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Operational and financial effectiveness of e-collaboration tools in supply chain integration

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Abstract

This paper develops a comprehensive model of supply chain integration and uses it to analyze and assess the operational and financial effectiveness of different e-collaboration tools at various levels of supply chain integration. This model is also used to evaluate the importance of the sequence in which e-collaboration tools are adopted in supply chain integration. Computational results from a validated system dynamics simulation model with different implementation sequences of e-collaboration tools and different financial scenarios show that local financial constraints can also severely impact operational and financial performance of the entire supply chain.

Keywords: Supply chain management; Business modeling; System dynamics; Operational and financial evaluation; simulation results

1. Introduction

Internet based information systems offer a great opportunity to improve supply chain management (SCM). The new Internet based e-collaboration tools allow us to integrate multiple organizations and facilitate the flow of information from any one source in a supply chain (SC) to all SC partners (Mentzer, 2001). These low cost tools use the emerging standards for data exchange such as XML (extended markup language). While the collaboration and synchronization of all SC participants, both within and outside the firm, is now feasible, such supply chain integration needs to be carefully studied in order to improve its implementation.

There is a wide consensus that information systems integration is essential (Ellram and Cooper, 1990; Houlihan, 1985; Stevens, 1989; Ellram, 1991). Therefore, issues involved in supply chain integration have been studied in the literature from various perspectives. Gavirneni et al. (1999) analyzed the benefits of the integration of information flows in a supply chain for a capacitated

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two-echelon SC. Chen (1999) studied the importance of having access to accurate demand information for the SC upstream members. The benefits of integrating the SC and diminishing the demand oscillation transmission along the chain (the bullwhip effect) has been explored by Wikner et al. (1991), Towill et al. (1992), and Chen et al. (1999). These studies show that information sharing can significantly impact the SC performance. However, information sharing is only a subset of the supply chain. Researchers agree that the SC planning and control activities are also included in integration (Jones and Riley, 1985).

When considering the planning and control activities, the effectiveness of SC integration may depend on the sequence of tools used in SC integration. However, this issue has received only a scant attention in the existing literature. Stevens (1989) presented an integration model with four phases: baseline, internal functional integration, integrating supply and demand along the company's own chain, and full supply chain integration. Stevens described the integration process in terms of building a customer-driven supply chain instead of a product-driven one. Hewitt (1994) expanded Stevens' model with a fifth phase that would be dedicated to better administration and re-engineering of the global business processes, pursuing the total effectiveness and efficiency of those processes.

Scott and Westbrook (1991) suggested a three phase model to reach an integrated supply chain: an initial "phase of study" where lead times and inventory levels are analyzed for potential improvements; a "positioning phase" to identify new opportunities emerging as a consequence of collaboration activities among the members of the chain; and an "action phase" to put previous plans into effect. Towill et al. (1992) present a SC integration approach that is similar to the one presented by Scott and Westbrook (1991). In their work, Towill et al. (1992) also use operations management principles to reduce the amplification of the demand signal along the chain when the integration is produced.

Cooper and Ellram (1993) identified a set of characteristics that would influence a company's decision to be a part of an integrated supply chain. These characteristics are related to the current level of internal process and functional integration of the company, and with the required level of inter-companies integration for the competition with other SC. Therefore, the importance of those characteristics may differ along the SC integration process (Cooper et al., 1997). Bowersox (1997) discussed the idea of two types of integration: internal and external. He concluded that the companies need to have a high level of internal integration to be good candidates for the extensive external integration within a supply chain. By reviewing the practices in the industry under the perspective of supply chain integration, Bowersox found two types of generic integration schemes: basic and advanced. The basic integration scheme means that the SC has developed a set of initiatives and agreements in order to improve connections with customers and suppliers. Under this scheme, benefits are reached through information sharing and common forecast and planning. Such agreements are implemented many times by establishing new venture companies or specific contracts with different members of the supply chain. The advanced integration scheme enlarges the collaboration horizon to reach a more sophisticated dimension. The idea is to integrate the value creation processes with a total end-customer driven orientation. The goal is collaboration to improve competitiveness through a coordinated effort that is, at the same time, feasible in a lean environment (therefore, it results in a reduction in the number of total resources of the supply chain). This advanced integration is normally implemented through profound long-term agreements between companies, and positions the supply chain as an effective competitive unit. Finally, Bowersox (1997) suggests that the creation of time and location benefits not only requires sharing the information to allow suitable business agreements with that purpose, but also requires the existence of a suitable environment for financial transactions.

The integration of SC financial flows is also becoming a common topic in literature, because of its impact on the entire supply chain performance. Automated freight payment software is available to pre-audit, summarize, batch, and pay carriers by electronic checks on a scheduled basis (Cooke, 1996). There is evidence (Orr, 1996) that the use of information integration in conjunction with buyers' and sellers' banks to transfer funds can improve cash flow and reinforce the "partnering" relationship between the parties in the supply chain. Further, in many supply chains, credit provision is a key factor in supplier choice among distributors and their customers (Neal, 1994). Suppliers often finance their customers' transactions through the extension of free credit (in Neals' study, only 1% of the distributors charged interest for credit given to their customers, and only 5% were charged interest for credit taken, only 12% offered more generous price discounts when customers did not take credit, and only 5% received bigger discount when they did not take credit from suppliers). Clearly, cash flow is affected by the terms of sale, and buying and selling companies often have a different capital cost, which raises the opportunity of improving supply chain performance by having the company with the lowest cost of capital own goods for as long a period as possible (Bianchi, 2002; Mentzer, 2001). Many times, a financial organization can provide the "banking function" financing shipments by purchasing those receivables, at a discount, eliminating the seller's extension of credit terms and their incurring payment delays from letters of credit (Davis, 1998).

The review of the existing SC integration literature reveals that there is no comprehensive SC integration model. Therefore, the purpose of this paper is to develop and evaluate a comprehensive supply chain model that can be used to determine the operational and financial benefits of various levels of supply chain integration using e-collaboration tools. Such a SC model would also enable us to analyze the impact of partial integration efforts.

