E-Business Applications for Supply Chain Management:
Challenges and Solutions

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Abstract
Supply chain management is a crucial activity in every company. Surprisingly, today most of the supply chain activities are carried out manually, and IT support is often limited to having a set of (disconnected) data repositories. In addition, B2B communications are performed via phone, fax, or email. Increasing the operational efficiency of the supply chain results in huge savings, and is the key towards remaining competitive or even gaining a competitive advantage. Furthermore, a more efficient supply chain also enables revenue growth, which is often impossible to sustain with the current manual operations.

In this paper we discuss the requirements and challenges for e-business applications that support supply chain management. Then, we propose an architecture that meets the requirements and enables solutions that deliver results quickly and evolve with the business and IT environment. Both the requirements and the architecture are the results of several different types of supply chain automation projects in which we have been involved.

1. Introduction
Supply Chain is the set of operations executed to fulfill customers' requests for products and services. There is no precise and agreed definition of what exactly is the scope of the supply chain and which functions of a company are considered as being part of the supply chain. However, a supply chain is often viewed as composed of the following activities: quotation, order processing, order fulfillment, and return management (see Figure 1).

Quotation involves processing customers' Request For Quotes (RFQs) in order to reply with information about the price, availability, and expected delivery dates of the desired goods. In general, RFQs may include products from different vendors.

Order processing involves the analysis of customers' orders, to verify that they correspond to a previously given quote and that they can be fulfilled under the conditions requested by the customers.

Order fulfillment is the process of procuring the requested products and of delivering them to the customers. Depending on the products and their suppliers, orders may be directly shipped from the suppliers to the customers (dropship), or they may be consolidated in a warehouse and shipped only when all ordered items are in stock. Order fulfillment also includes invoicing the customer and paying the supplier.

Return management is the process of handling products that customers want to return, for instance because they are defective or because they do not correspond to the ones included in the order. Handling returns is a fairly complex function, which includes

Figure 1 - Phases of the supply chain and related setup and consolidation operations.
inventory updates and reimbursements, and varies depending on the agreements stipulated with customers and suppliers.

To enable and complement supply chain operations, additional preparation and consolidation activities are required. For instance, companies need to set up product and supplier databases and to define customer support strategies for each product. In addition, financial reconciliation operations must be performed periodically (e.g., month-end closing). While these operations are not typically considered as part of the supply chain, they are strictly related to it since they produce and consume information that is also processed by supply chain operations.

Improving the quality and efficiency of the supply chain is the key success factor for most businesses. Today, supply chain operations are carried out manually, and automated support is limited to having a set of heterogeneous systems, one for each phase or sub-phase of the supply chain, that basically act as data repositories. Some of the systems are homegrown, others are off-the-shelf packages, and others can be e-services offered by an Application Service Provider (ASP). The "integration" among these systems is still conducted manually in the large majority of the companies, and the whole process involves a lot of frustrating and repetitive human labor, exchange of paper documents, inefficiencies, and errors. Orders are difficult to monitor and to track, so that it is also difficult to have an overall view of the current operations and to give information about the status of an order. Furthermore, the use of any automated support, where available, is often limited to administrative employees, and any information exchange with managers, salespersons, customers, suppliers, and other partners, is performed manually, typically by fax or email. These problems strongly affect the quality and efficiency of the supply chain operations, and severely harm the ability to sustain growth, thereby resulting in high operating costs and missed revenues.

In order to increase profits, companies are trying to automate supply chain operations, both internally and across enterprises. While the huge benefits in terms of quality, scalability, and efficiency are tempting, achieving operational excellence presents many hard challenges, due to the need of automating processes over heterogeneous and autonomous systems, of managing interactions across organizations, of monitoring and tracking orders, and many other issues.

In this paper we present the requirements and challenges involved in developing e-business applications for supply chain management (SCM), and we illustrate several solutions that can help companies in improving the efficiency of their supply chain. The proposed architectural solution enables a progressive, stepwise automation, in order to deliver results quickly and then improve as the project advances. In addition, it allows for the solution to evolve in accordance with changes in the business and technical environment. Both the requirements and the architecture are the results of several supply chain projects in which we have been involved, for internal and external customers as well as for supply chain hubs.

