A New Approach to Solve Supply Chain Management Problem by Integrating Multi-agent Technology and Constraint Network

Stanley K. Yung and Christopher C. Yang

Department of Computer Science and Information Systems
The University of Hong Kong

Abstract

Supply Chain Management is an important issue for manufacturing enterprises. Most of these manufacturing enterprises are depending on their logistic system to improve their efficiencies. However, information distortion from the raw material suppliers to the distributors can make the whole process to enormous inefficiencies. Therefore, this research aims to propose a new method to solve the bullwhip effect by integrating multi-agent technology, artificial intelligence and Internet technology.

1. Introduction

In 1995, H. L. Lee and the logistic executives of Proctor and Gamble have examined the order pattern of Pampers. The sales of the retailers are fluctuating within a small range. However, when they examined the order pattern for the distributors, they discover a greater variability on the sales. Finally, there is even a greater swing for the suppliers. This phenomenon is unreasonable because the demand of diaper is steady for the baby. The demand orders variability is amplified as they move up the supply chain and this phenomenon is named bullwhip effect by Procter and Gamble [8]. In addition to the Pampers of Procter and Gamble, Hewlett-Packard (HP) has discovered that there are some fluctuations in their supply chain of their printer [9]. Therefore, bullwhip effect is a common scenario for most of the supply chains.

It is important to ask how much does the bullwhip affect the company. By observation, there are some consequences can be identified. The warehouse has to maintain a high inventory of the goods because they do not want to lose sales when they cannot forecast demand appropriately. When the inventory is high, there will be excess capacity of the product, low utilization, lower quality of the product and high supply cost. Moreover, the information of the market value of the product will be distorted if demand pattern of the consumers is one of the major components for the company to plan their strategy. These consequences will jet up the operation cost of the company significantly.

H. L. Lee has identified four major causes of the bullwhip effect [10].

- Firstly, the demand signal processing is often based on the order history. And repeating forecast processes would automatically amplify order variability. When there is a longer replenishment lead-time, the amplification is even greater.
- Secondly, the batch ordering is one of the common practices due to the economics of transportation and high order cost.
- Thirdly, the price fluctuations will lead the buyers to make orders when the price is low. And this will cause the higher order variability.
- Finally, the shortage gaming of the supplier will cause the buyer to exaggerate their real needs in order to meet their demand. However, when the shortage crisis is over, orders will disappear suddenly. Therefore, this will amplified the demand variability.

1.1 Contribution

We have approached the bullwhip effect by integrating the multi-agent and constraint satisfactory problem techniques. The contribution of our work can be summarized as follows:

(i) Development of constraint propagation techniques for the supply chain, and
(ii) Propose multi-agent architecture with constraint satisfactory problem to reduce the bullwhip effect in the supply chain.

2. Literature Review

2.1 Related work in bullwhip effect

The early academic descriptions of the bullwhip effect are shown in many operations management. Forrester's work in 1961 was the earliest research in study supply chain [4]. He states that the information feedback loop of the supply chain system is too complex for managerial intuition alone to get better performance. He also claims that the performance can be improved if the management could understand the system as a whole and model that system with a specific dynamic simulation model. If these are true then appropriate actions can be planned and executed accordingly.

Sterman described the bullwhip effect using the beer distribution game [14]. In the beer distribution game, the participants need to simulate a supply chain consisting of a beer retailer, wholesaler, distributor and brewery. The participants cannot communicate with each other and must make order decisions based only on orders from the next downstream player. This game has been played many times by students as well as executives in firms and the result shows that exaggerated responses occur upstream in the supply chain. Sterman also describes the reason of the bullwhip effect that it is difficult to make decision in evaluating the complex feedback loops in the conjunction with time delays. In addition, most of the managers tend to order based on a current on-hand inventory level minus the backorders and they will not consider the on-order inventory. They will not perceive even more with this kind of system thinking. Sterman suggests a retraining program for the managers in order to correct those system thinking but this is very expensive.

