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Beyond Intelligent Agents:
E-Sensors for Supporting Supply Chain Collaboration and Preventing the Bullwhip Effect

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ABSTRACT

This article presents a new concept for supporting electronic collaboration, operations, and relationships among trading partners in the value chain without hindering human autonomy. Although autonomous intelligent agents, or electronic robots (e-bots), can be used to inform this endeavor, the article advocates the development of e-sensors, i.e., software based units with capabilities beyond intelligent agent's functionality. E-sensors are hardware-software capable of perceiving, reacting and learning from its interactive experience through the supply chain, rather than just searching for data and information through the network and reacting to it. E-sensors can help avoid the "bullwhip" effect. The article briefly reviews the related intelligent agent and supply chain literature and the technological gap between fields. It articulates a demand-driven, sense-and-response system for sustaining e-collaboration and e-business operations as well as monitoring products and processes. As a proof of concept, this research aimed a test solution at a single supply chain partner within one stage of the process.

Keywords: bullwhip effect; collaboration; IS operations; MIS; operations management; real-time operations; sense-and-response; supply chain management

INTRODUCTION: FROM E-BOTS TO E-SENSORS

As e-business and e-commerce has grown, so has the need to focus attention on the: (1) Electronic communications between e-partners; (2) operational transactions (e.g., sales, purchasing, communications, inventory, customer service, ordering, submitting, checking-status, and sourcing, among others); and (3) monitoring improvements in the supply (supply, demand, value) chain of products, systems, and services (Gaither & Fraizer, 2002).

Integrating continuous communication protocols and operational and supply chain management (SCM) considerations, early on in the enterprise design process, would greatly improve the successful implementation of the e-collaboration technologies in the enterprise. It is particularly important to examine the resources and systems that support the electronic communications, and relationships among partners, in the supply chain.

In addition, there is a need for obtaining (sensing) real time data for managing (anticipating, responding) throughout the supply chain. Typically companies need to synchronize orders considering type, quantity, location, and timing of the delivery in order to reduce waste in the production and delivery process. The data collection and availability provided by the e-sensing infrastructure/architecture discussed later in this article will allow for a collaborative environment, improve forecast accuracy, and increase cross-enterprise integration among partners in the supply chain.

Current supply chain information technologies (IT) allow managers to track and gather intelligence about the customers purchasing habits. In addition to point-of-sale Universal Product Code (UPC) barcode devices, the current IT infrastructure may include retail radio frequency identification (RFID) devices and electronic tagging to identify and track product flow. These technologies aid mainly in the marketing and re-supply efforts. But, how about tracking partners' behaviors throughout the chain in real time?

Artificial intelligent agents (or e-bots) can be deployed throughout the supply chain to seek data and information about competitive pricing, for instance, e-bots can search for the cheapest supplier for a given product and even compare characteristics and functionality. For this reason, the concept of an *agent* is important in both the Artificial Intelligence (AI) and the e-operations fields.

The term "intelligent agent" or "e-bot" denotes a software system that enjoys at least one of the following properties: (1) Autonomy; (2) "Social" ability; and (3) Reactivity (Wooldridge & Jennings, 1995). Normally, agents are thought to be autonomous because they are capable to operate without direct intervention of people and have some level of control over their own actions (Castelfranchi, 1995). In addition, agents may have the functionality to interact with other agents and automated systems via an agent-communication language (Genesereth & Ketchpel, 1994). This agent attribute is termed here *e-sociability* for its ability to interact with either people, or systems (software).

The next evolution of the intelligent agent concept is the development of integrated hardware/software systems that may be specifically designed to sense (perceive) and respond (act) within certain pre-defined operational constrains and factors, and respond in a real time fashion to changes (not a just-in-time fashion) occurring throughout the supply chain. These integrated hardware-software systems are termed *e-sensors,* in this article. Indeed, there is a real opportunity for process innovation and most likely organizations will need to create new business applications to put e-sensors at the centre of a process if they want to be competitive in this new supply chain environment. Aside from asset tracking, each industry will have specialized applications of e-sensors that cannot be generalized. Before getting into the e-sensors details, let us review some key supply chain management (SCM) issues relevant to this discussion.

