply chains, reproduces the bullwhip effect, in this case due to periodical ordering policy (batching), delay time in knowing the true inventory levels and the duplicated demand forecast updating. Note that the vendor-managed inventory practice structure also presents unstable behavior, which indicates that it is not enough practice to guarantee the equilibrium in the inventories. Collaborative planning offers the biggest stability and the smallest weekly investment in inventories.

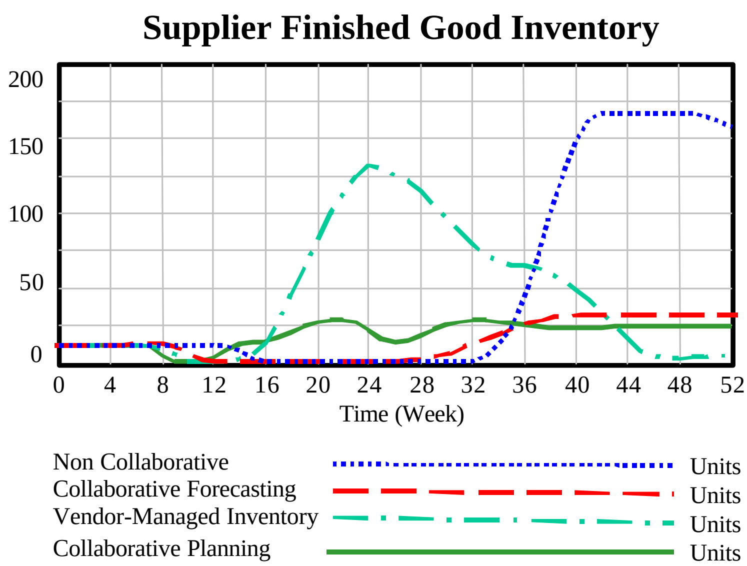


Figure 10. Supplier Finished Good Inventory

Figure 11 shows the inventory of finished products for the first manufacturer of the chain. No stock-outs are produced, but the inventory in the NC structure still shows a higher decrease in its original value and a smaller amplification (in all e-collaboration tools), although it reaches the new steady state earlier. Whit this result, we can assert that the virtual position in the chain favors to the distributor. Once again, note that the CF tool process offers bigger stability in the inventory behavior than the VMI tool process, and the CP presents the best advantages.

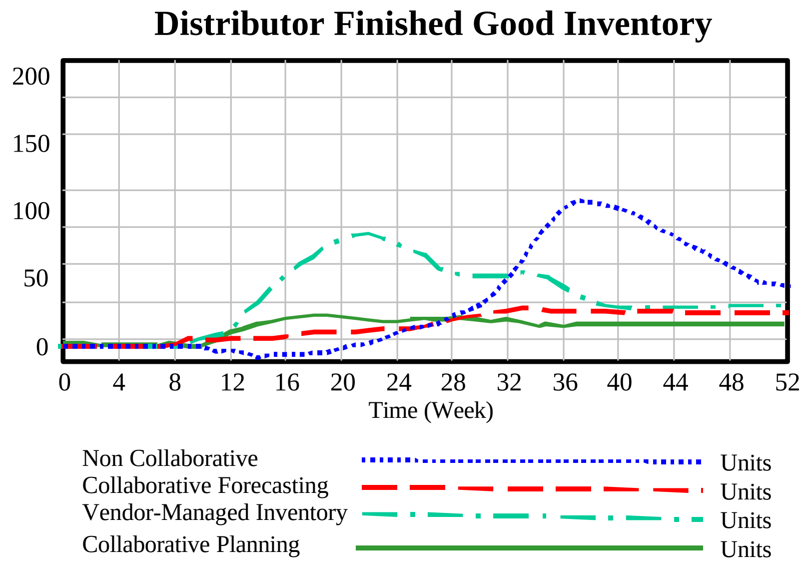


Figure 11. Distributor Finished Good Inventory

Figure 12 shows how the service levels metric (percentage of customer incoming orders fulfilled on time, i.e. percentage of times that the whole incoming orders in a period were immediately fulfilled by the SC) increases as the collaboration is expanded. This means that the quality of the service that is offered to the customer, the SC efficiency is increased when using the collaboration in the SC. This is propitiated by the reduction in the cycle time (consequence of the elimination of delay times) and the increased stability in the inventories.