On the other hand, some economists also recognize this phenomenon. They note that the variance of production is greater than the variance of sales. The reason behind is described as the rational actions of profit optimizing managers responding to either demand shocks (forecast the demand by the demand history of stocks) [12], stockout avoidance (prevent lost sales from shortage of stocks) [6], or production cost smoothing (optimize the cost function) [3]. However, the economists only model the causes of the phenomenon and they do not remedy the bullwhip effect.

In addition to the economists, the operational researchers are also interested in this bullwhip effect around that time. They indicate the overriding cause of the bullwhip effect is the time delays between supply chain links. In fact, many other business problems are having the same scenario as the bullwhip effect. Blackburn [2] indicates that, forecast errors can be reduced significantly when sales are increased by compressing the time delays between supply chain links.

Table 1. Framework for supply chain coordination initiatives

	Initiatives		
Causes	**Information Sharing**	**Channel Alignment**	**Operational Efficiency**
Demand Forecast Update	Understanding system dynamics Use point-of-sale (POS) data Electronic Data Interchange(EDI) Internet Computer-assisted ordering (CAO)	Vendor-managed inventory (VMI) Discount for information sharing Consumer direct	Leadtime reduction Echelon-based inventory control
Order Batching	EDI Internet Ordering	Discount for truckload assortment Delivery appointments Consolidation Logistics outsourcing	Reduction in fixed cost of ordering by EDI or electronic commerce CAO
Price Fluctuation		Continuous replenishment program (CRP) Everyday low cost (EDLC)	Everyday low price(EDLP) Actively-based costing(ABC)
Shortage Gaming	Sharing sales, capacity, and inventory data	Allocation based on past sales	

Metters [11] has come up with an optimization equation to quantify the bullwhip effect under the consideration as a periodic, time-varying, stochastic demand dynamic program with capacitated production. He divides the cost for the production policy into production costs, expected holding costs, excess demand costs and discounted future costs. However, the equation represents only one component in the supply chain links. If the supply chain network is large, then the computation of this optimization problem will be difficult. In addition to the high complexity of the equation, this optimization equation may not capture the unexpected cost, for example, the cost of producing the unqualified products or the broken goods during transportation.

After the causes of the bullwhip effect are identified, H. L. Lee also addresses the counteraction strategies. The principal is to improve the supply chain performance by coordinating information and planning along the supply chain. He [10] uses different methods to handle the different causes of the bullwhip effect. The following table has summarized the framework for supply chain coordination initiatives.

2.1.1 Propose new methodology for information sharing in supply chain management

In this framework, EDI is important in sharing information especially for the causes of demand forecasting and order batching. It can provide an effective way to record, process and disseminate the supply chain information. It can also enhance the Just-In-Time (JIT) inventory management by faster and more accurate filling of orders. In addition, the processed data can be used in management decision making. Therefore, EDI is a powerful tool in managing the supply chain in the past years.

However, there are limitations in the EDI. First, it is costly to develop and operate. Secondly, it limits the accessibility to the customer. It is only a standard that can be communicated between companies or vendors. Thirdly, EDI needs the users to fulfill rigid requirements. If one small company and one big company cannot agree at the same standard, they cannot use EDI to communicate. Fourthly, EDI cannot cover all the services needed in the supply chain, and it only automates the transaction process. In fact, it may take the companies more time to handle the data conversion from the EDI data to the standard of the value-added systems. Finally, EDI is a peer-to-peer system and it does not have a good negotiation mechanism for the companies [13].

Internet is breaking through some of the limitations by developing new technologies with less cost. Browser is one of the cheapest tools, which is powerful in visualizing the interface. In addition, agents can be built into the browser and communicate with each other through the Internet. In fact, it can model most of the processes of EDI. Therefore, the agent technologies can provide portability with different platforms that EDI cannot provide. Moreover, it can provide value-added services by embedding intelligence into the agent but EDI applications need to do conversion before and after the transaction processes. Extended Markup Language (XML) and Pull technologies allows the vendors to get comments and promote products through the Internet but EDI cannot contact the user directly. All these factors show that Internet application is the future trend of developing business systems.