SUPPLY CHAIN MANAGEMENT IN THE E-COLLABORATION CONTEXT

SCM is the art and science of creating and accentuating synergistic relationships among the trading partners in supply and distribution channels with the common shared objective of delivering products and services to the 'right customer' at the 'right time.' (Vakharia, 2002)

In the e-collaboration/e-business context, supply chain management (SCM) is the operations management discipline concerned with these synergistic communications, relationships, activities and operations in the competitive Internet enterprise. SCM involves studying the movement of physical materials and electronic information and communications—including transportation, logistics and information-flow management to improve operational efficiencies, effectiveness and profitability. SCM consists in the strategies and technologies for developing and integrating the operations, communications and relationships among the e-trading partners (producers, manufacturers, services providers, suppliers, sellers, wholesalers, distributors, purchasing agents, logisticians, consultants, shipping agents, deliverers, retailers, traders and customers) as well as improving their operations throughout the products' or services' chain.

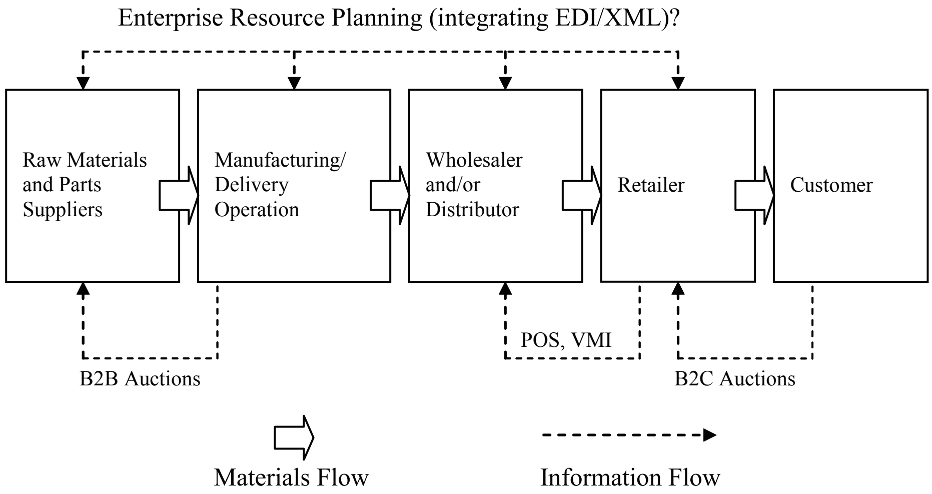
Integrated e-business SCM can enhance decision making by collecting real time information as well as assessing and analyzing data and information that facilitate collaboration among trading partners in the supply chain.

To achieve joint optimization of key SCM decisions, it is preferable that there be a free flow of all relevant information across the entire chain leading to a comprehensive analysis. (Vakharia, 2002)

As shown in Figure 1, IT systems, such as, enterprise resource planning (ERP), point of sale (POS), and vendor managed inventory (VMI) systems permit and, to some extend, automate information sharing.

The advent of reliable communication technologies has forced business partners throughout the supply chain to rethink their strategies as well as change the nature of the relationships with suppliers and customers. Companies

Figure 1. Information flow using electronic information technologies in the supply chain (after Burke & Vakharia, 2002; Vakharia, 2002)



that have made the shift have benefited from: "Reduced operating expenses, increased revenue growth, and improved customer levels," according to IBM ERP/Supply Management Division (Cross, 2000). According to the same source, the companies that have implemented supply chain improvement projects have been able to increase forecast accuracy and inventory reduction (up to 50% in overall improvement!). Some of the newer activities being implemented include: Supply-and-demand auctions, integrated collaborative product design (CAD/CAM), cross-enterprise workflow processes, demand management collaboration. In addition, some companies are even deploying SCM as an offensive tactic to gain a competitive edge (Cross, 2000).

