Supply Chain Infrastructures: System Integration and Information Sharing

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Abstract

The need for supply chain integration (SCI) methodologies has been increasing as a consequence of the globalization of production and sales, and the advancement of enabling information technologies. In this paper, we describe our experience with implementing and modeling SCIs. We present the integration architecture and the software components of our prototype implementation. We then discuss a variety of information sharing methodologies. Then, within the framework of a multi-echelon supply chain process model spanning multiple organizations, we summarize research on the benefits of intra-organizational knowledge sharing, and we discuss performance scalability.

1 Introduction

Recently, two kinds of enterprise systems have been widely adopted in industry: enterprise resource planning (ERP) systems and supply chain management (SCM) systems. The ERP systems are able to provide an integrated transaction processing fabric for an organization, which enhances organizational performance by reducing information inconsistency and by improving transaction-processing efficiency. SCMs, on the other hand, are aimed at providing a higher level of business planning and decision support related to activities that involve the coordination and execution of multi-organization wide production and distribution processes. As these software systems have matured, their capabilities and features have begun to overlap based on normal product enhancements as well as business acquisitions and mergers. We now are seeing the emergence of integrated ERP/SCM solutions [6,12].

Our research at the Smith School of Business on the effective use of SCIs within and across organizations follows a two-fold strategy. First, we investigate issues in implementing a prototype SCI, in collaboration with software vendors. We document our experiences with methodologies for intra-organizational information sharing. Second, within a process oriented model of a multi-echelon SCI spanning multiple organizations, we investigate the following: Decision models to measure the benefits of knowledge sharing for multi-echelon SCIs; limitations of performance scalability for multi-echelon SCIs.

The paper is organized as follows: Section 2 describes the test-bed architecture. Section 3 reviews several methodologies for intra-organizational information sharing. Section 4 describes a multi-echelon supply chain process model spanning multiple organizations. Within this framework, we summarize research on the benefits of intra-organizational knowledge sharing of demand on decision models, and research on performance scalability for SCIs in the noisy wide area environment.

2 SCI Architecture and Components

Our supply chain prototype illustrated in Figure 1 consists of six main components: an ERP component, an SCM component, a simulation component, middleware, collaboration software and a visualization and decision component. In the prototype, the ERP component contains multiple ERP instantiations for individual supply chain members. Under the current implementation, these ERP instantiations are implemented using multi-organizational configurations of the Oracle ERP solution. The SCM component, which employs software from Manugistics, is designed to integrate with the ERP instantiations to support planning and execution across the total supply chain [11,14]. The integration of the SCM component and the ERP components forms the integrated Supply Chain Infrastructure (SCI) architecture. The middleware component uses TIBCO software and consists of an integration manager, a message broker, data adaptors and a variety of APIs [24]. The collaboration component is the web-enabled Network/Collaborate software from Manugistics [15]. The simulation component is based on Arena simulation software from Rockwell Software Inc., and a library of supply chain simulation templates [10]. The visualization and decision component provides activity animation, graphical information display, and decision-support.

The configuration of our prototype SCI reflects our expertise gained from extensive surveys and case studies of companies in the electronic industry such as Maxtor, Toshiba, and Compaq. Such an SCI usually includes a focal company with multiple suppliers and customers. The focal company has one headquarters for global supply chain management, multiple factories and multiple retailers to serve customers. The suppliers and customers may be independent organizations that have their own ERP and/or management systems. However, they are supply chain business partners linked by common end products, e.g., a Printed Circuit Board (PCB) linking a supplier to the focal company, or a Disk Drive, linking the focal company to its customers.