Therefore, we can replace EDI by agent and Internet. In addition, more functions, which are Internet ordering, sharing sales capacity, sharing inventory data, computer assisted ordering and etc., can be integrated together in order to enhance the performance of the system. As a result, it can reduce the bullwhip effect even better than EDI.

2.2 Related work in Intelligent Agent

Generally, agent is a program that can perform a specific task without any direct human supervision. In addition, the detail descriptions of agent have been categorized into strong notion and weak notion. For the weak notion, an agent is a hardware or software-based computer system that have the properties of autonomy, social ability, reactivity, proactivity, temporal continuity, and goal orientedness. For the strong notion, an agent is a computer system that is either conceptualized or implemented using concepts that are more usually applied to human such as mobility, benevolence, rationality, adaptivity, and collaboration ability.

Hinkkanen [5] has suggested a distributed decision support system for real time supply chain management using agent technologies. He suggests that agent can be modeled as a human and accommodate as many situation as possible. Thus, the supply chain can be driven and managed by agents completely. In addition, he uses auction market model, which have resource agents and request agents to bid and ask simultaneously, to do the optimization for the resource allocation. However, this paper suggests employing EDI as the medium to exchange information between companies. Therefore, it is still a closed world to the others.

Barbuceanu and Fox [1] have integrated an agent-based system with rule-based mechanism to the supply chain industry. There is an associated probability for each rules and states. By employing the Markov Decision Process, the optimal actions can be determined to execute in order to maximize the expected accumulated rewards of the rules and states. However, due to the complexity of the rules and rule chaining, the rule-based system is difficult to adopt to the dynamic changes in the supply chain. In addition, there may be conflicts existed in the rule-based system and this conflict may affect the level of optimization. Therefore, another method should be entertained to coordination the agents in the supply chain.

2.3 Related Work in Constraint Satisfactory Problem

A constraint satisfactory problem (CSP) involves a set of variables, a domain of potential values for each variable, and a set of constraints, which specifies the acceptable combinations of values. There are many approaches to solve the CSP but we can classify these techniques into (i) problem reduction which is to remove redundant values and redundant compound labels, (ii) solution synthesis which incrementally builds a lattice, called minimal problem graph that represents the minimal problem, and (iii) searching which includes backtracking algorithm, forward checking (lookahead) algorithm, truth maintenance system, and constraint propagation. In addition to the original CSP, there is interval constraint satisfactory problem (ICSP) with the domain of variable as interval.

In a normal CSP, the solution is not the optimal solution because there is no optimization within the CSP or ICSP. Traditionally, optimization will be done after all possible solutions are propagated and select the most optimized one. Yang [15] has proposed a propagation technique that can optimize the solution during propagation and this technique can facilitate a real-time system with its parallelism.

Kalakota [7] has designed an agent-based real-time system to coordinate the supply chain and model it as a multi-commodity network flow problem (MCNFP) with side constraints. He employs the Primal (Benders-type) Decomposition approach to decompose the whole problem into a sub network problem in each time period naturally. When all the sub network problems are solved, the overall problem will be solved accordingly. However, it does not consider the transshipment between warehouses and the lead times. It will cause the bullwhip effect if the upstream produce more goods without knowing and managing the inventory at the downstream.

3. Design

In the traditional supply chain, the path between customers and the suppliers is. The longer the path is, the bigger the distortion is. Most of the enterprises have shorten their supply chain from usually five layers to three layers in order to reduce the operation redundancy. Therefore, there are only three layers, which are manufacturing plant, warehouses and customers. However, if the coordination model between those layers is not efficient, the shorter path will cause a bigger complexity in the system. As the agent technologies are growing with the performance of the Internet, it is one of the solutions for this logistic management system in a distributed and real time environment.

In this section, we will discuss

(i) the static supply chain model,
(ii) the constraints of the supply chain,
(iii) the optimization functions of the supply chain model, and
(iv) the work of agents.