Meixell's "Collaborative Manufacturing for Mass Customization" (2006)site, at http://www.som.gmu.edu/faculty/profiles/mmeixell/collaborative%20Planning%20&%20Mass%20Customization.pdf, provides extensive information about the use of collaborative technologies in the supply chain. The same author recently compiled a literature review; particularly, on decision support models used for the design of global supply chains (Meixell & Gargeya, 2005). This, however, does not mean that there are no strategic and technological gaps in the supply chain.

PARADIGM SHIFT: FROM 'PUSH' (SCM) TO 'PULL' (SRS)

We are not smart enough to predict the future, so we have to get better at reacting to it more quickly. (GE saying quoted by Haeckel, 1999)

E-business forces have shifted both the enterprise landscape and the competitive power from the providers of goods and information (makers, suppliers, distributors and retailers) to the purchasers of goods and information (customers). For this reason, e-businesses must collaborate electronically and sense-and-respond very quickly to the individual customer's needs and wants. So, rather than considering SCM analysis from the "supply" perspective, some researchers and practitioners advocate analyzing the market operations from the "demand" perspective: Sensing-and-responding to the consumer changing needs and wants by quickly collaborating and communicating in real-time throughout the chain. Researchers argue that e-businesses should measure and track customers' demands for products and services, rather than relying solely on demand forecasting models.

Fisher (1997) studied the root cause of poor performance in supply chain management and the need to understand the demand for products in designing a supply chain. Functional products with stable, predictable demand and long lifecycle require a supply chain with a focus almost exclusively on minimizing physical costs—a crucial goal given the price sensitivity of most functional products. In this environment, firms employ enterprise resource planning systems (ERP) to coordinate production, scheduling, and delivery of products to enable the entire supply chain to minimize costs and maximize production efficiency. The crucial flow of information is internal within the supply chain. However, the uncertain market reaction to innovation increases the risk of shortages or excess supplies for innovative products. Furthermore, high profit margins and the importance of early sales in establishing market share for new products, the short product lifecycles increasing the risk of obsolescence, and the cost of excess supplies require that innovative products have a responsive supply chain that focuses on flexibility and speed of response of the supplier. The critical decision to be made about inventory and capacity is not about minimizing costs, but where in the chain to position inventory and available production capacity in order to hedge against uncertain demand. The crucial flow of information occurs not only within the chain, but also from the market place to the chain.

While Selen and Soliman (2002) advocate a demand-driven model, Vakharia (2002) argues that push (supply) and pull (demand) concepts apply in different settings. That is, since businesses offering mature products have developed accurate demand forecasts for products with predictable lifecycles, they may rely more heavily on forecasting models. While businesses offering new products, with unpredictable short cycles, are better off operating their chains as a pull (demand) system, because it's harder to develop accurate demand forecasts for these new (or fluctuating demand) products.

The difficulty in synchronizing a supply chain to deliver the right product at the right time is caused by the distortion of information traveling upstream the supply chain. One of the most discussed phenomena in the e-operations field is called the Forrester (1958) or "bullwhip" effect which portrays the supply chain's tendency to amplify or delay product demand information throughout the chain (Sahin & Robinson, 2002). For instance, a particular supplier may receive a large order for their product and then decide to replenish the products sold. This action provides the quantity to restock the depleted products, plus some additional inventory to compensate for potential variability in demand. The overstated order and adjustments are passed throughout the supply chain causing demand amplification. At some point, the supply chain partners loose track of the actual customer demand.

Lee et al., (1997) proved that demand variability can be amplified in the supply chain as orders are passed from retailers to distributors and producers. Because most retailers do not know their demand with certainty, they have to make their decisions based on demand forecast. When it is not very accurate, the errors in the retailers forecast are passed to the supplier in the form of distorted order. They found that sharing information alone would provide cost savings and inventory reduction. Other factors that contribute to the distortion of information is over reliance on price promotion, use of outdated inventory models, lack of sharing information with partners, and inadequate forecasting methods.