The rest of the paper is organized as follows. Section 2 uses system dynamics (Angerhofer and Angelides, 2000; Forester, 1961; Sterman, 2000) to model the sequence in the implementation of the e-collaboration tools and formalizes the interaction between operational and financial variables within the SC. The idea is to show where, under certain circumstances, financial constraints could impact the material flow. Section 3 is dedicated to the presentation of results for three basic scenarios of financial constraints. The first case is intended to measure operational and financial performance of the different sequences of SC integration when there are no financial constraints. The second case is dedicated to the same analysis but considers different financial constraints in all the SC nodes. The idea is to determine whether the relaxation of various financial constraints produces the same benefits regardless of the integration sequence that is followed. The third case assesses the potential impact of a local financial constraint in the whole SC, and for each particular SC integration structure. Finally, Section 4 summarizes the potential implications of different integration processes for the global SC and its members.

2. Supply chain modeling

SCM refers to the means by which firms engage in creating, distributing and selling products (Poirier, 1999). It requires the coordination of the information, material, and financial flows along different nodes of the supply chain (Lee and Billington, 1995). Therefore, by considering each of these different flows, we can develop a model of a supply chain. Utilizing the model for the material flow relationships developed by Crespo et al. (2001), we develop a model for integrating e-collaboration tools in the supply chain. Fig. 1 depicts the basic nature of various flows and the conceptual model of the supply chain.

Four main integration phases are: information sharing (including R&D information for product design and the information to track the materials flow along the chain); collaboration for a common forecast; common planning; and automated financial transactions. These phases could be implemented with a different sequence. For instance, the information about the material flow could be used to plan the build rates along the chain. However, in such a case, a common forecast would not be accessible. At the same time, the partners of the chain could have access to a common forecast, but the available inventory information would only be local. Thus, global inventory information would not be used.

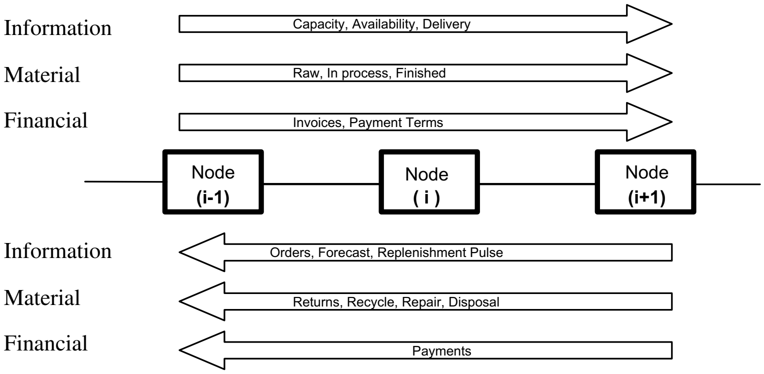

Fig. 1. Vision of the supply chain.

A visit to existing internet portals for e-collaboration indicates that automated financial transactions could be introduced at different points of the process.

Based on their use, the e-collaboration supply chain integration tools can be categorized into the following five classes:

1. Tools to "wire" the company, offering real time information about the material flow, which is basically managed by exception.
2. Tools to share documents in real time.
3. Tools to do collaborative forecasting.
4. Tools to do collaborative planning (currently very scarce).
5. Tools to implement automated payments (currently very scarce).

In practice, the perceived value of a supply chain is linked to class 1 and class 2 tools. Therefore, in this paper we assume that class 1 and class 2 tools are implemented first. However, the sequence of using tools in classes 3 through 5 can be changed in their implementation process. To address this issue, this section constructs a formal model and characterizes different integration possibilities.

2.1. Notations and definitions

Before proceeding with the model development and discussion, we first describe the notations and definition of the main variables as follows (please notice that the explanation for each of these variables will be given later in the paper):

Information related variables

D_t^{i+1} orders of units received in the node i in period t
DC_t^{i+1} orders received in the node i in period t, when node $i+1$ has financial constraints
B_t^i existing backlog of orders in node i in t
S_t^i amount of orders finally shipped to the next node $i+1$ (equivalent to units shipped to the next node) in t
$\hat{\mu}_t^i$ forecast of node i in period t
ib_t^i information provided to the node i through the *i*nformation *b*ackbone in time t

Material related variables

P_t^i pipeline from node i to the next node $i+1$ (includes work in process inventory in the node 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 node i, on-hand inventory in period t
S_t^i amount of units finally shipped to the next node $i+1$
O_t^i output from the pipeline of node i in t
I_t^i input to the pipeline of the node i in t

Financial variables

C_t^i cash of the node i in time t
IV_t^i inventories value of the node i in time t, includes materials in the pipeline plus those in the finished inventory

R_t^i node i accounts receivable in time t
Py_t^i node i accounts payable in time t
Cos_t^i cost of sales of node i in the period t
Cpm_t^i cost of purchased material of node i in the period t
Cps_t^i cost of production/shipping of node i in the period t
Sr_t^i sales revenue of node i in the period t
Sc_t^i sales collections of node i in the period t
Mpu_t^i materials purchases of node i in the period t,
Mpy_t^i materials payments of node i in the period t
Cf_t^i cash flow of node i in the period t
Iwc_t^i increases of working capital in node i in the period t
Fe_t^i financial expenses in node i in the period t
Csf_t^i cumulative cash flow of node i, in time t
Ab_t^i available bank credit of node i, in time t
Mor_t^i maximum orders to place by node i, in time t
Icr^i cash requirements per unit of material flow in node i

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 node i (policy of each node)
α^i node i forecast smoothing factor
β_S fractional adjustment coefficient for the on-hand inventory
β_{SL} fractional adjustment coefficient for the pipeline inventory
Cm^i unit contribution margin of node i
Pm^i price of a unit of product shipped from node i in time t
Wso^i weeks of sales outstanding of node i
Mb_t^i maximum bank credit of node i, in time t