3.1 The Static Supply Chain Model

We can simplify the supply chain from usually multi-commodities problem to a single commodity problem in order to have a clear evaluation of the agent performance. Let's consider a single commodity supply chain with one manufacturing plant, two warehouses, and many customers. The definitions of consistency of a constraint and satisfaction of the constraint network for the supply chain model design are as follows:

Definition 1:
A constraint, C_i (U,k,f()), is consistent if and only if $\cap_{j\in U} (\forall \mathbf{v}_j \in V_j \mid V_j = \mathbf{v}_j), (\exists \mathbf{v}_k \in V_k \mid V_k = \mathbf{v}_k)$

such that C_i(U,k) is satisfied,

where U is the set of indexes for the input variables and k is the index of the output variable for the constraint C_i, f() is the constraint function of C_i.

Definition 2:
The constraint network for the supply chain design is satisfied if and only if all of the constraints are consistent.

3.2 Constraints

Constraint Network of the Static Supply Chain

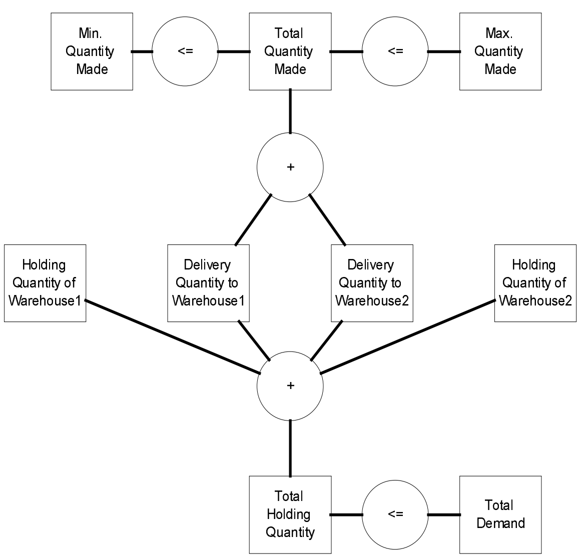

Figure 1. **Constraint Network of the Static Supply Chain**

Manufacturing plant constraints:

Minimum quantity made $\le$ quantity made $\le$ maximum quantity made

Warehouse constraints:

quantity hold of warehouse1 $\le$ capacity of warehouse1
quantity hold of warehouse2 $\le$ capacity of warehouse2
total demand $\le$ total quantity hold of warehouse1 and warehouse2

3.3 Optimization

To integrate the optimization of the total cost with propagation, the optimization problem is formulated as follow:

Minimize the following subject to the above constraints:

Manufacturing plant cost functions:
total production cost = quantity made $\times$ production cost on a single product

Warehouse cost functions:
holding cost = quantity hold $\times$ holding cost for a single product

Delivery cost functions:
(quantity from plant to warehouse1 $\times$ cost of delivery per unit) +
(quantity form plant to warehouse2 $\times$ cost of delivery per unit) +
(matrix of delivery cost from warehouse1 to customers/warehouse2) $\times$ (vector of quantity to customers) +
(matrix of delivery cost from warehouse2 to custoemrs/warehouse1) $\times$ (vector of quantity to customers)

We can solve the problem concurrently by using agents. In fact, the optimization problem may be a problem of linear programming. However, this is not efficient to do the linear programming in a single server. We can employ the parallel propagation to solve the constraint satisfaction problem above by utilizing distributed computer system. In addition, intelligent agent can be the channel to solve the problem in a distributed environment and it will enhance the real time performance of the system as well.

3.4 Work of Agents

In this paper, an agent-based system will be proposed. The major task of this system is to work as a team to solve the constraint satisfaction problem in the supply chain. In this system, it consists of the propagation agents and information agents. The propagation agent will perform the constraint propagation algorithm in a discrete time fashion. In addition to find the consistent solution, it will optimize the problem during the propagation. The information agent is responsible to show the inventory information to the manger before and after the propagation. It can also alert the manager with

the supported emergency messages. The following is the system architecture.