2. Requirements and Challenges

In this section we list the main requirements for SCM applications and discuss the challenges they pose. We will limit the description only to requirements that are characteristics of SCM solutions. "Classic" requirements, such as performance and high-availability, are not discussed here. In addition, we will focus on the overall supply chain management, rather than discussing the many requirements of each individual application that manage a specific phase or aspect of the supply chain, such as quotation, e-procurement, or inventory management.

Integration. Supply chain operations are supported by many autonomous and heterogeneous systems. Hence, developers of SCM systems are faced with a huge integration problem, spanning several systems, several departments, and possibly several companies. Systems in place typically include homegrown as well as commercial applications, and may be mission-critical (i.e., practically untouchable). They may differ in the interfaces, interaction protocols, security requirements, and programming models, just to name a few. In addition, supply chain processes involve several enterprises, and therefore it is desirable to integrate systems across enterprises. Integration across enterprises includes all the problems present in Enterprise Application Integration (EAI). In addition, it is complicated by factors such as:

- **Security**: Since communications occur outside the protected intranet, message exchange needs to be encrypted. Other security issues, such as authentication, authorization, non-repudiation, and integrity, also need to be addressed.

- **Autonomy**: Applications running in different companies need to agree on the languages and protocols used for the interaction. The problem is further complicated by the fact that supply chain transactions involve several companies, and therefore agreements need to be reached and maintained with several companies (unless supply chain hubs act as mediators to simplify the interactions).

- **Small enterprises**: Every company, including very large ones, needs to interact with small organizations in order to procure certain goods or
Automation. The main purpose of SCM applications consists in allowing companies to reduce operating costs and fulfill increasing order volumes. These objectives require the automation of supply chain processes, at least for what concerns the many repetitive tasks involved throughout the phases of the supply chain. Besides bringing all the "traditional" advantages of automation (e.g., less involvement of costly human labor, faster executions, no slowdowns due to sickness or holidays), one of the main desire of the clients we have been working with was to put "more feet on the street", i.e., free people from repetitive work and give them more time to market products or assist customers. Hence, the main goal of SCM applications is the automation of all the supply chain business processes.

Note that application integration, both within and across enterprises, is a fundamental prerequisite for automation, since it provides a homogeneous view of a heterogeneous environment. In fact, once the underlying environment can be seen as homogeneous and all systems can be accessed in the same fashion (e.g., by using the same protocol and the same programming model), it becomes practically possible to develop applications that automate those business processes that need to access such systems.

Process monitoring and exception handling. Supply chain processes (both manual and automated ones) need to be monitored in order to detect delays and exceptional situations that prevent on-time delivery and, in general, the fulfillment of Service Level Agreements (SLAs). SCM applications should be capable of monitoring process executions and reacting to slowdowns or exceptional situations automatically (wherever possible), or at least by notifying the appropriate employee, customer, or supplier.

Process tracking. It frequently happens that people involved in the supply chain (such as customers, suppliers, managers, and employees) need to verify the current status of an order. This is often quoted as being one of the main time-consuming activities in the day-to-day operations. In the traditional supply chain, it involves looking through lots of paper documents and making telephone calls to the suppliers or to the warehouse, trying to estimate if and when the goods will be delivered, and why delays occurred. SCM applications must support process tracking in order to readily provide this information.

Process Diversity. Large companies operate in many countries throughout the world. The way in which supply chain processes are structured and managed considerably vary from country to country, due to the differences in the laws, practices, and technological developments. In addition, offices in large countries have many employees, and typically follow structured processes. On the other hand, offices in small countries may have as little as one or two employees, and they often handle business in an ad-hoc way.