2.2. Modeling the material and information flows

In our model, it is assumed that the orders received at node i, D_t^{i+1}, are immediately shipped, up to availability, to node $i+1$. When delivering materials, inventory constraints may appear at the node reducing the amount of units finally shipped to the next node, S_t^i (see Fig. 2). The equations for the orders delivered are as follows:

$$S_t^i = \begin{cases} B_{t-1}^i + D_t^{i+1} & \text{if } Y_t^i \geqslant B_{t-1}^i + D_t^{i+1}, \\ Y_t^i & \text{if } Y_t^i < B_{t-1}^i + D_t^{i+1}, \end{cases} \quad (1)$$

$$B_t^i = B_{t-1}^i + D_t^{i+1} - S_t^i, \quad (2)$$

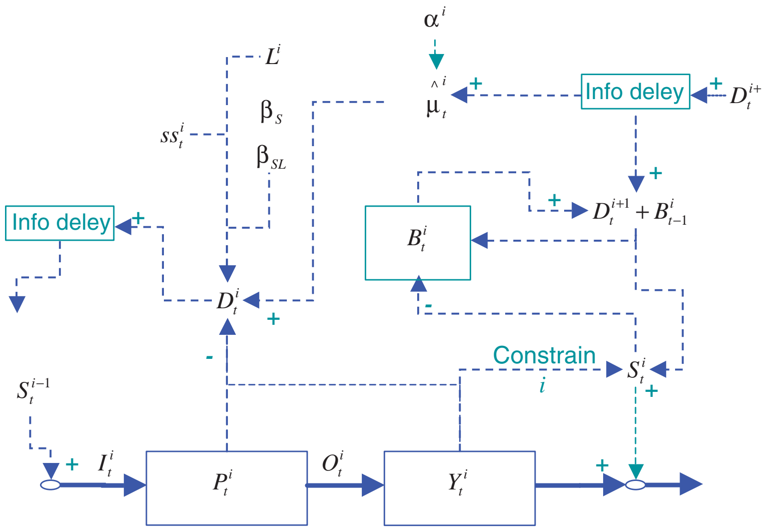

Fig. 2. Basic influence diagram for the variables in node [*I*], and no integration in the supply chain.

$$Y_t^i = Y_{t-1}^i + O_t^i - S_t^i, \quad (3)$$

$$O_t^i = I_{t-L^i}^i, \quad (4)$$

$$I_t^i = S_t^{i-1}, \quad (5)$$

$$P_t^i = P_{t-1}^i + I_t^i - O_t^i. \quad (6)$$

Eqs. (2) and (3) above show the calculations for the level of backlog and on-hand inventory. Eq. (4) expresses the input to the pipeline of node i as the shipments from node $i-1$. Eq. (5) formalizes the output of the pipeline from node i as a delay of time L^i of its input. Eq. (6) shows the calculation of the pipeline inventory. These relationships are shown in Fig. 2, where the dotted lines indicate information flows and the continuous lines show the material flows.

2.2.1. Modeling information flows according to the integration sequence

Table 1 depicts various integration possibilities in a supply chain. In the first case, there is a *no* integration in the SC (called non-integration—NI—in Table 1), meaning that there is no communication at all between the nodes (e.g. retailers do not talk to anyone else; same for wholesalers, distributors, and factories). This is a very common circumstance in real life, when for example, there may be two or three factories, 20 or 30 distributors, two or three thousand wholesalers, and 20 or 30 thousand retailers. They never find out what the total activity of the others is. Each node produces their own forecast and places their orders accordingly. Therefore, communication is only through orders.

Now, assume that the supply chain is "wired" (i. e., the different members can receive real time information about the materials flow and orders flow along the SC). Then, an option would be to implement tools to do *collaborative forecasting* (called partial integration *A*—PIA—in Table 1). In this case, the final SC member would trust its upstream partners to do the right thing with their end customer's information, and all nodes in the SC would use the same forecast to place their orders. The chain now collaborates on meeting end-customer demand and discusses issues and sales expectations (on a time period/weekly basis).

Once the SC is wired, another possibility, a second option for the members would be to use the real time information about the materials flow, before discussing and sharing any common forecast, and do their planning and inventory management accordingly (called partial integration *B*—PIB—in Table 1).

Finally, the SC may reach a situation where all partners gain *total access to information they do not control*, about end-customer demand and materials flow, and they use it in their planning process. There is no need for local forecast and collaborative planning extends to inventory management and ordering in the entire network (called full integration—FI—in Table 1).

In order to obtain the mathematical formulation for placing orders to the upstream node, we consider four different possible levels of implementing e-collaboration tools shown in Table 1. Thus, we obtain the following relationships.

- *Equations for a NI SC:*

$$\hat{\mu}_t^i = \alpha^i D_{t-1}^{i+1} + (1-\alpha^i)\hat{\mu}_{t-1}^i \quad \text{with} \quad 0 < \alpha^i \leqslant 1, \ \forall i. \quad (7)$$

In Eq. (7), an exponential smoothing constant is used to produce the forecast, since it is widely used in modeling a SC (see e.g. Chen et al., 1999), and has been found to be a very popular practice (Sanders and Manrodt, 1994). To choose appropriate values of α, the reader is referred to Makridakis et al. (1998).

Table 1
Integration possibilities

	No integration (NI)	Partial integration *A* (PIA)	Partial integration *B* (PIB)	Full integration (FI)
Demand forecast	Local	Shared	Local	Shared
Inventory information and planning	Local	Local	Shared	Shared

$$D_t^i = \mathrm{Max}(\hat{\mu}_t^i + \beta_S(\hat{\mu}_t^i ss_t^i - Y_t^i) + \beta_{SL}(\hat{\mu}_t^i L^i - P_t^i), 0). \tag{8}$$

Orders placed are modeled using an anchoring and adjustment heuristic (Tversky and Kahneman, 1974), which has been shown to apply to this kind of SC decision-making task (Sterman, 1989).

- *Equations for a PIA SC:*

$$\hat{\mu}_t^i = \hat{\mu}_t^n, \quad \forall i = 1, \ldots, n, \tag{9}$$

$$\hat{\mu}_t^n = \alpha^n D_{t-1}^{\text{cust}} + (1 - \alpha^n)\hat{\mu}_{t-1}^n \quad \text{with} \quad 0 < \alpha^i \leqslant 1, \ \forall i, \tag{10}$$

where D_{t-1}^{cust} is the last time period demand for the end customer of the chain. Once the new node forecast is obtained, the orders are calculated as in (8).

- *Equations for a PIB SC:*
For this case, while Eq. (7) is valid, Eqs. (9) and (10) are not applicable. Assuming that we know information about all the nodes, and it is in the backbone, we use a generalized form of the anchoring and adjustment heuristic (Sterman, 1989) in an iterative way. Discounting the backlog from the order since the previous node is already expecting this to ship that amount ASAP and noting that the order quantity cannot be negative, the following equation (11) replaces Eq. (8):

$$D_t^i = \mathrm{Max}(\hat{\mu}_t^i + \hat{\mu}_t^i(ss_t^i + L^i) - (P_t^i + Y_t^i) - B_{t-1}^{i-1} + ib_t^i, 0), \tag{11}$$

where ib_t^i is a variable expressing the information provided to the node i through the *i*nformation *b*ackbone in time t:

$$ib_t^i = \hat{\mu}_t^i(ss_t^{i+1} + L^{i+1}) - (P_t^{i+1} + Y_t^{i+1}) + ib_t^{i+1}. \tag{12}$$

As an additional improvement, the backlog of the upstream node at the end of last period $t-1$ is included in Eq. (11) for the orders to be placed by node i. The reason for this is enable immediate shipments (zero expected backlogs under normal conditions). Further, each node includes its last period backlog as part of the desired shipments in the next period t. Therefore the backlog will be fulfilled as soon as on-hand inventory becomes available.