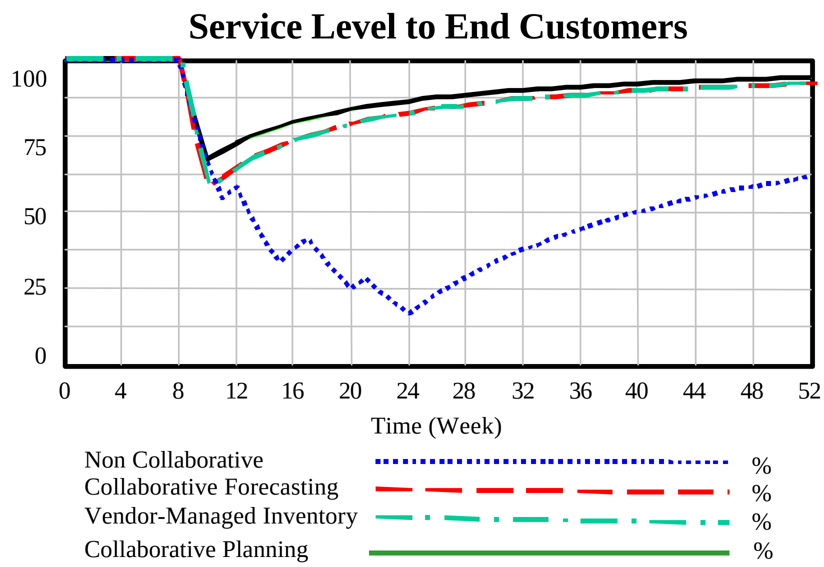


Figure 12. Service level to Final customers

Figure 13 illustrates that, in absence of collaboration in the SC, bigger global average cash requirements (it is understood as the sum of the cash requirements of the four trade partners considered in this example) are obtained as a consequence, mainly, of the inventory cash requirements since the sales outstanding periods are all assumed to be equal (2 weeks). The benefits reached with the CP tool structure can be clearly appreciated in terms of less funds required to run that business model, especially during demand increases. This metric also demonstrate that, when using the CF tool to establish a first step of information sharing between SC trading partners, a better global (when period 52 is reached) performance is achieved (smaller average cash requirement in this case) above the one offered using the VMI tool.

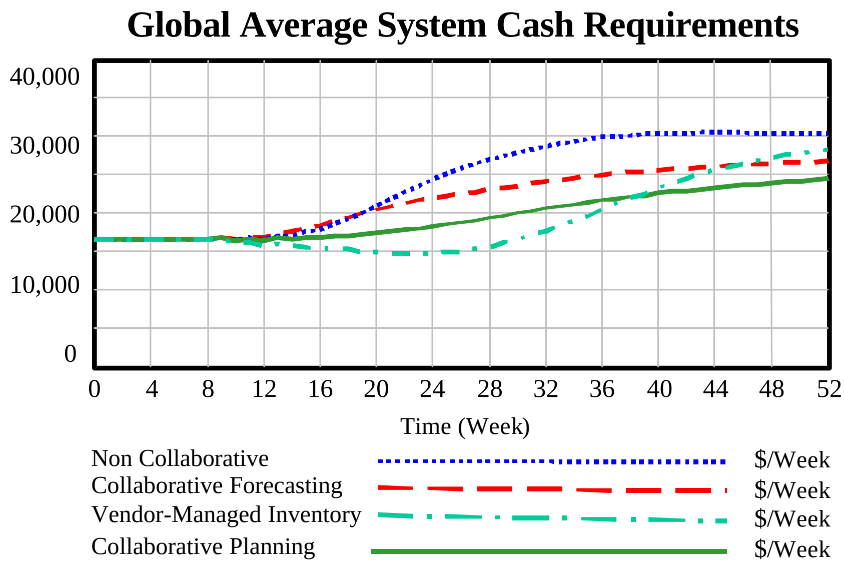


Figure 13. Global Average System Cash Requirements in US$

By using the System Dynamics to study the behavior of the metrics used until now, and under these results, we come to the first clear conclusion in this paper. When the first collaboration step is settled down via CF practice, the obtained improvement on the SC performance is higher than the obtained improvement when the first collaboration step is settled down via VMI practice, while they offer similar service level.