In the supply chain, there are many different tasks and no single agent can be designed to handle these tasks. Thus, multiple specialized agents should be employed to serve the supply chain entirely. Agents can be categorized into different agent organizations depending on some factors such as functionality difference, geographical location and implementation purposes of agents. We have categorized them into three major organizations, which are interface agents, functional agents and control agents.

3.4.1 Interface Agent

For the interface agent, each agent will communicate with each manager in the supply chain. It collects information from the managers effectively in order to trigger other functional agents to do the optimization work. On the other hand, it has the ability to alert managers to perform specific actions to deal with different problems. For example, when the functional agents has ordered the products from the upstream of the supply chain, this interface agents has to keep track of the arrival of the physical products and update the data in the inventory database.

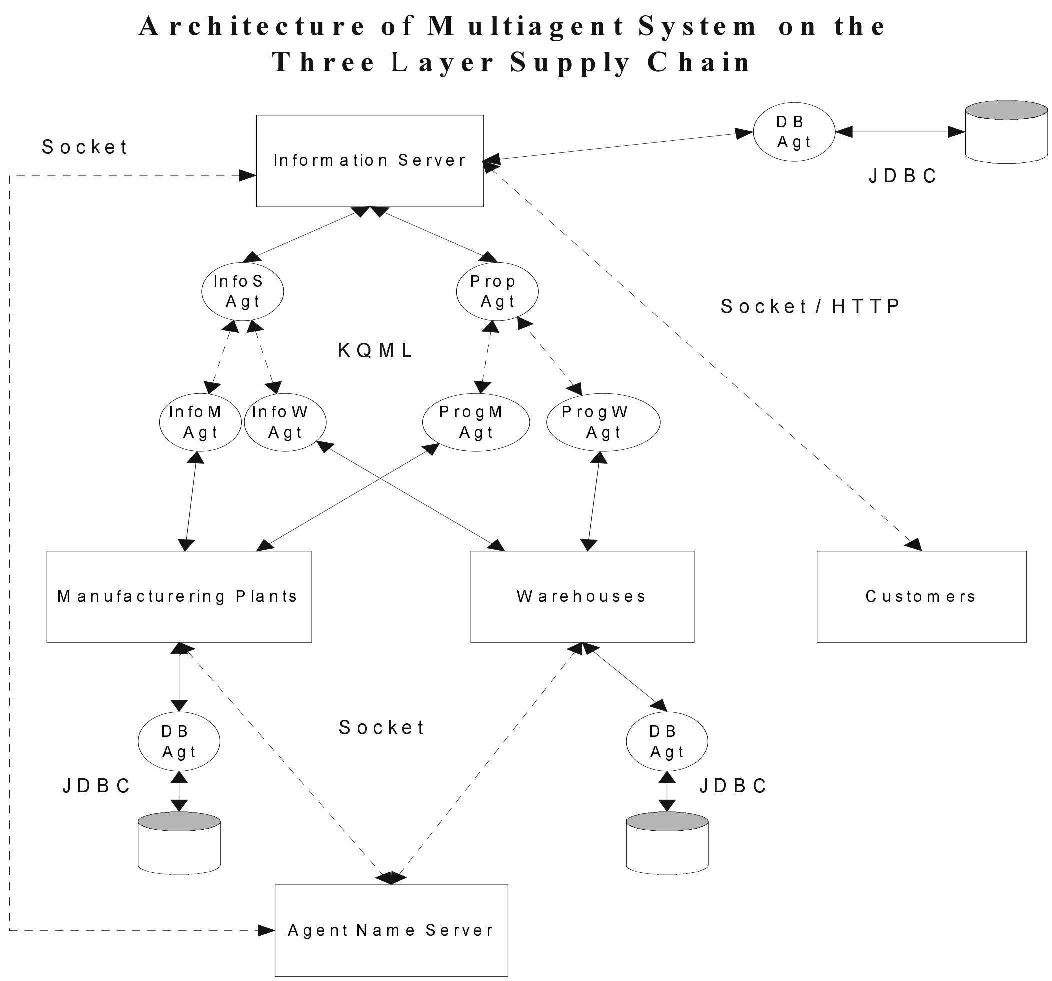

Figure 2. **Architecture of multi-agent system on the three layer supply chain**

Table 2. Major functional areas of the supply chain management system in electronic commerce