- *Equations for a FI SC:*
Eqs. (9) and (10) are applicable (replacing (7)), and also Eqs. (11) and (12) (replacing (8)).

2.3. Modeling the financial flows

One of the most important responsibilities of the treasurers of different nodes of the supply chain is the management of the sources and uses of funds. While making sure that cash is available to meet short-term needs, such as payrolls and invoice payments to the other nodes, treasurers must plan for strategic funds management to facilitate long-term growth via capital expansion or acquisition.

The tool for this kind of analysis is the "sources and uses of funds statement" that may be estimated for any interval of time. The change in the SC node's cash position will be defined as the difference between sources and uses of funds [3] (the reader is referred to Weston and Copeland (1989, pp. 21–25) for the implications of the elements of this financial statement). Since there is a multiplicity of factors impacting a firm's cash position, we pay special attention to those aspects that are related to the income from operations, and to the increments of the net working capital (an overview of this financial model is shown in Fig. 3 where for sake of simplifying the presentation, we have not included depreciation and other non-stationary costs thus making the inflow equal to its current income). In this context, the importance of inventory will be analyzed for the overall financial picture. Notice that inventory is frequently the largest asset in the SC and source of controllable costs (Rockhold et al., 1998).

[3] Another possibility would be to define increases in cash balances as a use of funds and decreases as a source. Then total sources would have to equal total uses. Normally, sources and uses statements adopt this procedure.

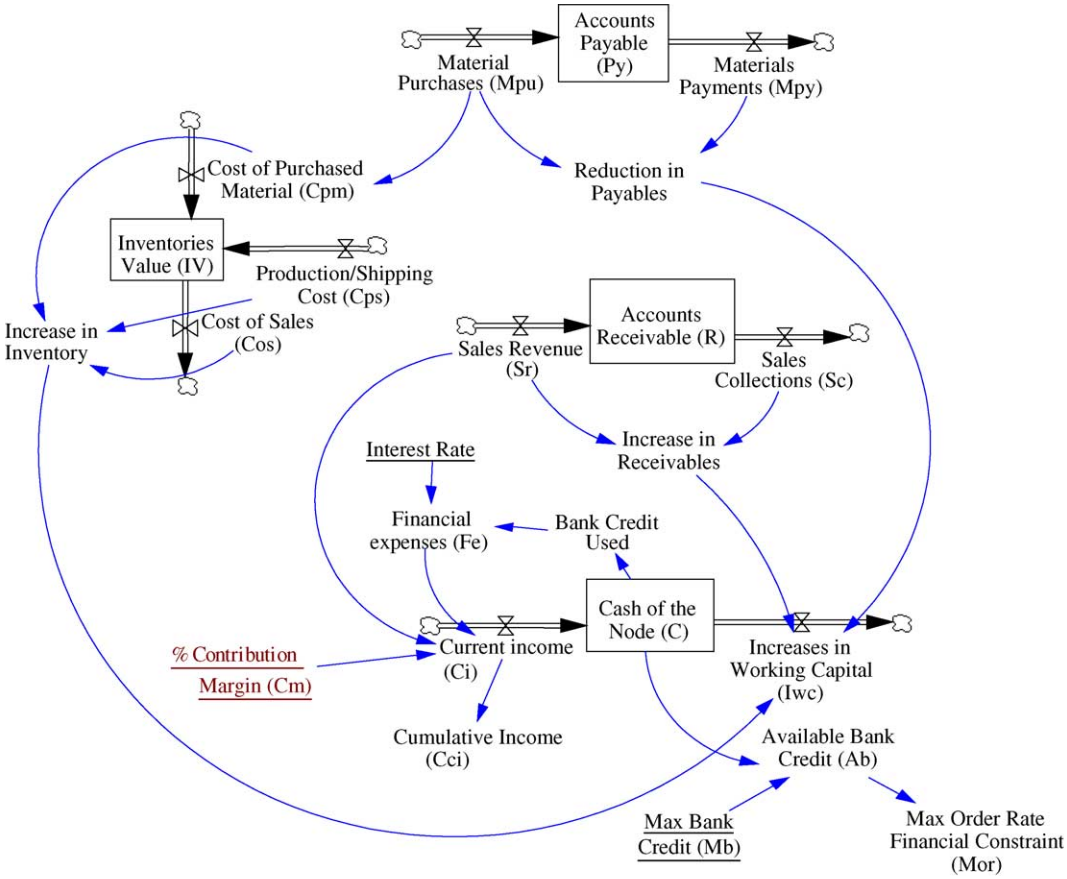

Fig. 3. Overview of the financial model through a "stock and flow" diagram, and for a generic node of the supply chain.

In our analysis, we make the following assumptions regarding the statement of changes in the financial position, and for our simulation horizon that does not exceed one year (52 weeks):

- Regarding the uses of funds:
  (1) There is no gross fixed assets expansion.
  (2) There is no dividends assigned to stockholder.
- Regarding the sources of funds:
  (3) There is no increase in long term debt.
  (4) There is no new equity offering during the time of the analysis.
  (5) There is no net fixed assets reduction.
  (6) There is no credit regarding production/shipping costs.
- Regarding the cash generation:
  (7) Product contribution margin is the same within the product volume ranges of the simulation.