The trend towards centralization and automation, in order to achieve cost reductions and more efficient operations, is contrasted by the need of managing tens or even hundreds of different ways of doing business and of fulfilling the orders (with different levels of structure, repeatability, and flexibility). While in some cases it is possible to standardize processes and interactions, and to reduce differences across countries, it is often practically impossible (and counterproductive) to force all countries to follow the same process. Even if this were possible in the first place, the problem of being able to evolve and improve the process with time and to apply the changes to every country at the same time would still harm the goal of having a single, standardized way of doing business. Hence, SCM applications must be able to support the executions of business processes that have variations depending on the country for which they are executed.

User diversity. Although SCM applications have the purpose of automating the operations of a specific company (or of a supply chain hub), limiting its usage only to the administrativeemployees of that company involved in the day-to-day operations would also limit the benefits.

Indeed, many different types of users, possibly belonging to different companies, need to retrieve or provide information related to supply chain operations. For instance, suppliers need to notify shipments or delays in procuring goods, while customers need to get information about expected shipment dates. Even within the company that is supported by the SCM application, managers need to get reports about revenues, profits, and costs, or about the business with specific customers or suppliers, while salespersons notify customers' RFQs.
Figure 2 - A supply chain management system should benefit internal employees, managers, and partners

Hence, an important and often neglected requirement is that the SCM application should be made accessible to all these different types of users (see Figure 2). In addition, users should be provided with a personalized interface, that allows them to see what they need, what they want, and what they are allowed to see. This is useful for two reasons:

- It makes more convenient (and reduce costs) for partners to participate to the supply chain, since they can interact directly with the system at their convenience, without having to look for employees and contact them by phone or fax. By reducing the costs not only for the company that implements it, but also for the other parties, the SCM application can attract more customers and suppliers, thereby enabling more revenues and better offering.

- It offloads employees that would normally be involved in interacting with customers for the only purpose of acting as “interface” between them and the SCM application.

**Analysis, forecasting, and optimization.** One of the most important differentiators in today's economy consists in identifying those customers, suppliers, and products that enable the generation of larger profit margins. This is one of the goals of data mining applications, and specifically of Customer Relationships Management (CRM) applications, which also help in understanding the most effective way to target customers and manage relationships with suppliers.

Besides optimizing external interactions, companies are constantly engaged in the effort of improving internal operations, both from a business and IT perspective. Examples of analysis and optimizations that can help companies in reducing their costs and improving the efficiency of their operations include:

- Identifying which internal (human or automated) resources do not perform with the expected quality and efficiency.

- Discover bottlenecks in process executions, understanding which organizational and technical changes could remove these bottlenecks or reduce their impact.

- Detect, as early as possible in the execution, the business process instances that are at risk of not meeting Service Level Agreements (SLAs).

- Predict order volumes and the corresponding load on resources (especially peaks and bursts), to be able to appropriately size systems and organizations.

3. Solutions

The previous section has outlined the requirements and presented the challenges that must be faced by the developers of e-business applications supporting supply chain operations. In this section we propose an architectural solution that we have found to be well suited to all the supply chain automation projects in which we have been involved, including both solutions for a single company as well as for supply chain hubs. We will also
mention the alternative approaches we considered and motivate our choice.

The first option we considered was the single-system solution. The hope was to find an application that could handle all the phases of the supply chain in an integrated fashion, and that could satisfy all the requirements listed in the previous section. This solution has several appealing characteristics: it (typically) involves reduced development and management costs, and can be rolled-out in a relatively short time. Indeed, the time factor is very important, as underlined by all of our internal and external customers. In fact, in many cases, the business is growing faster than it can be supported by the current operational structure. Hence, without an adequate system, a company cannot fulfill all the orders. Missed revenues and high operating costs result in what are typically referred to as *opportunity costs*. Hence, it is important that any proposed solution can be rolled out quickly and can start giving benefits as soon as possible.

