Research on Mobile Agent System for Agile Supply Chain Management

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***Abstract*—Today's competition between companies has been turned into the competition between their supply chains. To satisfy the rapidly changing demand in global market, Supply Chain Management (SCM) must be agile and flexible enough. In agile SCM, some intelligent activities, such as negotiation, decision and collaboration, have become the "bottleneck" to improve its performance.**

This paper explored the application of Mobile Agent (MA) to deal with the intelligent activities in SCM and thereof improve its agile capability. First, a mobile agent-based agile SCM work model was presented, and then the development of mobile agent and its application in that SCM were discussed. Finally, the mobile agent system for agile SCM was described by the case of flower trading. It can deal with the trading processes intelligently and automatically.

***Index Terms*—mobile agent, multi-agent system, agile supply chain, supply chain management, intelligent**

I. INTRODUCTION

The primary objective of Supply Chain Management (SCM) is to fulfill customers' demands through the most efficient use of resources, including distribution capacity, inventory and labor [1]. In the global market, single enterprise is no longer capable to deal with the fast changing and customized demands, so the SCM-based alliance is becoming the mainstream of business organization in the 21st century. Thereof; competition in today's market is no longer of company versus company but rather the supply chain versus supply chain [1]. The performance of SCM has become the decisive factor to satisfy various demands with the lowest cost.

The performance of SCM depends on the efficiency of complicated collaboration and integrated management in the whole of supply chain. Traditional SCM is usually restricted by a rigid, linear and centralized method [2]. It is limited for effective collaboration between supply partners and the dynamic reconfiguration of supply chain, and is difficult to be adapted to dynamic environment [3]. Accually, untimely or low-quality information usually leads the poor performance in traditional SCM [4].

In recent years, information technology, such as database, application software and communication network, has been widely applied in SCM to improve its performance. It has solved the information sharing problem and some ordinary management problems. But there are still a lot of intelligent activities to be improved, such as negotiation, decision and collaboration. Especially in the dynamic business environment, agile capability and flexibility have been the new requirements in today's SCM, and those activities have become the "bottleneck" to affect performance.

This paper explores the application of Mobile Agent (MA) to deal with the intelligent activities in SCM. It first presents a mobile agent-based work model for agile supply chain management, and then discusses the development and application of mobile agents in that SCM. With the case of flower trading, this paper presents the mobile agent system for its agile SCM. It can deal with the trading processes intelligently and automatically.

This paper is organized as follows: Section 2 presents a work model for agile supply chain management. Section 3 discusses the development and application of mobile agents in that SCM. Section 4 describes the mobile agent system for agile SCM with the case of flower trading. Section 5 is the conclusion of this paper.

II. AGILE SCM WORK MODEL BASED ON MOBILE AGENTS

A supply chain is a system of organizations, people, technology, activities, information and resources involved in moving a product or service from supplier to customer [5]. Nowadays, customers become more demanding and the supply chain which involves managing a wide range of business and passing information sequentially from downstream to upstream is obviously inefficient. Therefore, companies should replace traditional linear supply chains with adaptive supply chain networks in which partners are given simultaneous, accurate information about purchase, production, demand, supply,

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sale and other operational activities [6]. An ideal supply chain should deliver right products at right cost to right customers at right time and right places.

Today, organization in a diverse range of market is facing the challenges of new product, innovation, decreasing product life, product proliferation and customers who are becoming ever more demanding [7]. Coordinately, supply chain management is facing more challenges than ever before, such as the worldwide dynamic network of supply chain, the renovation of technology. There are two board means for improving compositeness of a supply chain. One is closer integration involved and the other is better coordination of material, information and financial flow [8]. Figure 1 presents an agile supply chain management work model based on mobile agents. Mobile agents move between different layers to exchange information of supply chain and take out negotiation activities.

There are three layers in the model, and different layers are managed by different agents:

(1) Enterprise resource layer: Resource grid manages the products and services information. Enterprise resource agent in this layer is responsible for finding out the best service provider according to the requirement and resource grid information.