6. COMPLEMENTARY ASSESSMENT OF THE COLLABORATION PLANNING TOOL IN THE SC

Once validated the model and studied the importance of the sequences of the information sharing expanding in the supply chain, now we concentrate in assessment the advantages of the "full collaboration" embody in the collaboration planning practice. This paper presents a series of additional results measuring and comparing the collaboration planning, exclusively with the non-collaboration scenario, in order to establish more specific local and global differences.

The results are presented for a four trading partners SC (Factory, Distributor, Wholesaler and Retailer) as described by Sterman (1984) in the article for the beer game. Initial conditions and lead times are assumed to be the same values used by Sterman (1984) in the beer game. Also, fractional adjustment coefficients are assumed to be the mean values of the experiments presented by Sterman (1989). We remind the reader that, in this work the retailer does not hold any backlog (end-customers do not wait). The simulation runs are for a total of 52 weeks and the demand signal from the customers changes from 4 cases/week to 8 cases/week of beer in week number 5.

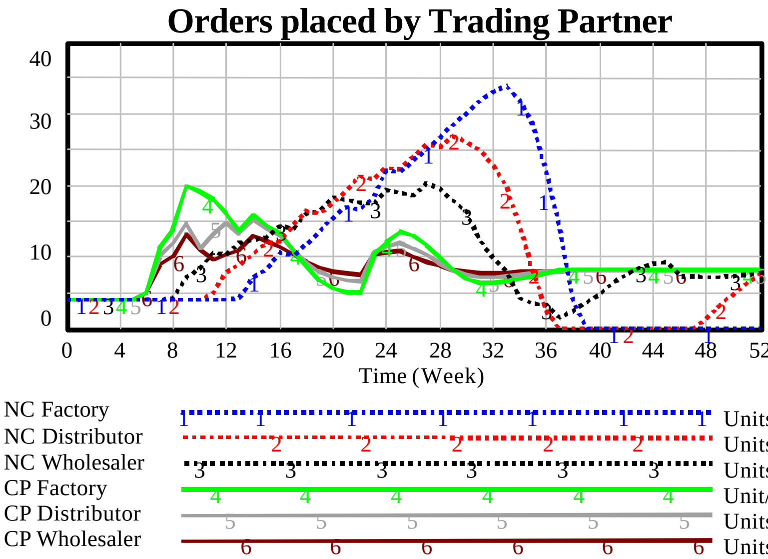
The metrics that will be presented are both, global and local for each Firm of the SC.

Table 3 shows how the full collaboration produces a higher throughput (this metric is the cumulative shipment from retailer to the final customer in the 52 weeks). Results in the second line reveals that, when the collaboration planning practice is carry out in the SC, the material requirements are smaller in the SC, and in consequence, the movement and storage of materials and parts through the chain is smaller too. Finally, regard to cost of administration of inventories (holding + stock out penalties), CP practice is more robust to incur in less global average costs. These results demonstrate more uniform materials flow, easier inventory control and better synchronization between firms. It is important to realize that these global metric improvement, measuring the effectiveness of the supply chain, implies also a local improvement for each Firm.

Metric	Collaboration Practice NC	CP
Cum. Throughput (Units)	372	393
Cumulative Orders Placed by Factory	562	458
SC Average System Inventory Cost (US$/week)	187	45