Major Functional Areas	Set of Key Activities in Each Functional Area
Manufacturing	Engineering and product configuration, production planning and cost management, production execution, and quality management
Logistics	Purchasing and ordering management, distribution, inventory, and warehousing
Financial	General Ledger, payable and receivable, billing, budgets and asset management
Marketing	Advertising, sales, order management, customer service and support, and market research and strategy
HRMS	Payroll management, time and labor management, benefits administration, and pension administration

3.4.2 Functional Agent

For the functional agent, each agent handles a specific problem and tries to find an optimal solution. Kalakota [13] has defined the major functional areas of the supply chain management system in Electronic Commerce.

According to the functions in Table 2, there are at least five agents can be identified. The Production and Cost Management Agent (PCMA), the Purchase-Order and Inventory Control Agent (POICA), the Accounting Agent (AA), the Order Management Agent (OMA) and the Labor Management Agent (LMA). In the following, the job descriptions of the agents will be discussed.

First of all, the Production and Cost Management Agent (PCMA) contains the functions for calculating the operation cost of the production. This agent should keep the consistency with the constraint satisfaction problem in the supply chain. It should be able to maintain the optimal cost by communicating with other agents within the manufacturing plant.

Secondly, the Purchasing-Ordering and Inventory Control Agent (POICA) contains the functions for calculating the inventory level in the warehouse, for example, the safety inventory level. In this case, this agent should be able to manage the inventory level with the corresponding interface agents.

Thirdly, the Accounting Agent (AA) should be able to communicate with all other agents because all the transactions in the supply chain are related to cash flows between different accounts. In addition to the bookkeeping and accounting functions, it should contain a set of variables, e.g. the exchange rates, tax rates and other financial derivatives that will affect the financial efficiency of the supply chain.

Fourthly, the Order Management Agent (OMA) contains the functions to calculate the cost in the distributing the products and controlling the ordering period. In addition to the ordering management, this agent can store the product demand and customer services statistics, and shares information to others in the supply chain.

Finally, the Labor Management Agent (LMA) contains the functions to calculate cost of the labor force. In fact, this is a sub-agent of the Production and Cost Management Agent (PCMA) because the labor cost is one of the operation cost. However, the LMA should be separated from the PCMA due to the complexity of the human resources management.

3.4.3 Control Agent

For the control agents, they will store all necessary information for the supply chain system, for example, the agent name server and the database agent. The agent name server will keep the name, address, status, functionality and ownership of each agent. This information is important for the communication between agents. The database agents are providing data conversion between proprietary databases and the supply chain system.

4. Current Status

As described in Section 3, we have developed three different types of agents in our system, interface agents, functional agents, and control agents.

Figure 3 shows the agent name server of the control agent. In the first dos prompt, an agent name server is started up waiting for new client to register. The second dos prompt shows an information server registering to the agent name server. Figure 3 also shows an interface agent, which uses a Netscape browser and allows customers to order product online. Figure 4 shows two interfaces. The first interface allows warehouse and manufacturing plant to login through a browser on the Internet. The second interface shows how a manager can retrieve information through the functional agents after login to the system.