Taking into account these considerations, the change in the SC node's cash position is defined as in Eq. (13):

$$C_t^i = C_{t-1}^i + Ci_t^i - \mathrm{Iwc}_t^i, \quad (13)$$

where

$$Ci_t^i = \mathrm{Sr}_t^i \mathrm{Cm}_t^i - \mathrm{Fe}_t^i, \quad (14)$$

$$\mathrm{Iwc}_t^i = \mathrm{IV}_t^i - \mathrm{IV}_{t-1}^i + R_t^i - R_{t-1}^i + \mathrm{Py}_{t-1}^i - \mathrm{Py}_t^i. \quad (15)$$

Eq. (13) implies that sources of funds will be those obtained from operations (current income), while uses of funds will be increases in the net working capital. This means that an increase in inventories is a use of funds because some product has to be bought. Further, account payables increase the available funds because, in effect, the node has borrowed from suppliers (see Fig. 3).

$$\mathrm{IV}_t^i = \mathrm{IV}_{t-1}^i + \mathrm{Cpm}_t^i + \mathrm{Cps}_t^i - \mathrm{Cos}_t^i, \tag{16}$$

$$R_t^i = R_{t-1}^i + \mathrm{Sr}_t^i - \mathrm{Sc}_t^i, \tag{17}$$

$$\mathrm{Py}_t^i = \mathrm{Py}_{t-1}^i + \mathrm{Mpu}_t^i - \mathrm{Mpy}_t^i, \tag{18}$$

$$\mathrm{Cci}_t^i = \sum_{k=0}^{k=t} Ci_k^i. \tag{19}$$

Variables in the right hand side of Eqs. (16)–(18) are basically "co-flows" of the material ones; defining the levels of inventory value, receivables and payables of the node. [4] The cumulative income in Eq. (19) is used as a metric of the model to assess system's performance.

2.3.1. Supply chain modeling with limited financial resources

Let us now assume that each SC node has an established price and credit with its SC partners. Suppose that a node could be exposed to a financial limit (for instance, there is a limited bank credit available for a certain period of time for that particular node). Further, suppose that demand for the node's products increases and it requires a consumption of cash (in net working capital) which is higher than the cash generated by the node operations. Clearly that node could experience financial constraints impacting its operations. How much could the financial constraint of a node impact its current income and the global SC income? Would this impact depend on the integration of the SC? In order to answer these questions, we have to ascertain the node's reaction to the constraint. If we assume that the node cannot delay payments to suppliers, cannot buy cheaper parts, cannot get early payments from customers, and cannot conveniently increase the price of the products sold, the only possibility would be to order less from the suppliers. This would decrease the service level to the customers since the node will be holding less safety stock.

$$\mathrm{Ab}_t^i = \mathrm{MAX}(\mathrm{Mb}_t^i + C_t^i, 0), \tag{20}$$

$$\begin{aligned}\mathrm{Icr}_t^i = L_t^i\left[\frac{(\mathrm{Pm}^{i-1} + \mathrm{Pm}^i(1 - \mathrm{Cm}^i))}{2}\right] \\ + ss^i\mathrm{Pm}^i + (\mathrm{Wso}^i - \mathrm{Cm}^i)\mathrm{Pm}^i \\ - \mathrm{Wso}^{i-1}\mathrm{Pm}^{i-1},\end{aligned} \tag{21}$$

$$\mathrm{Mor}_t^i = I_{t-1}^i + \frac{\mathrm{Ab}_{t-1}^i}{\mathrm{Icr}^i}. \tag{22}$$

Eqs. (20)–(22) model the process that the members would follow to decrease their purchases to suppliers when they are limited by financial constraints. If increasing their purchase rate could lead to higher cash utilization, they would estimate the maximum affordable increase in purchase rate. This is done by dividing their current available bank credit by the cash requirements to increase a unit of their materials flow. Eq. (21) estimates the cash requirements by obtaining the marginal consumption of cash produced if the flow of orders and materials increases by one unit along the SC. Each node would therefore need to fund more work-in-process, safety stock, and customers credit A/R and would receive some funds from the income of the increase in sales and from the suppliers credit A/P. The maximum order rate to supplier could now be obtained by adding the results of a previous division to the current build rate and pipeline input to the node as shown in Eq. (22).

Finally, new orders to be placed from the suppliers shown in Eq. (23) would be the minimum between the order rate formulated for each integration level of the SC (see (8) and (11)), and the maximum value obtained in Eq. (22). New

[4] We could study only the policies related to reductions/increases in the credit period between the nodes (that could decrease/increase the delay between the time of a sale and the cash flow from that sale, but also lower/rise the volume of unit sales). However, to be complete, we will also consider that these aspects are established within the existing contractual terms, in the agreements between the supply chain nodes (to study such a firm's dynamics we refer the reader to Lineys (1980)).

equation (23) will also change Eqs. (1) and (2) to Eqs. (24) and (25) as follows.

$$\mathrm{DC}_t^{i+1} = \mathrm{MIN}(D_t^i, \mathrm{Mor}_t^i), \tag{23}$$

$$S_t^i = \begin{cases} B_{t-1}^i + \mathrm{DC}_t^{i+1} & \text{if } Y_t^i \geqslant B_{t-1}^i + DC_t^{i+1}, \\ Y_t^i & \text{if } Y_t^i < B_{t-1}^i + DC_t^{i+1}, \end{cases} \tag{24}$$

$$B_t^i = B_{t-1}^i + \mathrm{DC}_t^{i+1} - S_t^i. \tag{25}$$

Fig. 4 shows the relationship between the material, information, and financial flow variables for a node of the supply chain, as formulated in Eqs. (20)–(25). This Fig. 4 describes how the financial constraints may appear in the node i, limiting the orders to be placed to node $i-1$, specially at times when demand of node $i+1$ ("incoming orders" in the figure) could be growing (see an example of the behavior of these variables, for PIBSC and node "Factory", in Fig. 5, where it is assumed that a financial constraint in factory i will then limit the possibility to place orders to their suppliers). Notice how, by default, some of the variables of node i of the SC correspond to the previous node $i-1([i-1])$. For example, orders placed by node i (DC in Fig. 4) will increase the backlog of node $i-1(B[i-1])$. Also some of the variables are redundant and not defined in our mathematical model (Inventory investments, Reduction in Payables, Increase in Receivables or Bank Credit Used), but are added to facilitate the interpretation of the formal model.