(2) Process operation layer: Process operation agent in this layer deals with the business process, and works out a good supply scheme.

(3) Sale service layer: Demand grid manages customers' demands. Sales service agent in this layer first accepts customers' orders, then assigns tasks to mobile agents, and confirms order contract with customers at last.

Mobile network has become common in our daily life, and 3G mobile communication network indicates a promising application. More and more people who own the mobile facilities like PDA, laptop, mobile phone, wish to utilize the commerce information at anytime and anywhere. So 3A (Anyone, Anywhere, Anytime) is a new character of the supply chain in mobile environment, which we can call "Mobile Supply Chain (MSC)". In MSC, end users can follow the order information anytime anywhere.

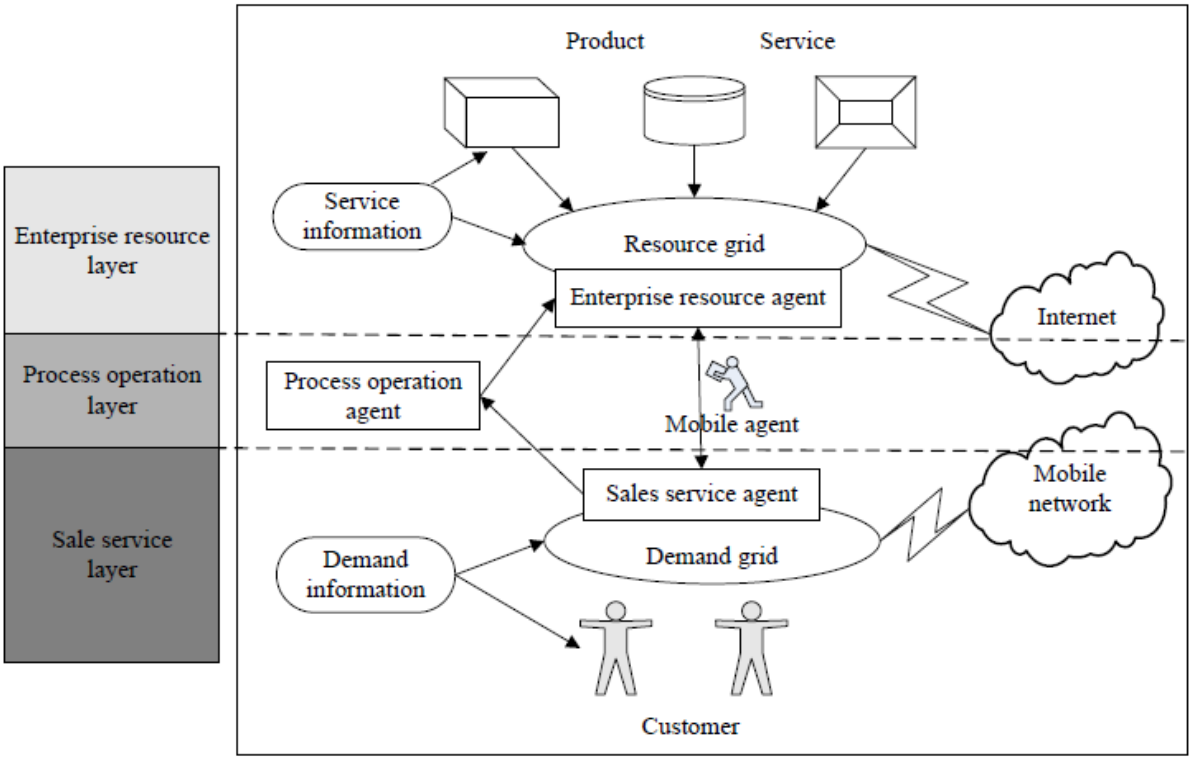

Figure 1. Agile supply chain management work model

III. DEVELOPMENT AND APPLICATION OF MOBILE AGENT IN AGILE SCM

A. Mobile Agent and Its Development

A Mobile Agent (MA) is actually the hybrid of distributed computing technology and agent technology. It is a type of software agents with the features of autonomy, social ability, learning, and the most important feature mobility [9].