Despite these attractive features, the single-system solution presents some key limitations that prevent its adoption in the cases we have examined:

1. While each of these systems was excellent in managing a part of the supply chain and provided part of the required functionality, none of them was able to adequately support all the phases.
2. Single-system solutions only allow limited ability to configure and modify the implemented supply chain processes, and in general are not very flexible. In particular, it is difficult to describe and manage the many different variations of the processes for the different countries.
3. The ability to evolve and to stay competitive is bound to the vendor. Even if the solution is of high quality and satisfies all the current needs, there is no guarantee that the application will evolve with business and technical changes and in accordance to the customer strategy and needs, while maintaining appropriate quality standards. Large vendors may have the capability of constantly improving their offering and keeping their products up-to-date, but it is often difficult to have them implement specific desired features in a short time. On the other hand, small vendors are more likely to be willing to support specific needs of a single (large) customer. However, small
vendors imply a higher risk of going out of business.

Similar consideration can be made for approaches based on the outsourcing of the entire supply chain IT infrastructure, at least as far as the current state of the practice is concerned. In this kind of solution, the SCM application is not offered as a product, but as an e-service. With respect to the approach described above, this one has the same advantages and disadvantages, although both of them are pushed even further: in fact, license, development, management, and opportunity costs are even lower, but also lower are the flexibility, the support for change, and the ability to take advantage of best-of-breed applications. In addition, this solution raises the issue of privacy and control over data and processes, to which many companies are very sensitive.

The above reasons urged us to consider a different approach for supporting the needs of our customers. In particular, the requirements presented in the previous section suggest that the solution should have the following characteristics:

1. Offer easy, controlled, personalized access to different types of users.
2. Have an open and extensible architecture enabling stepwise evolution and flexible application integration.
4. Allowing business process analysis, forecasting, and optimization.

In order to address these three issues, we propose the use of a layered architecture depicted in Figures 3 (operational part) and 4 (analysis part). Components that are part of the solution are shaded. Figure 3 shows that the architectural solution is composed of three layers, built on top of the existing applications that support the current supply chain operations. The three layers provide integration, automation, and personalization functionalities, taking care of the above-mentioned points 1 to 3. In the following we detail the characteristics of these layers.

The integration layer has the purpose of providing a homogeneous view of the underlying heterogeneous environment. Providing such homogeneous view is of paramount importance, since it considerably simplifies the development and management of the applications that access the legacy systems in place. There are several products on the market that provide the functionality of the integration layer, from such vendors as BEA, Tibco, IBM, and WebMethods. They are all based on similar principles: they include a message broker (sometimes called event bus) that provides the backbone for exchanging messages across applications according to a product-specific format and protocol. In addition, they include adapters to convert from this format to the one supported by the invoked applications and vice versa. Typically, adapters for connecting to the most widely used ERP, CRM, and DBMS packages are provided. Application integration packages also include adapters that enable communication across organizations according to B2B standards such as EDI and RosettaNet.

While this set of adapters usually satisfies the needs of many integration applications, it will not cover homegrown systems as well as systems developed by small vendors. In these cases, ad-hoc adapters must be developed. However, integration platforms also support the development of ad-hoc adapters to integrate systems that are not supported out-of-the-box.

Once an integration layer has been deployed, it becomes possible to automate the execution of processes that access applications within and across enterprises. The design and implementation of such processes need not be concerned neither with the kind of application invoked at a given step, nor with whether the application runs in the same or in a different enterprise, since application access is made uniform.

Despite the high costs (an integration platform can cost several hundreds of thousands US dollars), companies often choose to buy rather than build an integration layer (unless only a few systems must be integrated), due to the complexity involved in developing and maintaining such a layer. However, the decision should naturally be based on ROI analysis. Criteria to be considered in performing make or buy decisions for the integration layer have been discussed in [1]. However, we expect the price of integration platforms (as well as the development and maintenance effort) to decrease in the near future, especially if the trend towards supporting XML over TCP or HTTP continues. In fact, the widespread use of common formats and protocols considerably reduces the burden of integrating applications, and enables the development of general-purpose adapters that basically perform conversions among different XML formats.