An important question in supply chain research is whether the bullwhip effect can be preventable. Chen et al., (2000) quantified the bullwhip effect for a multi-stage system and found that the bullwhip effect could be reduced but not completely eliminated, by sharing demand among all parties in the supply chain. Zhao et al., (2002) also studied the impact of the bullwhip effect and concluded that sharing information increases the economical efficiency of the supply chain. In a later study, Chen (2005) found that through forecast sharing the bullwhip effect can be further reduced by eliminating the need for the supplier to guess the retailer's underlying ordering policy.

The causes of uncertainty and variability of information leading to inefficiency and waste in the supply chain can be traced to demand forecasting methods, lead-time, batch ordering processes, price fluctuation, and inflated orders. One of the most common ways to increase synchronization among partners is to provide at each stage of the supply chain with complete information on the actual customer demand. Although this sharing of information will reduce the bullwhip effect, it will not completely eliminate it (Simchi-Levy et al., 2003). Lee et al., (1997a, 2004) suggests a framework for supply chain coordination initiatives which included using electronic data interchange (EDI), internet, computer assisted ordering

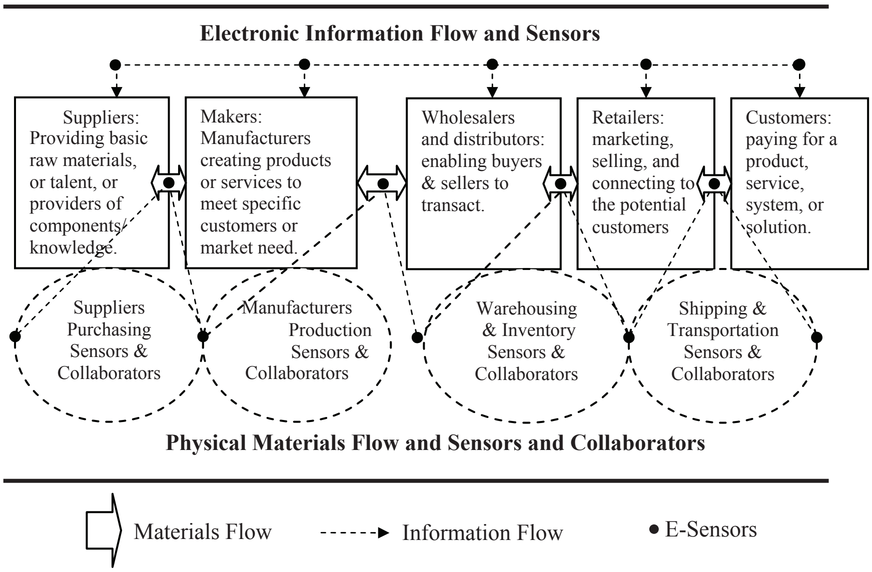
(CAO), and sharing capacity and inventory data among other initiatives. Another important way to achieve this objective is to automate collection of Point of Sale data (POS) in a central database and share with all partners in a real time e-business environment. Therefore, efficient information acquisition and sharing is the key to creating value and reducing waste in many operations. A specially designed adaptive or sense-and-response system may help provide the correct information throughout the supply chain. The proposed system would have two important system functions—maintaining timely information sharing across the supply chain and facilitating the synchronization of the entire chain.

Haeckel (1999) indicates that "unpredictable, discontinuous change is an unavoidable consequence of doing business in the information age." And, since this "intense turbulence demands fast—even instantaneous—response," businesses must manage their operations as adaptive systems. Adaptive (sense-and-response) models may help companies systematically deal with the unexpected circumtances, particularly, e-businesses need to be able to anticipate and preempt sensed problems.

SENSE-AND-RESPONSE SYSTEM (SRS) MODEL AND FRAMEWORK

Figure 2 shows the proposed SRS model and framework for integrating

Figure 2. SRS framework for integrating communication, information and materials flow and monitoring the e-business supply/demand chain



real-time electronic communications, information sharing, and materials flow updating as well as monitoring the e-supply/demand/value chain—towards a new e-collaboration paradigm.