A mobile agent consists of three parts: code, state and data. The code is executed when mobile agent migrates to a new platform. The state is the data execution environment of the agent, including the program counter and the execution stack. The data consists of the variables used by the agents, such as knowledge, file identifiers. And there are two primary types of migration of mobile agent: strong migration and weak migration [10]. Strong migration is more complex and is the case where an agent's execution is frozen, migration takes place and then execution is restarted from the very next instruction

[10]. Weak migration does not send the agent state, and agent execution restarts from the beginning of the code.

There are already many platforms for the development of mobile agent, such as Aglets, Ajanta, JADE, and Voyager. Due to the features of JADE, we choose it as the mobile agent development platform. JADE is a software platform that provides basic middleware-layer functionalities. It contains two parts: a platform for agent following FIPA standard, and a software package for Java agent development. A significant merit of JADE is that it implements this abstraction over a well-known object-oriented language, Java, providing a simple and friendly API [10]. Figure 2 is the reference architecture of agent platform following the FIPA standard.

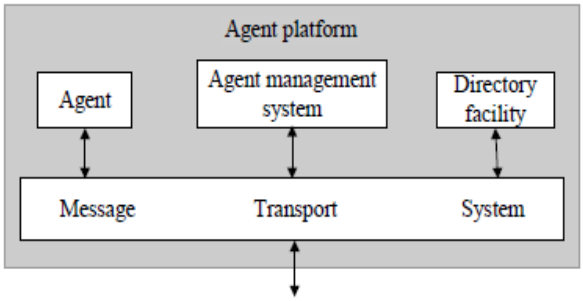

Figure 2. Architecture of agent platform following the FIPA standard

JADE platform is composed of agent containers that can be distributed over the network. Agents live in containers which are the Java process that provides the JADE run-time and all the services need for hosting and executing agents. We can consider agents as objects, but agents have some special traits: they are autonomous (i.e. they decide for themselves whether or not to perform an action on request from another agent); they are capable of a flexible behavior; and each agent of a system has its own thread of control [11].

Agent Management System (AMS) and Directory Facilitator (DF) are parts of the platform. There is only one AMS on one platform, which offers the white page service and agent lifecycle service, and maintains the directory of agent identifiers (AID) and the state of agent. DF offers the yellow page service.

B. Application of Mobile Agent in SCM

Supply Chain Management (SCM) is the management of a network of interconnected businesses involved in the ultimate provision of product and service packages required by end customers [5].

As mentioned in [12]-[14], there are some advantages when mobile agent is applied in SCM:

(1) Delegate of task: Because mobile agent is simply a more specific type of software agent a user can employ a mobile agent as representative.

(2) Code shipping versus data shipping: Instead of transferring data to client where it will be processed, filtered, and probably cause a new request (data shipping) this code can be transferred to the location of data by means of mobile agent.

(3) Mobile agent reduces the network load: Moving the mobile agent to the target server will enable mobile agents to access the resources of the server and reduce its interaction with the initiator. This helps reduce the flow of data in the network, ease the bandwidth on which the whole system relies, diminish communication delays and improve service quality.

(4) Mobile agent moves autonomously and asynchronously: The tasks can be packaged into a mobile agent that can be sent through the network. Then the connection between originator and destination machine can be disconnected. Afterward, the mobile agent is independent of the process that created it, and runs autonomously and asynchronously. The originator may connect to the destination machine to get the computation result at a later time.

(5) Agents adapt dynamically: Mobile agents can sense their execution environment and react autonomously to change activity dynamically determines its next move based on the load of servers and network, and thus helps load balancing. Additionally the intelligent routing of mobile agents also lessens the judgments that need to be made when users are browsing and searching.