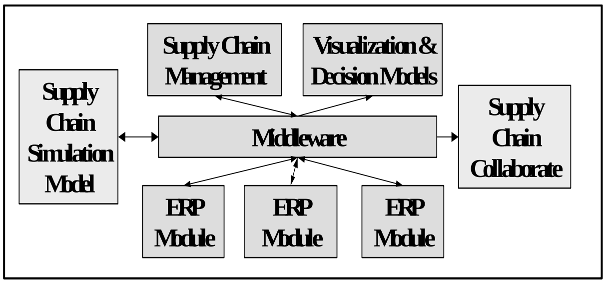

Figure 1: Architecture of the SCI Prototype

The prototype SCI was implemented in conjunction with experts from the software vendors including Manugistics and Oracle. Key to the success of our implementation was the technical expertise provided by TIBCO Software Inc. While there was significant effort devoted to investigating the specific ERP and SCM APIs, as well as towards the programming involved, the most serious challenges in implementing our prototype was defining the integration architecture and the business process model, and selecting and choosing methodologies for information sharing. Our contributions include defining and benchmarking the integration task, noting problems encountered during implementation, and documentation of the models for information sharing (to be discussed next). A critical finding is that simplification of the integration data and the business process has a significant impact on success. Second, the different characteristics and requirements of different industry sectors will also impact the model for information sharing.

3 Methodologies for Information Sharing

We consider information sharing both within the focal organization (intra-organizational) as well as across organizations (inter-organizational). In our prototype, intra-organizational information sharing employs middleware technology, while collaboration technology is used at the inter-organizational level.

Intra-organizational information sharing must take place at two levels: one is at the data level and another is at the business-process level. These two levels of information sharing have been widely studied by SCOR [20] and RosettaNet (www.rosettanet.org). We have borrowed concepts and ideas extensively from these standards. The main difference between our approaches is that we focus on high-level (application driven) integration of multiple heterogeneous enterprise systems, where each component can be compared to a black box. Solutions such as RosettaNet interoperate at a lower level of abstraction and rely heavily on the definition of EDI-like standards for the exchange of data, process knowledge, messages, etc.

For information sharing at the intra-organizational level, middleware components tie together the SCM system with factory ERP systems and retailer ERP systems. The middleware serves as an information backbone to transact and convert data among disparate ERP systems and SCM systems. In the middleware-based infrastructure, the message broker (or information bus) is used to implement distributed transactions and the integration manager is used for business processes execution [2]. The middleware provides inter-operational services such as transactions, shared directories, persistence, event-handling, messaging and process execution based on standards, e.g., CORBA (Common Object Request Broker Architecture and DCOM (Distributed Common Object Management. The protocol and data exchange language and format may come in many flavors including flat file, EDI (Electronic Data Interchange), HTML (Hyper-Text Markup Language), and XML (eXtensible Markup Language) [22]. Presently, many sophisticated middleware solutions are available such as Integration Manager and activeDB from TIBCO (www.tibco.com), iBann OpenWorld (www.iBann.com), WebConnect from Manugistics (www.manu.com), etc. The benefits of this integration are effective information sharing and support for distributed transactions.

For data level information sharing, all distributed data sources along the supply chain should be properly connected. Specifically, data is retrieved from one database, for example an ERP database, to update another database, say the SCM database. This approach is relatively easy to implement since application changes are not required. To support this integration we use an **integration data model** [28], which defines general integrated data transactions across different applications. Figure 2 illustrates the components and data flow for some generic processes and data exchange that characterize intra-organizational information sharing. Specific details of data exchange are in Table 1.

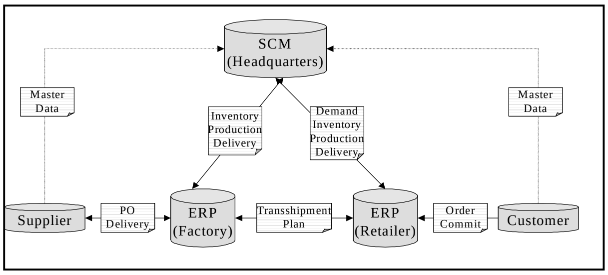

Figure 2: Model of Supply chain integration (SCI)

For information sharing at the business-process level, one could employ Application Programming Interfaces (APIs) or Enterprise Application Interfaces (EAIs) and develop transaction specific integration modules [12]. However, this approach is challenging because of the difficulty in integrating disparate applications. Moreover, this kind of integration is not practical since different applications may be distributed globally and has autonomy to a certain extent and because of the need to develop new code for each transaction class. An alternative approach, the business event driven approach, triggers applications based on business events. To support this capability, an ***integration process model,*** which describes the general business process relationship, is required [29]. The integration process model defines the execution sequence of different applications in the integrated scalable supply chain infrastructure. This model is embedded within the middleware. It corresponds to the business process execution logic across the integrated supply chain. The advantages of using event-driven integration model are that it can guarantee the seamless integration of different business processes.