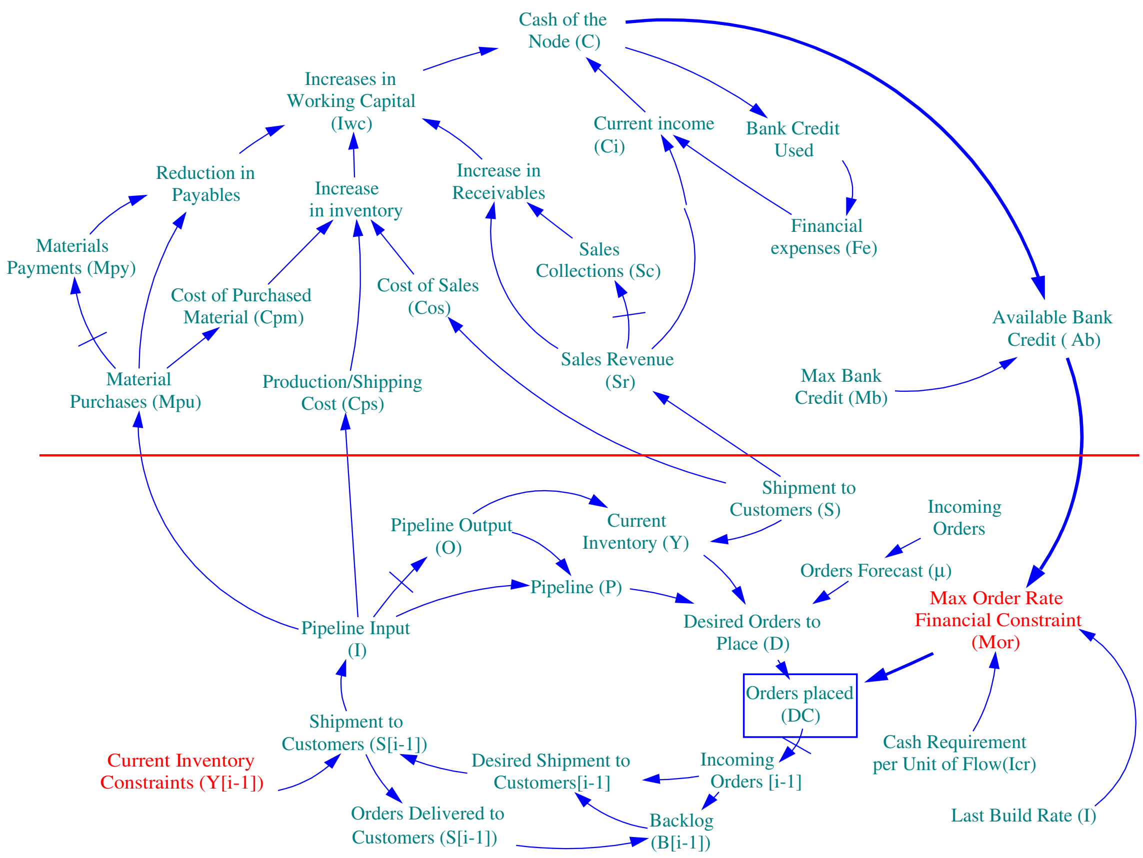

Fig. 4. Influence diagram showing the interface between financial and material flow variables for a node of [i] (default variables) of the supply chain.

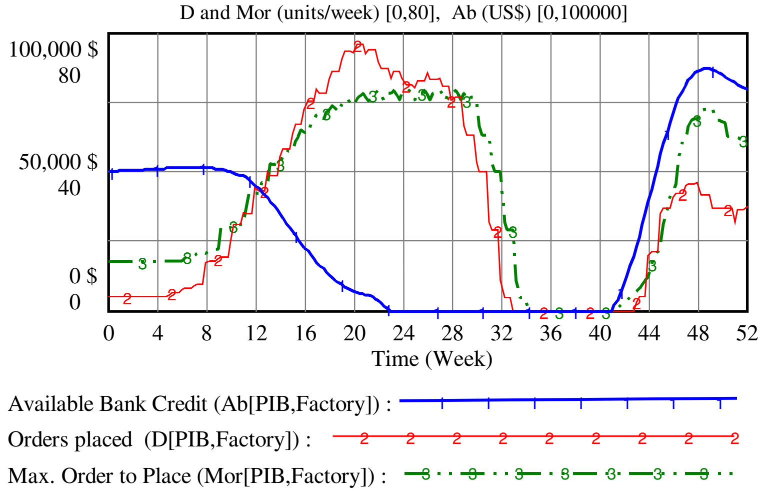

Fig. 5. Graph showing maximum order rate (Mor) vs. orders placed (*D*) according to financial constraints limiting the orders to place for a PIB SC.

3. Simulation results

In order to apply different SC integration possibilities (NI,PIA,PIB,FI) to a well known example, a four-node SC (Factory, Distributor, Wholesaler and Retailer) as described by Sterman (1984) was selected and modeled. Fractional adjustment coefficients are assumed to be the mean values of the experiments presented by Sterman (1989) (see Table 2). The non-integrated SC structure in this paper is intended to be a representation of the scenario described by Sterman (1989). The only exception in this paper is the assumption regarding the customer's behavior: the retailer does not hold any backlog (end-customers do not wait). The simulation runs are for a total of 52 weeks.

In our example, we will change the demand of the retailer, SC end-customers demand (see Fig. 6, showing a selected real demand of a product). Also we considered a price structure as in Table 2, and the price of the raw materials at the factory to be 200 $/unit.

3.1. Simulation results with no financial constraints

Table 3 shows the orders placed by various nodes for different SC integration structures. The results show a higher "bullwhip effect" [5] (amplification in the range of Min–Max orders placed in the first nodes of the SC) for the NI and PIB structures, and a good performance of the PIASC (even better than the FISC). Collaborative forecasting, and therefore the speed of the demand information flow along the chain, turns out to be the more relevant factor conditioning this amplification problem in this simulation.

Table 4 shows the SC integration improvements in terms of inventory by node. From these results, it is clear that full integration of the SC results in less standard deviation (StDev) of the units in inventory, although other structures (NI,PIA) yield better mean values.

Table 5 shows backlog per node, where the FISC presents the best values, especially for the retailer, in terms of mean, maximum (Max) and standard deviation (StDev).

Table 6 shows values for the variable "cash of the node" (*C*). This variable has been initialized to zero in this simulation study. In the event that *C* reaches a negative value, the bank credit is used,

[5] The "bullwhip effect" can be incremented by ordering periodically (batching), by customers overreaction anticipating possible shortages, or by price fluctuations (Lee et al., 1997).