(6) Mobile agent facilitates parallel processing: Mobile agents can create a cascade of clones in the network when administering parallel processing tasks, which will help increase efficiency and reduce processing time. Multiple mobile agents have the unique ability of distributing themselves among the hosts in the network to maintain the optimal configuration for solving a particular problem.

However, there are some key problems that have to be considered:

(1) Design pattern of the mobile agent: Because mobile agent itself has size, when it is sent out to fulfill the task, some information is encapsulated. After finishing the task, the result will be added to the mobile agent. Thus the size of mobile agent will increase. Considering the size of mobile agent, the size of information, the number of mobile agents roaming on the net, and the limitation of bandwidth, how to design the mobile agent?

(2) Load balance of nodes: In the supply chain, there is a possibility that a large number of mobile agents roaming on the net, and many agents arrive at the same node at the same time. How does the node agent provide services to the waiting agents efficiently to avoid dead-lock phenomenon happening?

(3) Data synchronization: The market is dynamic and changeful, when mobile agents are moving on the way to the destinations, but the information of the destinations is being changed or has been changed, how do the mobile agents sense the change in time, and how to change the moving route?

(4) Routing planning: When mobile agents are assigned to complex tasks, and at the same time they need to move to lots of destination nodes, how to make a high efficient route to finish the task in short time?

(5) Security problem: How to enforce the security to protect the sensitive information, and how to protect the hosts and agents from attacking?

There are eight kinds of agent design patterns [15]: Itinerary, Star-Shaped, Branching, Master-Slave, MoProxy, Meeting, Facilitator, and Mutual Itinerary Recording. Here, we choose the branching pattern to be considered in SCM and discuss how to solve the related problems in the following section.

On the Branching pattern, the agent receives a list of agencies to visit and clones itself according to the numbers of agencies in the itinerary. Then, all clones will visit an agency of the received list. Figure 3 shows this pattern.

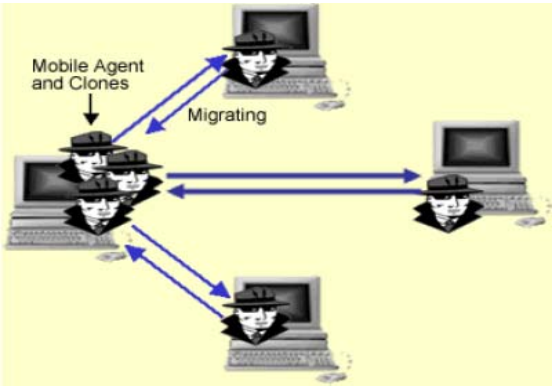

Figure 3. Branching pattern

JADE provides Agent Mobility Service which implements intra-platform mobility. The agent mobility is simply controlled via the method doMove() in the Agent class. Java serialization is used to transmit an agent instance over a network connection by recursively recording the internal member values of the agent object into a byte stream [10].

When mobile agent needs to migrate to another platform, the Inter-Platform mobility Service (IPMS) is provided by JADE. FIPA-ACL messages are used as the transportation medium and these messages are sent between the AMSs of the endpoint platforms [10].

C. Coordination in multi-agent system based on Contract Net Protocol

In multi-agent systems, one agent cannot solve the complex problem solely since it has no sufficient competence, resources or information [16][17]. Each agent needs to coordinate and cooperate with other agents to fulfill tasks for the whole system. Protocol, objectives of coordination and behavior mechanism of the agent are essential for coordination [18].Contract Net Protocol (CNP) provided by Smith and Davis is often used as coordination mechanism in a multi-agent system. Because contract net specifies the interaction between agents for fully automated competitive negotiation through the use of contracts and it allows tasks to be distributed among a group of agents.

The complexity of coordination is achieved by structuring mutually constraining entities into a whole, integration and harmonious adjustment of individual work efforts toward the accomplishment of a larger goal [19][20]. There are two types of agents in the contract net protocol, Initiator and Participant. At any time, any agent can be an Initiator, Participant or both.