A supply chain involves several business processes. To improve supply chain operations these processes need to be modeled, analyzed, automated, managed, monitored, and tracked. The automation layer provides this functionality. Products that support flexible and controlled process automation are called Business Process Management Systems, or Workflow Management Systems (WfMSs). Many WfMSs are currently available on the market, from such vendors as IBM, HP, Vitria, Tibco, and many others. They allow users to define a
process by using a high-level, graphical language. A process definition includes the description of the steps to be performed, their execution dependencies, the application that should be invoked at each step, and the data exchanged with the application. In addition, state-of-the-art WfMSs allow the definition of processes that adapt to changes in the environment and can handle (limited and confined) variations in the processes due for instance to country-specific supply chain needs (see [3,5,7] for a discussion of adaptive and dynamic features in workflow systems). WfMSs also enable process monitoring and tracking, and include several facilities for monitoring and managing exceptional situations, so that SLAs can be met or their violations can be detected as soon as possible.

Although the automation layer could be developed by hard-coding the business logic using some programming language, WfMSs are needed unless processes are very simple and stable over time, and the application requirements are limited to simple exception handling, monitoring, and tracking functionality. The advantages of using a workflow management tools versus hard-coding (for many practical applications) have been discussed elsewhere in the literature and will not be presented here (the interested reader is referred to [2,4,6]).

Once the automation layer is in place, then SCM processes can be invoked automatically or by a human user. Ideally, invoked processes flow through completion with no latency, at least for what concerns all the internal operations. Human intervention should be needed only to handle failures and exceptions or particularly complex orders for which it was not possible or not convenient to provide automated support.

The personalization layer provides different, personalized views of the same system. It enables different types of users to access applications and information in a controlled way. In addition, it supports different content delivery protocols, to allow access with different kinds of devices such as cellphones and PDAs. Personalization layers are provided by several vendors, such as ATG, Broadvision, and Bluestone.

When a personalization layer is in place, different access modes and views can be configured for the different types of users that participate in the supply chain. For instance, customers will have access to functionality for browsing catalogs or submitting RFQs,
suppliers will have access to functions for notifying shipments or shipment delays, while managers will be able to see statistics and analytic information about the business, in general or under specific perspectives.

The three layers described above represent the operational part of the solution. The products used for each of these layers generate lots of information that can be analyzed with OLAP tools. In addition, data mining technologies can be applied in order to optimize process executions and make predictions on system load and on the usage of resources. Integrated support for data analysis is an additional reason for buying (rather than implementing) the functionality of the three operational layers of Figure 3.

However, in many cases, such tools do not provide sophisticated OLAP or data mining capabilities. To apply these techniques, data should be first extracted and loaded into a warehouse (as shown in Figure 4) and then separately processed using commercial data analysis packages. Hence, Extract, Transfer, and Load (ETL) as well as OLAP/data mining applications are also part of several SCM solutions we have designed, particularly when large operations were involved, where the benefits of automated analysis and knowledge extraction justified the (high) license and development costs.

4. Discussion and Concluding Remarks

In this paper we have discussed the requirements for e-business applications that supports supply chain management. We have then presented an architectural solution that meets the requirements and that we have found suited for all the supply chain projects in which we have been involved.

The main advantage of the proposed solution is that it enables the reuse of existing applications and allows the evolution (or replacement) of such applications with minimal or no impact on the SCM system. This characteristic is very important since new applications supporting one or more phases of the supply chain become frequently available, and being able to quickly integrate them within the architecture can provide a significant competitive advantage. In addition, it also minimizes the impact due to changes of back-end systems imposed by company-wide policies.

Another important characteristic of the architecture is the ability of centralizing IT support while still offering the flexibility required to execute different processes for the different operational centers. Thanks to the customization functionality offered by the personalization engine and to the adaptive features provided by the automation layer, diversity can be managed with reduced efforts, and can be implemented on top of the same back-end applications.

The architecture also enables the achievement of both short and long-term goals. In fact, early benefits can be achieved by implementing the automation layer to get rid of manual labor and provide monitoring and tracking capabilities for at least a part of the supply chain. Then, automation can be progressively extended to all the supply chain and to manage the interaction with all the back-end systems. Finally, the personalization layer can be configured, in order to allow access to all (internal and external) users involved in the supply chain.

References