Components	Data Exchange
Retailer ERP ⇔ Headquarters SCM	• Sales master information • Forecasted demands (sort and long-range)
Headquarters SCM ⇒ Factory ERP	• Distribution requirements plan • Master production schedule • Key parts transshipment schedule
Factory ERP ⇒ Headquarters SCM	• ERP master information • DRP deployment, acknowledge & confirmation • MPS deployment, acknowledge and confirmation • Inventory • Production schedule and execution plan
Factory ERP⇔ Retailer ERP	• Key parts transshipment schedule

Table 1: Instances of Data Exchange in the Integration Data Model

A typical process in our model is the supply chain planning process. Following supply-chain-level demand forecasting, distribution requirements planning (DRP) for all supply chain actors, and master production scheduling (MPS) for all production factories, should be executed. Then, the MPS results should be passed on to factory-level ERP systems to start the material requirements planning (MRP) and capacity requirements planning (CRP) for individual locations. All subsequent activities are triggered by the completion of events of previous activities in a predefined sequence that is defined in the integration process model. We have specified, designed and documented an integration process model.

Inter-organizational information sharing employs collaboration techniques to create a multi-echelon supply chain involving the focal organization and additional suppliers and customers. At present, the most popular collaboration model available has been the Collaborative Planning, Forecasting and Replenishment (CFPR) model [5]. The Network/Collaborate solution from Manugistics implements this model and was used in our prototype. Alternately, RosettaNet based software solutions like WebLogic can also be used.

4 IMPACT of Information Sharing for Multi-Echelon on SCI

In Section 3, we focused on an integration model for intra-organizational information sharing and implementation details of our prototype. In this section, we focus on the potential benefits of intra-organizational information sharing. Intra-organizational information sharing (described as collaboration in the prior section) can bring together suppliers, customers and the focal company toward achieving decision consensus with shared goals. Clearly, this kind of information sharing can improve transaction efficiency and reduce information delay along the entire supply chain. Meanwhile, by sharing information among all partners in the supply chain, all participants in an extended supply chain system can gain competitive advantage, optimizing performance and profits. [7,9,19].

We first briefly define a multi-echelon supply chain configuration. At each level of retailer, distribution center, manufacturer and supplier, there could be multiple players. A manufacturer or supplier may further extend the "internal" supply chain if they themselves participate in an "external" supply chain. Depending on the extensiveness of the internal and external supply chains, a request generated in one chain could spawn multiple requests in another chain. Within this framework of multi-echelon SCIs, we briefly describe simulation based research on the advantages of information sharing on decision models and limits on performance scalability.

4.1 BENEFITS of Knowledge Sharing on Decision Models

The SCI is described by one or more upstream or downstream flows of products, services, and information [16]. Many researchers have suggested that information sharing can substantially improve overall supply chain performance [1,4,21,23].

Sharing information such as demand, sales orders, inventory status and order fulfillment status can help companies to reduce inventory cost, shorten time-to-market, and improve decision making along the total supply chain. Consequently, customer service can be improved. Thus, information sharing boosts the efficiency and performance of a supply chain. By using simulation-based experiments, Closs et al demonstrated that a supply chain in which retail sales information is shared instantaneously with the retailers' respective distributor(s), as well as with manufacturer(s) and raw materials suppliers, places a premium on consumer service and can reduce inventory level dramatically, comparison to the traditional anticipatory supply chain strategies [4].

Our research explores the key driving forces that encourage an individual firm to share information with others. Firms are distinguished as being an "***upstream member***" or "***downstream member***". When considering a supply chain as a material flow, materials or products flow from upstream members to downstream members. For instance, the supplier is an upstream member of a manufacturer and vice versa.

A widely cited benefit of information sharing is that it can dampen the Bullwhip phenomenon [11]. The "bullwhip effect" differentiates upstream and downstream members as follows: " *… orders to the supplier tend to have larger variance than sales to the buyer (i.e. demand distortion), and the distortion propagates upstream in an amplified form*." As a result, an upstream member who only gets order information from a downstream member may be misled. This results in excess cost, such as inventory cost, transportation cost or excess raw materials cost due to unplanned and unbalanced production. Using simulation and analytical research, they showed that sharing "sell-through" data and inventory information from downstream members might reduce the bullwhip effect on upstream members.