There are five phases during coordination process guided by Norm-based CNP [20]:

(1) Task announcement: This phase is devoted to the task announcement. Managers prepare the announcements of the tasks and issue them to every agent.

(2) Evaluation of the task and bids based on rigid norms, which contains two steps: Step1, Task evaluation by the receivers of announcement; Step 2, Evaluation of bidders by managers.

(3) Negotiation between the manager and candidates based on flexible norms. Final agreement is achieved by mutual selection through negotiation.

(4) Contract awarding: Successful negotiation leads to a contract.

(5) Task execution.

The Norm-based CNP can improve the efficiency and effectiveness of the coordination processes in a multi-agent system. And it can improve the agile capability of supply chain management.

IV. MOBILE AGNET SYSTEM FOR AGILE SCM ON FLOWER TRADING

A. System Structure

We present a mobile agent system for agile SCM with the case of flower trading. In this trading, the participants are customer, sales, seller, supplier and logistic company.

Figure 4 is the structure of mobile agent system. There are four subsystems in it: sales agent system, seller agent system, supplier agent system, and logistics agent system. Both local information service agent and mobile agent are common modules in seller agent system, supplier agent system, and logistics agent system. Local information service agent is a non-mobile agent, which maintains local information, takes out activities at local host, and provides services to other mobile or non-mobile agents. Mobile agent is moveable, and it can migrate to remote hosts and fulfill tasks. Seller agent, supplier agent, and logistics agent are agents in each agent system.

There are four modules in sales agent system: sales service agent, agent management system, mobile agent and directory facility. Each agent needs to register in the agent management system. Customers can access services through Internet or mobile network. Sales service agent communicates with customers and provides them with the order information on behalf of sales. Mobile agent encapsulated with the order information and migrates to remote hosts to fulfill tasks. Agent management system offers the white page service and agent lifecycle service, and maintains the directory of agent identifiers (AID) as well as the state of agent. Directory facility offers the yellow page service.

During the flower trading processes, agents communicate and negotiate with each other as intelligent entities rather than just sending and receiving information as the information reporting tools. So collaboration and interoperation among agents are the essential activities to fulfill the task. Figure 5 shows the structure of an agent.