Table 2
Structure of SC and table for parameters

	Factory	Distributor	Wholesaler	Retailer	
OPERATIONAL					
L^i	2	2	2	2	week
ss^i	3	3	3	3	week
β_S	0,24	0,24	0,24	0,24	1/week
β_{SL}	0,1	0,1	0,1	0,1	1/week
α^i	0,3	0,3	0,3	0,3	dimensionless
FINANCIAL					
Pm_t^i	500	600	700	1000	$/Unit
$Wso(i)$	2	2	2	2	days
Cm_t^i	0,13	0,13	0,13	0,13	%

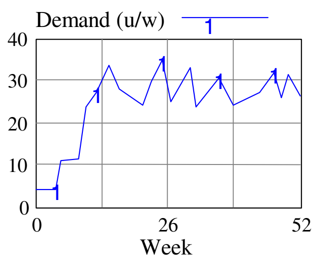

Fig. 6. End-customer's demand in units per week.

and financial expenses are paid. In this first scenario we assume no limit to the money borrowed from the bank.

Table 7 shows total funds generated by operations along the simulation by different nodes. FISC seems to perform better, especially for the retailer, followed by PIBSC, PIASC and NISC.

Table 3
Scenario 1 results for orders placed (units per week)

Variable	Min	Max	Mean	StDev
Orders placed (D)				
(NI,Factory)	4	74	33	24
(NI,Distributor)	0	60	28	19
(NI,Wholesaler)	0	48	23	16
(NI,Retailer)	1	43	26	15
(PIA,Factory)	4	40	30	12
(PIA,Distributor)	0	40	27	14
(PIA,Wholesaler)	0	40	25	14
(PIA,Retailer)	4	40	25	11
(PIB,Factory)	0	70	27	25
(PIB,Distributor)	0	56	26	16
(PIB,Wholesaler)	4	42	25	11
(PIB,Retailer)	4	37	24	9
(FI,Factory)	4	58	29	15
(FI,Distributor)	4	53	28	13
(FI,Wholesaler)	4	45	26	11
(FI,Retailer)	4	35	24	9

Table 4
Results for inventory of the node (units)

Variable	Min	Max	Mean	StDev
Total inventory $(P+Y)$				
(NI,Factory)	11	268	69	52
(NI,Distributor)	11	300	70	68
(NI,Wholesaler)	11	260	68	70
(NI,Retailer)	11	229	66	64
(PIA,Factory)	20	138	61	25
(PIA,Distributor)	20	243	73	54
(PIA,Wholesaler)	17	229	77	58
(PIA,Retailer)	11	174	74	51
(PIB,Factory)	20	309	150	105
(PIB,Distributor)	18	216	96	59
(PIB,Wholesaler)	15	116	68	34
(PIB,Retailer)	11	135	75	44
(FI,Factory)	20	116	87	34
(FI,Distributor)	20	127	86	37
(FI,Wholesaler)	20	127	83	39
(FI,Retailer)	11	118	77	40

Table 5
Results for backlog of the node (ordered units)

Variable	Min	Max	Mean	StDev
Backlog (B)				
(NI,Factory)	0	105	49	38
(NI,Distributor)	0	152	66	54
(NI,Wholesaler)	0	166	68	61
(NI,Retailer)	0	379	248	153
(PIA,Factory)	0	66	38	26
(PIA,Distributor)	0	95	44	38
(PIA,Wholesaler)	0	86	29	32
(PIA,Retailer)	0	204	149	81
(PIB,Factory)	0	23	3	6
(PIB,Distributor)	0	36	5	10
(PIB,Wholesaler)	0	46	11	16
(PIB,Retailer)	0	190	141	76
(FI,Factory)	0	32	5	10
(FI,Distributor)	0	34	5	11
(FI,Wholesaler)	0	25	3	7
(FI,Retailer)	0	141	107	55

Table 6
Results for cash of the node (US $)

Variable	Min	Max	Mean	StDev
Cash of the node (C)				
(NI,Factory)	−12415	5627	−5068	5936
(NI,Distributor)	−38359	22792	6397	8138
(NI,Wholesaler)	−58719	22056	4894	16104
(NI,Retailer)	−92020	21532	−5787	29154
(PIA,Factory)	−20241	46963	5749	19550
(PIA,Distributor)	−19724	56053	12828	18801
(PIA,Wholesaler)	−37987	41547	5261	15876
(PIA,Retailer)	−51863	53377	−2594	25039
(PIB,Factory)	−83496	37615	−32445	37112
(PIB,Distributor)	−45152	43888	−2352	24697
(PIB,Wholesaler)	−14253	57440	11082	17891
(PIB,Retailer)	−52949	52401	−2946	26253
(FI,Factory)	−44248	31611	−1635	21620
(FI,Distributor)	−24013	49993	6850	20668
(FI,Wholesaler)	−29606	51324	5140	21232
(FI,Retailer)	−51195	59127	−496	25430

Table 7
Results for cumulative income of the nodes (US $)

Variable	Min	Max	Mean
Cumulative income (Cci)			
(NI,Factory)	0	93239	28831
(NI,Distributor)	0	91072	31033
(NI,Wholesaler)	0	86009	31805
(NI,Retailer)	0	112774	39271
(PIA,Factory)	0	90792	36402
(PIA,Distributor)	0	93939	39992
(PIA,Wholesaler)	0	103393	41486
(PIA,Retailer)	0	135770	51829
(PIB,Factory)	0	79821	36081
(PIB,Distributor)	0	94428	39392
(PIB,Wholesaler)	0	105020	42287
(PIB,Retailer)	0	137437	52606
(FI,Factory)	0	88753	40067
(FI,Distributor)	0	100324	43571
(FI,Wholesaler)	0	108868	45155
(FI,Retailer)	0	144083	57009

3.2. Computational results with financial constraints for all nodes

As shown in Table 6, different nodes have different cash requirements under different stages of the integration process. The idea of the second simulation study is to assess the impact of financial constraints of equal magnitude for all nodes in the whole SC. To avoid excessive output data, we have selected just one operational metric (mean total inventory $(P+Y)$) and one financial metric (cumulative income (Cci)). At the same time, and for the same purpose, we have selected just the first and the last nodes (factory and retailer) to present the data.

We show and briefly discuss the results for five scenarios according to the maximum bank credit (Mb) which is available for all the nodes: US $ 0, 10000, 25000, 50000, and 100000. These results show how inventories and current incomes could change with the change in the sequence of integration and the existing financial constraints. For instance, PIBSCs produce higher factory inventory levels (Fig. 7) and lower incomes (Fig. 9) than the SC structures with no financial constraint (worse performance structure). But PIBSC performs better than the NISC, and similar to or better than the FISC and PIASC when financial constraints increase.

Figs. 9 and 10 show how PIASC and FISC maintain higher levels of cumulative income when constraints increase. Figs. 8 and 10 show that any integration structure, partial or full, always produces a better performance for the retailer.