Table 3. Results for several global operational and financial metrics

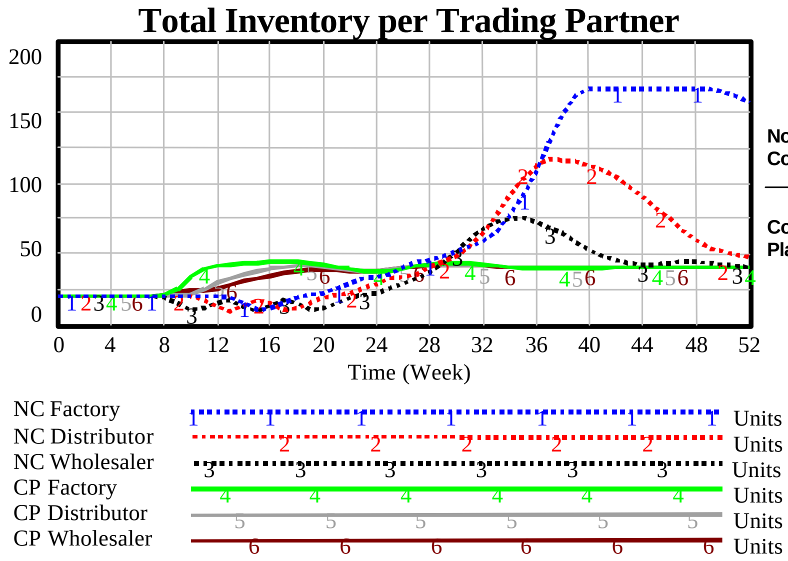
Results about orders placed by trading partner in Figure 14, show a significant reduction in demand amplification for collaborative planning tool. Results (for bigger graph clarity, only data includes the retailer information) indicate that, (a) in the non-collaborative scenario the fluctuation of delayed order information is expanded from downstream to upstream in the supply chain reproducing just the bullwhip effect, the delay amplifies the rate too, as a consequence of higher inventory consumption before response and next Firm behavior, (b) in the full collaboration scenario, the bullwhip effect is mitigated principally by a faster demand forecast transmission along the chain avoiding the sequential smoothing processes, and secondly by less mistrust (for this scenario the SC mainly suffers no end-customer demand variability and no price fluctuation), (c) when the orders placed in the whole supply chain reaches some balance point, everything becomes stable, and (d) The virtually nearest trading partners to the final customers in the chain, suffer less the amplification of the demand and also, they reach quicker the steady state.



		Min	Max	Mean	Std. Deviation
Non Collaboration	Factory	0	34	14	11
	Distributor	0	27	11	9
	Wholesaler	1	20	9	6
	Retailer	4	14	8	3
Collaborative Planning	Factory	4	20	9	4
	Distributor	4	15	8	3
	Wholesaler	4	13	7	3
	Retailer	4	10	7	2

Figure 14. Results for the demand oscillation (units/week)

In terms of total (WIP+FGI) inventory, the figure 15 shows important differences between the two Collaboration practices. An advantage of collaborative planning is a more uniform inventory level. The obtained results in this example are more significant than the obtained results for the variability in the ordered quantities. Furthermore in a collaboration scenario, the time and location benefits along the SC are smoothing operations in the chain, and producing better synchronization between the trading partners.



		Max	Mean	Std. Deviation
Non Collaboration	Factory	166	72	62
	Distributor	117	47	35
	Wholesaler	75	34	20
	Retailer	44	28	13
Collaborative Planning	Factory	43	36	8
	Distributor	42	32	8
	Wholesaler	41	24	7
	Retailer	40	16	7

Figure 15. Results for the total inventory (units)

7. CONCLUSIONS.

The simulation model characterizing the supply chain and considering the importance of sharing critical information between trading partners in the SCM, has enabled, after validation, the simulation of the impact of using the e-collaboration tools in order to increase this information sharing.

After running simulations for each of the e-collaboration tools described earlier in the paper, we can draw the following conclusions:

- It is certain that, the gradual increments of the information sharing, produces positive increases on the local and global performance of the SC.
- To carry out this new practices, we should first address the issue of collaborative demand forecasting (implementing the collaborative forecasting), which allows us to reach a bigger efficiency increment than the vendor-managed inventory practice, this is, more uniform behavior of the inventories along the chain and smaller average cash requirements, while both practices offer similar service levels.
- From the collaborative planning, the SC can benefit from the complete visibility of the total materials flow along the chain. This produces smallest movement and storage of materials along the chain, enabling the ordering policies to adjust new customer requirements earlier, and with more efficient inventory administration (less inventory investment and cost to reach a target service level) along the chain.

- Furthermore, collaborative planning leads to the prompt stability in critical variables, to the best service levels to final customers, the smallest required funds and most possibly, the highest throughput.