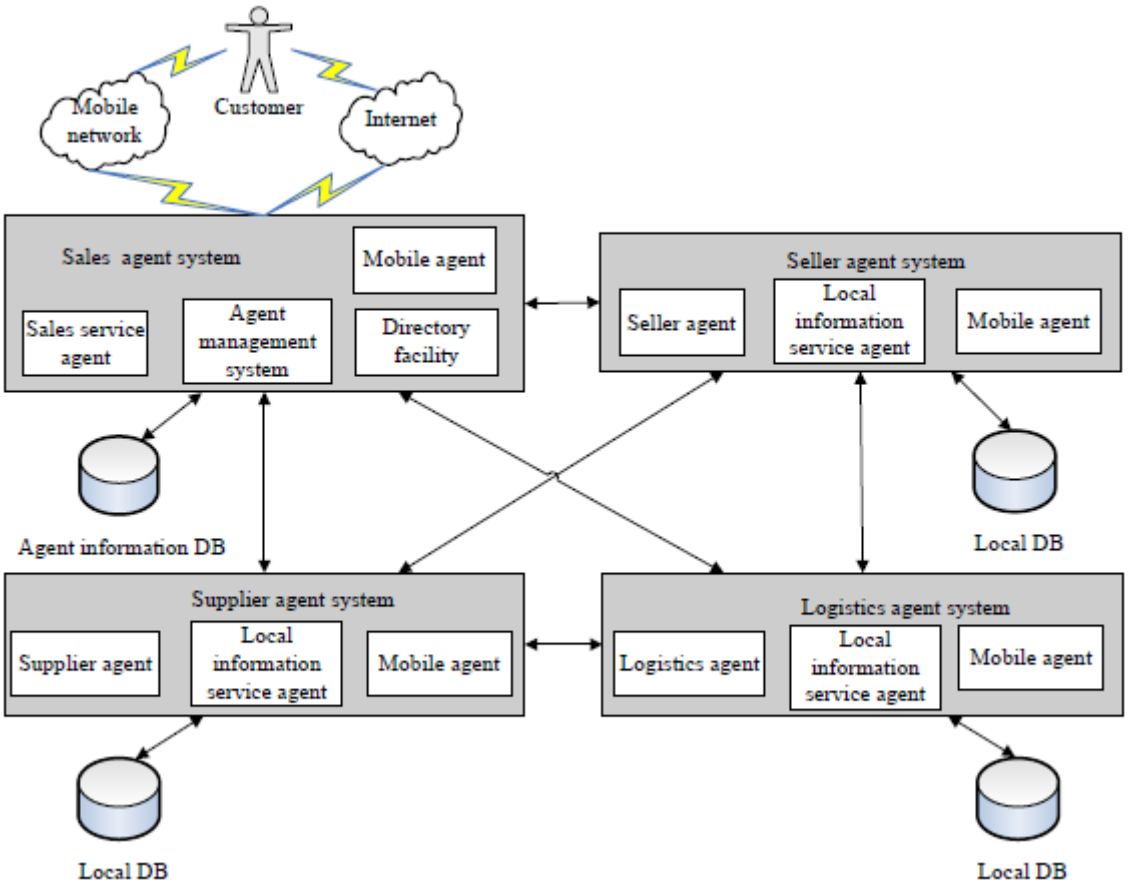

Figure 4. Structure of mobile agent system for agile SCM

We choose branching pattern as the design pattern of mobile agent, and weak migration as the migration type of mobile agent. The basic activities of mobile agent are: create, replicate, migrate, recall, suspend, wake, and destroy.

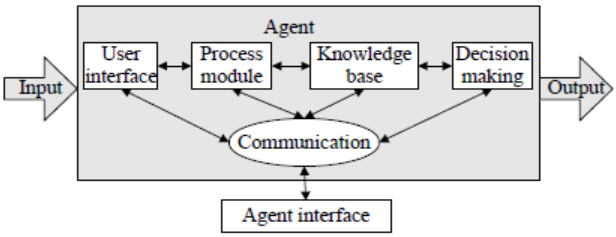

Figure 5. Structure of an agent

B. System Operation

Figure 6 is the information flow chart of MAS. However, for different partners, the original order information of customers will be changed into relevant order information, such as sales order, purchase order, delivery order.

There are some function agents in this system: BuyerAgent, SalesAgent, SellerAgent, SupplierAgent, LogisticsAgent, PurchaseAgent, QueryAgent, NegotiationAgent, ResourceAgent, OrderAgent, MemeryAgent, and ManagerAgent. OrderAgent is a mobile agent, which is encapsulated with different information in different process phases and for different partners. The system operation is described as following:

(1) All agents in MAS register in the agent management system to gain AID. Sellers, suppliers and logistics companies register their services information in the sales service system.

(2) Customers login the website by browser, and at the same time BuyerAgent starts up for a special customer. The relationship between the customer and the BuyerAgent is one-to-one. The customer can view and choose flowers he wants to buy, and input some query conditions, such as time limit of flowers, expected price, amount, and delivery date. After confirming the order information, the order is submitted to sales service agent.

(3) According to the order information, sales service agent confirms whether the required services (including required flowers, delivery and other services) exist. If the right services are available, it will form a rout list containing addresses and names of the service providers. Mobile agent migrates to destinations after obtaining the rout list. Like the branching pattern, mobile agent clones itself according to the numbers of destination. Then, all clones migrate to the destinations to query the matched information of flowers. Every mobile agent is a thread.

(4) When order agent arriving at seller agent system, QueryAgent queries local service according to the order information. The resource agent decides whether there

are enough amounts of flowers. If it's not enough, resource agent will make a purchase order to supplier agent to make supplement. If current resource can satisfy the order, the order agent will migrate to logistics agent.