In our research, we further explore the bullwhip phenomenon using two hypotheses governing information sharing in a supply chain. The first hypothesis is that upstream members will obtain greater benefit from information, in comparison to downstream members. The second hypothesis concerns an ***upward positive externality*** of specific improvements experienced by downstream members. For example, an upstream member can take advantage of a downstream member's improvements such as decreasing lead-time, and/or obtaining more accurate sales information.

We are engaged in research validating these hypotheses using a simulation-based study of different scenarios of supply chain information sharing. Preliminary results include the following:

- Sharing demand information leads to greater inventory reduction (on the average) for upstream members compared to downstream members (related to the first hypothesis).
- The benefit of sharing demand information on downstream members has a positive externality on upstream members (related to the second hypothesis).

Details of the simulation-based study are in [13].

4.2 Performance Scalability

The *scalability problem for* the supply chain infrastructure is that it must meet quality of service requirements, while the number of clients and requests increase, and as the extensiveness of the supply chains increases, in a dynamic environment such as the Internet. Quality of service has many dimensions as follows:

- The *end-to-end latency (delay)* between the time that a request is generated and an answer is obtained.
- The *data quality* related to the value of the response.
- The ability to meet performance targets in dynamic and unpredictable environments.

As the supply chain becomes more extensive, it will rely more heavily on wide area networks, and its services will increasingly become Web-enabled. There is related research in wide area applications. Adaptive query evaluation techniques have been developed to overcome initial delays and bursty data delivery in wide area networks [8]. Query optimization techniques have been developed for mediators that process queries on multiple remote sources [18, 25]. There is also research on optimization to meet performance targets in noisy environments [3, 26, 27]

Scalability in meeting quality of service requirements is being investigated in a simulation environment with multiple clients and servers, representing retailers, distributors, manufacturers and suppliers. Our simulation considers the impact of the following factors:

- The topology of the chain including depth and fanout at each level, and the impact of noise (variance).
- Response to client requests: This includes real-time response or off-line response to aggregated requests. A server can respond immediately to a request, or forward the request to a varying number of servers at the next level, or both.
- Degree of knowledge sharing: This includes knowledge about the quality associated with servers such as low latency or low noise (variance) as well as tailoring response corresponding to the priority associated with incoming client requests.

Our simulation will monitor end-to-end latency of the first response to each request (event) as well as average latency. We also consider the variance in latency and the ability to meet target latency as in [26]. Based on initial simulation results that vary the response to customer requests (specifically fanout), we observe the following:

- The latency of the first response to a request *reduces when we increase the fanout* from 1 to 2, i.e., we benefit when a server forwards a request to 2 servers at the next level rather than only one.
- However, when we increase fanout from 2 to 3, the latency of the first response shows some asymptotic behavior. If we consider 50% of the requests, the latency is similar to the latency with fanout = 2. However, for 100% of the requests, the latency is similar to fanout = 1.
- This indicates that there is only a limited benefit of increasing the fanout from 2 to 3 compared to increasing the fanout from 1 to 2. Thus, there is a limitation on the benefit represented by a reduced latency of the first response to a request, as fanout increases.

Next, we considered knowledge sharing of request (event) priority. We differentiated events of (high) priority level = 1 which were forwarded to multiple high quality servers (with low latency and low noise). In contrast, events with (low) priority level = 3 were forwarded to a single server (with higher latency and noise). Initial simulation results are as follows:

- We consider a baseline of [priority 1 25%, priority 3 75%], i.e., 25% of the requests have (high) priority level =1.
- When we consider a workload of [priority 1 50%, priority 3 50%], the end-to-end latency of all responses to requests (both high and low priority) increased significantly.
- When we consider a workload of [priority 1 75%, priority 3 25%], the latency of the high priority requests approaches the baseline but the latency of low priority requests remains above the baseline.

While this research is ongoing, our preliminary results reflect a limit of performance scalability by increasing fanout or sharing knowledge on priority of requests. Our objective is to determine potential business strategies based on performance scalability results as follows:

- Reducing the latency of the response to a request with increasing fanout could lead to strategies to improve the performance of the ATP task.
- The benefits of knowledge sharing can be reflected in developing strategies such as when to use the *best supplier* or how to assign priority to incoming customer requests.

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