Because all previously mentioned reasons, the use of these new business practices can certainly contribute to reach a faster and more flexible SC processes. When e-collaboration tools are implemented in the SCM, each upstream supplier has a stable sale and each downstream customer orders stable amount of products, in spite of the communication of the information has to go through multiple intermediaries between the consumers and the raw material sources. The processes are more agile, the costs are more favorable and the service to the final customer, is the best.

10. REFERENCES

Adam, N. R., O. Dogramaci, A. Gangopadhyay and Y. Yesha. 1999. Electronic Commerce: Technical, Business, and Legal Issues. *Prentice-Hall*.

Bauknight, D. N. 2000. The Supply Chain Future in the e-Economy. *Supply Chain Management Review* 4 (1): 28-35.

Chen, F., Z. Drezner, J. K. Ryan and D. Simichi-Levy. 1999. *Quantifying The Bullwhip Effect in a Supply Chain: The Impact of Forecasting, Lead Times Information.* Working paper, Northwestern University.

Cooper, M. C., D. M. Lambert and J. D. Pagh. 1997. Supply Chain Management: More Than a New Name for Logistics. *The International Journal of Logistics Management* 8 (1): 1-14.

Davis, H. L. 1986. An Anchoring and Adjustment Model of Spousal Predictions. *J. Consumer Res.*13: 25-37.

Ellram, L. M. 1991. Supply chain management: the industrial organization perspective. *International Journal of Physical Distribution and Logistics Management* 21(1): 13-22.

Ellram, L. M. and M. C. Cooper. 1990. Supply Chain Management, Partnership, and the Shipper – Third Party Relationship. *The International Journal of Logistic Management* 1(2): 1-10.

Gartner Group. 1999. C-Commerce: The New Arena for Business Applications. October.

Gavirneni, S., R. Kapuscinski and S. Tayur. 1999. *Value of Information in Capacitated Supply Chains. From Quantitative Models for Supply Chain Management*. Eds. Magazine, M. J., Tayur, S. and Ganeshan, R., Kluwer: Cambridge.

Gill, P. and J. Abend. 1997. *Wal-Mart: The Supply Chain Heavyweight Champ*. Supply Chain Management Review 1(1): 8-16.

Houlihan, J. B. 1985. International Supply Chain Management. *International Journal of Physical distribution and Materials Management* 15: 22-38.

Jones, T. C. and D. W. Riley. 1985. Using Inventory for Competitive Advantage through Supply Chain Management. *International Journal of Physical Distribution and Materials Management* 15: 16-26.

Lee, H. L., V. Padmanabhan and S. Whang. 1997. The Bullwhip Effect in Supply Chains. *Sloan Management Review* 38(3): 93-102.

Lee, H., and W. Whang. 1998. *Information Sharing in a Supply Chain*. Research paper No. 1549, Stanford University.

Lineys, J. M. 1980. Corporate Planning and Policy Design: *A System Dynamics Approach. MIT Press/Wright-Allen Series in System Dynamics*.

Makridakis, S., S. Wheelwright and R. Hyndman. 1998. Forecasting methods and Applications. *John Wiley and Sons*.

Raghunathan, S. 1999. *Interorganizational Collaborative Forecasting and Replenishment Systems and Supply Chain Implications*. Decision Sciences 30(4): 1053-1071.

Shore, B. Information Sharing in Global Supply Chain Systems. 29001. *Journal of Global Information Technology Management* 4(3).

Sokol, P. 1995. From EDI to Electronic Commerce. *McGraw-Hill Inc*.
Sterman, J. D. 1984. *Instructions for Running the Beer distribution Game (D-3679)*. Sloan School of Management, MIT.
Sterman, J. D. 1989. Modeling Managerial Behavior: Misperceptions of Feedback in a Dynamic Decision-Making Experiment. *Management Science* 35(3): 321-339.
Stevens, G. C. 1989. Integrating the Supply Chain. *International Journal of Physical Distribution and Materials Management* 19: 3-8.
Tversky, A., and D. Kahheman. 1974. Judgement under Uncertainty. Heuristics and Biases. *Science* 185: 1124-1131.

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