The "e-sensors" in the diagram are computer programs (software code) and its associated data and information collection devices (hardware), and communication interfaces. These sensors are designed for e-collaboration, data capturing (sensing), and information sharing, monitoring and evaluating data (input) throughout the value chain. Ultimately, this approach would result in semi-automated analysis and action (response) when a set of inputs are determined (sensed) without hindering human autonomy. That is, the sensors will gather the data, monitor, and evaluate the exchange in information between designated servers in the e-partners (suppliers and distribution channel) networks. Sensors will adjust plans and re-allocate resources and distribution routes when changes within established parameters are indicated. In addition, sensors will signal human monitors (operations or supply chain managers) when changes are outside the established parameters. The main advantage of this approach is that sensors will be capable of assessing huge amounts of data and information quickly to respond to changes in the chain environment (supply and demand) without hindering human autonomy. Particularly, e-sensors can provide the real-time information needed to prevent the bullwhip effect.

Companies like Cisco, Dell, IBM and Wal-Mart have led the development of responsive global supply chains. These companies and a few others have discovered the advantages of monitoring changes in near real-time. By doing so, they have been able to maintain low inventories, implement lean production and manufacturing operations, and even defer building and assembly resulting in lower costs and increase responsiveness to variable customer demands. This practice can be extended to incorporate e-sensors and human collaborators throughout the value chain and perceive and react to the demands.

SYSTEM ARCHITECTURE AND IMPLEMENTATION

To develop the implementation of the entire framework outlined in Figure 2 one faces involvement of multiple supply chain partners and months, if not years, of work just to develop a reliable communication infrastructure. In order to provide an immediate viable solution to test the concepts, in this research, the authors aimed at a single supply chain partner/company at only one stage illustrated in Figure 2, to provide interfaces to the immediate preceding and the immediate succeeding stage (Kirche et al., 2005). Choosing a wholesaler/distributor (the middle box in Figure 2) as the company to automate its information flows and material flows with e-sensors and e-controls interfacing to the manufacturers and retailers, as well as to internal storage and distribution centers, we developed the overall design architecture as illustrated in Figure 3.

The selected communication architecture is based on CORBA (Common Object Request Broker Architecture), a standard solution available from multiple vendors (Bolton, 2002). CORBA is an open system middleware with high scalability and potentially can serve an unlimited number of players and virtually any number of business processes and partners in the supply chain environment. As a communication infrastructure, it enables an integrated view of the production and distribution processes for an efficient demand management. Other benefits include continuous availability, business integration, resources availability on demand, and worldwide accessibility. The architecture presented in Figure 3 gives the wholesaler/distributor direct access to the assembly lines of the manufacturers and their shipping/transportation data via the operational data server. Full communication with the retailers is available. The wholesaler/distributor company does have itself full control over their financial data server and optimization server. The detailed functions of this architecture are described in (Kirche et al., 2005).

The goal of the real time system based on this architecture is to dynamically integrate end-to-end processes across the organization (key partners, manufacturers and retailers) to respond with speed to customer changes and market requirements. The real time CORBA framework enables employees to view current process capability and load on the system and provide immediate information to customers, by enabling tuning of resources and balancing workloads to maximize production efficiency and adapt to dynamically changing environment.

Figure 3. Architecture of distributed services for the wholesaler or distributor (after Kirche et al, 2005)