Figure 3. Agent Name Server and interface for customers to register

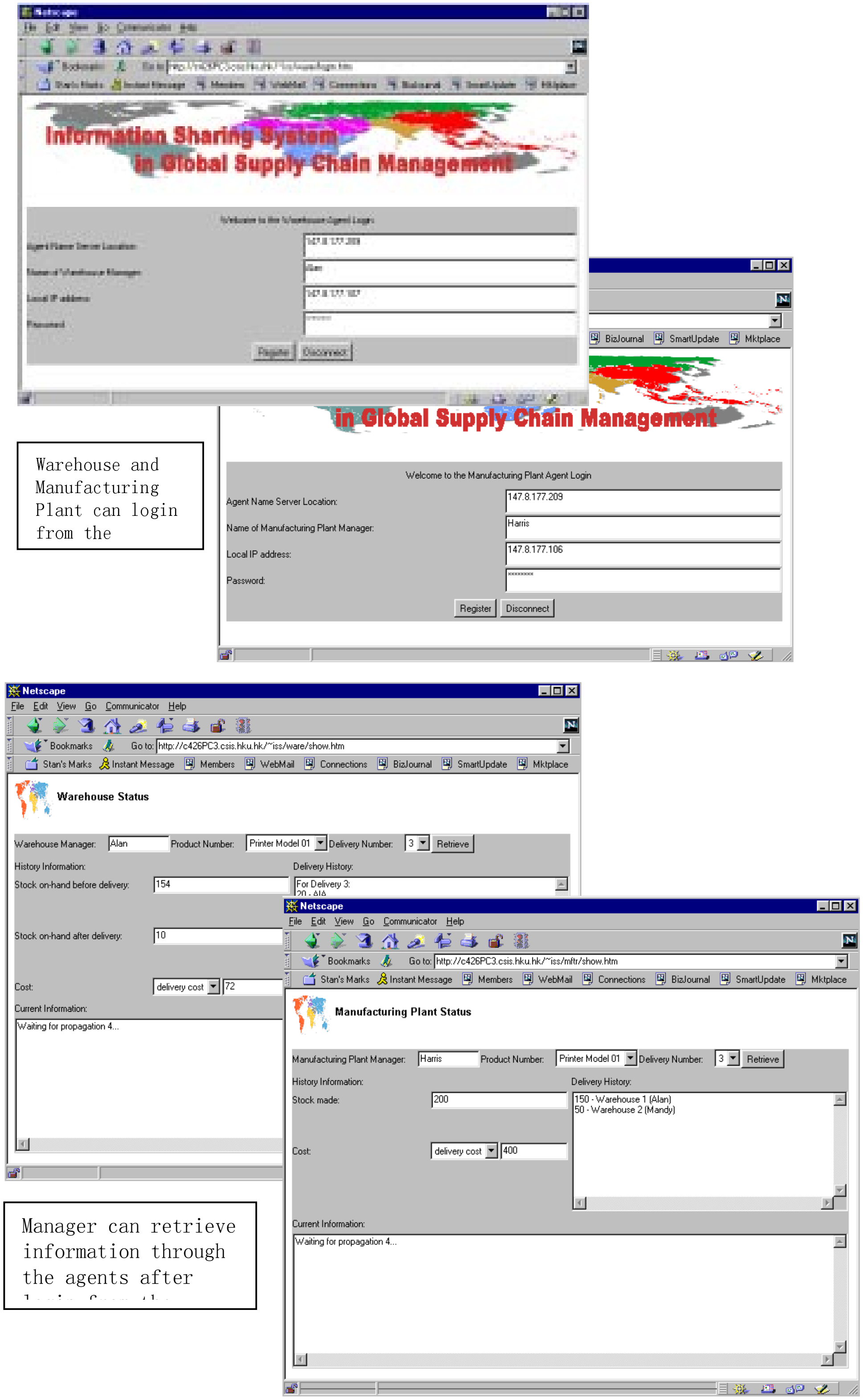

Figure 4 Interface for warehouse and manufacturing plant to login and interface for manager to use the functional agents

5. Conclusion

The bullwhip effect is the amplification the demand as it proceeds upstream in a multiple firm supply chain. And it is a well-documented problem in the area of operational management and it affects seriously throughout the supply chain. In fact, there are many researchers has proposed different kind of solutions, which are the mathematical solution using stochastic process, the rule-based multi-agent system and etc. However, most of the solutions need the firm to put more effort on setting up the devices to meet the standard or doing high complexity calculation. The purpose of this research is to investigate new technologies into the counteraction framework of bullwhip effect, development of constraint propagation techniques for the supply chain, and propose multi-agent architecture with constraint satisfactory problem to reduce the bullwhip effect in the supply chain.

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