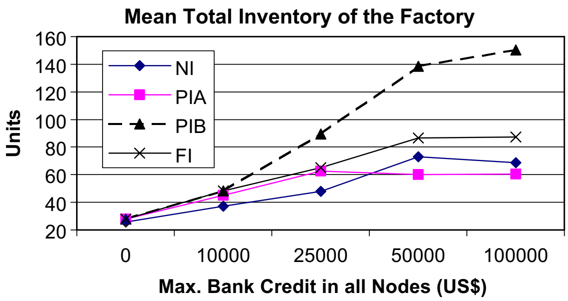

Fig. 7. Mean total inventory ($P + Y$) of the factory (units).

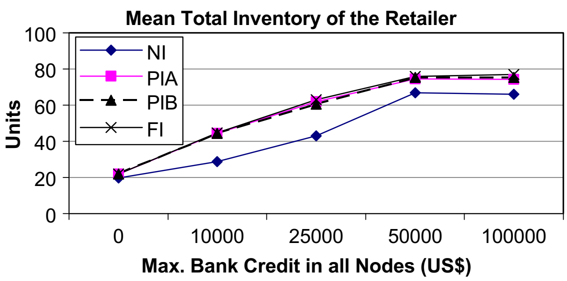

Fig. 8. Mean total inventory ($Y + P$) of the retailer (units).

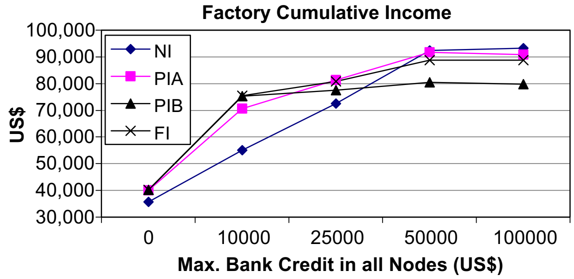

Fig. 9. Factory cumulative income (Cci) (US $).

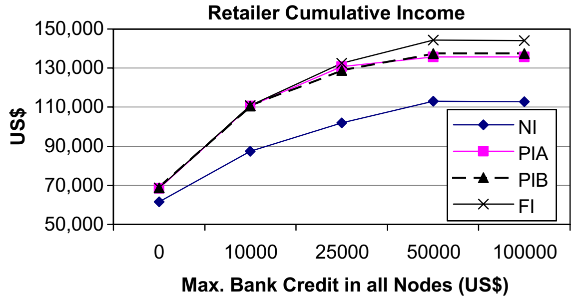

Fig. 10. Retailer cumulative income (Cci) (US $).

The above results show how collaborative planning without any previous collaboration and discussion to generate a common forecast (i.e. PIBSC structure) could lead to inefficient supply chain performance when there is no financial constraint. For the same reason, releasing financial constraints through electronic payments tools in a PIBSC, could not necessary be beneficial for the SC performance, and its seems reasonable according to these results, to apply these tools once the common forecasting is in place.

3.3. Results for financial constraints at a single node

Our proposed model allows this interesting analysis. Many SC engineers wonder, for instance, how can a supplier's financial situation impact the whole SC performance. This problem can be explored with the model. Let's increase the factory financial constraints only, and then obtain the impact on the retailer's cumulative income. Results are presented in Fig. 11, where the systemic nature

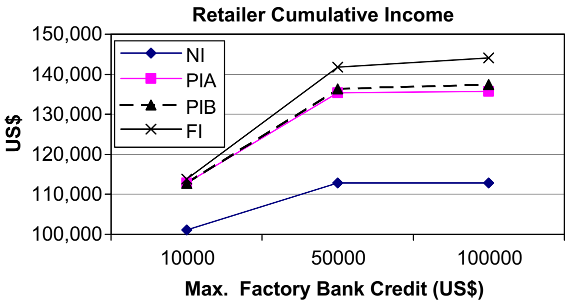

Fig. 11. Retailer cumulative income (Cci) (US $) for factory financial constraints only.

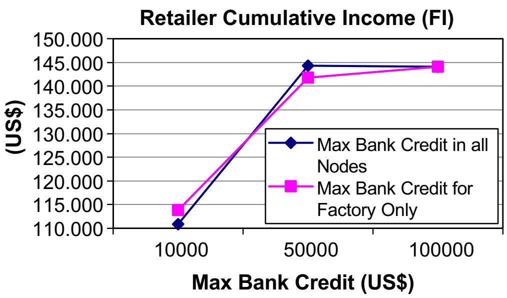

Fig. 12. Retailer FI cumulative income (Cci) (US $) comparison for all nodes vs. only factory financial constraints.

of the SC can be observed. The retailer's cumulative income drastically decreases due to the factory's financial constraints. In fact, the income amounts are very close to the amounts that we would observe when all nodes were constrained (see Fig. 12 for FI results).

4. Conclusions

This paper considered the issues involved in the integration of supply chain through the use of e-collaboration tools. It developed a comprehensive model to study the operational and financial benefits of using various e-collaboration tools. A system dynamics based simulation was used to study the impact of various levels of supply chain integration. Computational results from our experiments clearly show the potential improvements of the integration by using Internet tools for SC collaboration. The sequence of implementing this new technology should start by addressing the issue of collaborative demand forecasting (PIASC), and then continue with the collaborative planning by sharing and using the inventory information of the whole SC (FISC). Implementation of e-collaboration tools to do local planning using global SC inventories data when each node is producing its own forecast (PIBSC) could lead to significant increases in inventory and decreases in income, especially where nodes are not financially constrained.

Full integration of supply chain (FISC) clearly provides more benefits than any partial integration of supply chain. FISC benefits from the visibility of the total materials flow and backlog orders along the chain. Besides the fast access to demand information, it also enables the ordering policies to adjust to new customer requirements earlier and with more efficient inventory administration (less inventory cost to reach a target service level) along the chain.

Our computational results also show that it is risky to install e-collaboration tools for electronic payment when collaborative forecasting is not in place in the SC. Decreases in financial constraints could lead to unnecessary increase in inventories without improving SC performance. Local financial constraints can heavily impact the operational and financial performance of the entire supply chain. At times, this impact could be very close to the one produced by a global financial constraint at all the nodes of the SC. Therefore, helping the weakest financial node of the chain should be a main concern of the SC engineers and analysts, and not treated as a SC local issue.

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