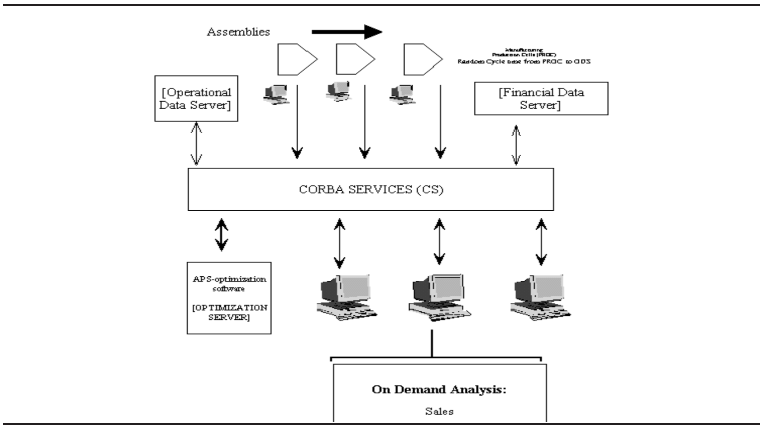
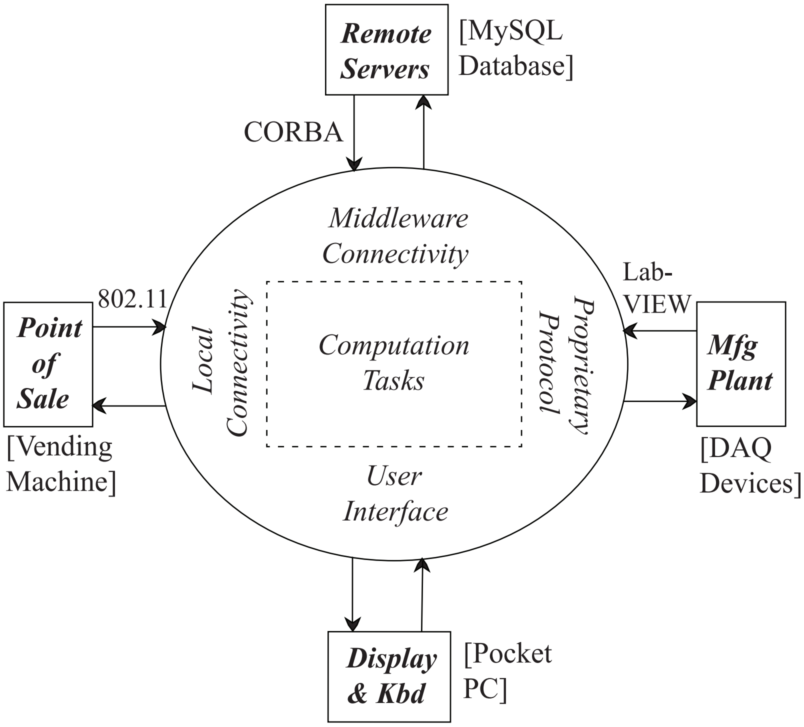


Figure 4. Context diagram of the system being implemented (DAQ stands for data acquisition and control, 802.11 stands for an IEEE Std 802.11 for wireless networks, SQL stands for standard query language)



A sample implementation of the system architecture from Figure 3 is presented in the form of a context diagram in Figure 4. To achieve the project's objective, that is, remote data access to enterprise networks with e-sensors/e-controls, we provide the capability of accessing enterprise-wide systems from a remote location or a vehicle, for both customers and employees.

The overall view of the system is as follows:

- When access to manufacturers from Figure 2 is considered, the focus can be on <u>*plant access*</u> for immediate availability of data and functions of the system; in that case, a remote *e-sensor/e-control* application using LabVIEW data acquisition software (Sokoloff, 2004) comes into play, with graphical user interface capable of interacting with remote users connected via the Internet.

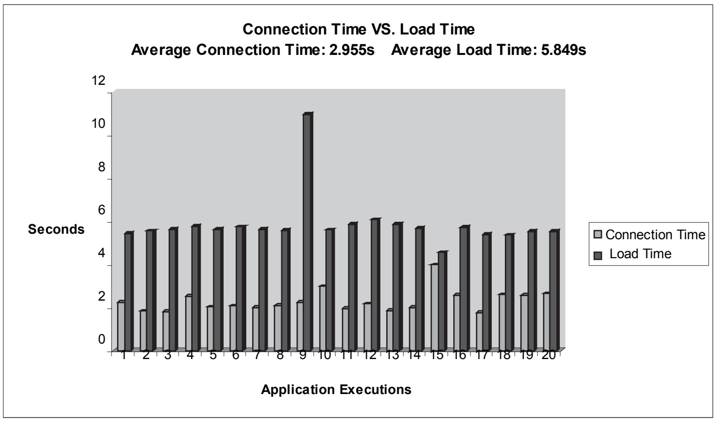
- When access to warehousing from Figure 2 is considered, the focus can be on *business integration* via a multi-purpose enterprise-wide network; in that case, a CORBA based framework is employed for a remote access to data objects identified as *e-sensors*, that can be stored on typical SQL database servers (Kirche et al., 2005).

From the network operation and connectivity perspective, e-sensors and e-controls provide business services, so they play the role of servers. Access to servers in this system is implemented via two general kinds of clients:

- When focus is on the *customer access* to obtain services, a cell phone location-aware application for business transactions has been developed, using order services as an example
- When focus is on the *employee access* to obtain services, such as conducting business on the road, a wireless PDA application for remote vending machine access has been developed, using the IEEE Std 802.11 wireless network protocol.

Several tests have been conducted to check behavior and performance of all four applications listed above and presented in Figure 4. For concision, it shows only a sample behavior of a PDA client via connectivity/performance test, in Figure 5. The graph shows how long it takes for the server to receive the connection request from the client application after the application was started. It is marked "Connection time."

Figure 5. PDA client connectivity/performance test



Another bar on the same chart shows how long the program itself took to load completely after being started (marked "Load time"). The connection graph was created to give an indication of how long, on average, one can expect for requests to be acknowledged and accepted by the server. Since all requests are handled the same way as the initial connection, this average connection time reflects sending and receiving of data to and from the client application. The load time is just a measure of performance for the application on the PDA itself. The data collected that way show the feasibility of all applications built within the SRS framework, as presented in Figure 2, for the architecture outlined in Figure 3.

CONCLUSION

This article briefly reviewed the current intelligent agent and supply chain paradigm and presented a conceptual framework for integrating e-collaboration tools in the operation and monitoring of products and services across value chain networks without hindering human autonomy. The demand-driven, sense-and-response framework model incorporates e-sensors and e-collaborators (humans using communication tools, computer software programs and its associated data-capturing hardware devices) throughout the supply chain. In practice, these e-sensors would be designed for data-capturing (sensing), monitoring and evaluating data (input) throughout the value chain, while humans collaborate and communicate in real-time, as tested in the above solution.

The implications of this new framework are that it contributes to the enhancement of the current SCM/DCM systems (such as Manugistics' demand planning system) that analyzes manufacturing, distribution and sales data against forecasted data. The addition of SRS sensors would signal human monitors (operations or supply chain managers) when changes are outside the established parameters. The main advantage of this approach is that sensors would be capable of assessing huge amounts of data and information quickly to respond to changes in the chain environment (supply and demand) without hindering human autonomy.

Ultimately, this approach would result in the semi-automated analysis and action (response) when a set of inputs are determined (sensed) without hindering human autonomy. That is, the e-sensors would gather the data and monitor and evaluate the exchange in information between designated servers in the e-partners (suppliers and distribution channel) networks. E-sensors would adjust plans and re-allocate resources and distribution routes when changes within established parameters are indicated. Particularly, the new approach will aid managers in the prevention of the bullwhip effect.

Having real time data is critical in managing supply chain efficiently. Typically companies need to synchronize orders considering type, quantity, location and timing of the delivery in order to reduce waste in the production and delivery process. The data collection and availability provided by the e-sensing infrastructure/architecture will allow for a collaborative environment, improve forecast accuracy and increase cross-enterprise integration among partners in the supply chain. E-sensors will also offer a more proactive solution to current ERP systems by giving them the ability to process in real time relevant constraints and simultaneously order the necessary material type and quantities from multiple sources.

This e-sensor concept opens additional research opportunities within the boundaries of the operations management and information technology fields, particularly in the development of new software-hardware interfaces, real-time data capturing devices and other associated technologies. Finally, it leads to future 'automated decision-making' where IT/operations managers can "embed decision-making capabilities in the normal flow of work" (Davenport and Harris, 2005).

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