(5) When the customer and the seller need to negotiate about the price, delivery date and other information, NegotiationAgent will carry out the negotiation according to the negotiation mechanism, and then transfer the result to mobile agent.

(6) Mobile agent moves back to sales service agent system with the negotiation result.

(7) Sales service agent deals with all the information brought back by mobile agents, and then transfers the final result to BuyerAgent.

(8) The customer chooses the best partner and confirms the order. Then the payment and delivery processes are ongoing until right product was received by right people at right place and right time.

Every local information service agent of seller agent system, supplier agent system, and logistics agent system has a memory agent which remembers the information of its copartners. For example, memory agent of seller agent system can remember the service information of suppliers and logistics companies. Therefore, when an order agent arrives at the seller host, the seller agent can offer the integrated information, which can also shorten the lifecycle of supply chain. But service information is often changed in the changeful global market, so memory agent should sense the changes and update its memory information in time.

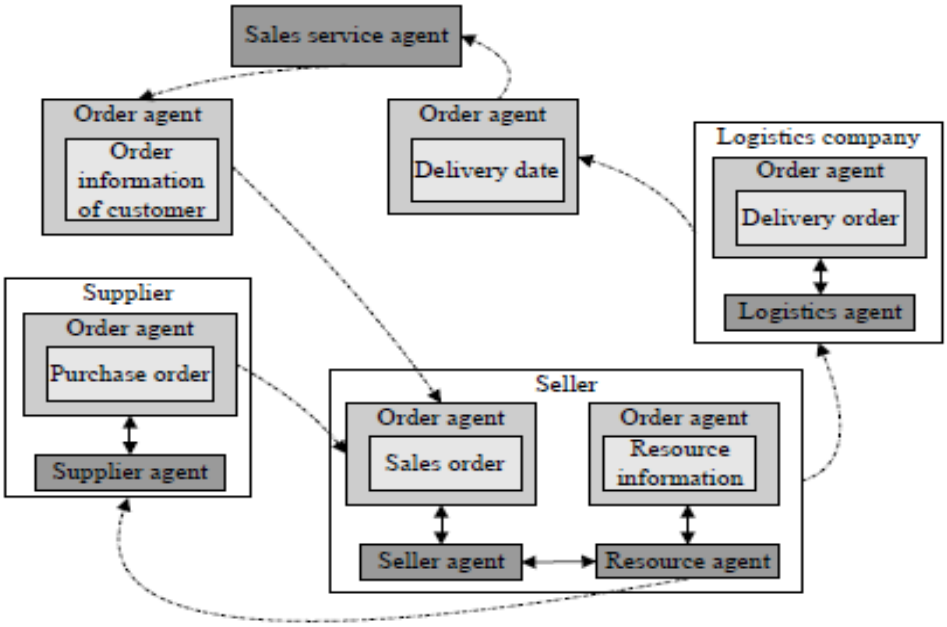

Figure 6. Information flow chart in supply chain management

C. Query and Negotiation Mechanism

Flower is a special kind of goods, because flower's lifecycle is short. When considering the query and negotiation activities, agents should obey the following mechanism:

(1) Sellers maintain their own database for all the flowers they sell. Flower's lifecycle is one of the information items (lifecycle = leaving off market date – coming into market date). And the order contains buyer's expected delivery date.

(2) Match according to the date: if the expected delivery date exceeds the flower's leaving off market date, this candidate will be discarded; if the expected delivery date between the flower' s coming into market date and leaving off market date, the relative information will be transferred to mobile agent.

(3) Some flowers are on sale, and the discount price is defined as the formula: discount price = rated price * (leaving off market date – current date) / (leaving off time – coming into market date).

(4) Match according to the price: there is rated price for every kind of flowers when sellers publish the flowers information, and there is also an item named "expected price" for customers when making orders. If the expected price is lower than flowers' discount price, trading fails. But the information of discount price will be transferred to mobile agent, in order to give the buyer another chance to make an order. If the expected price is between flowers' discount price and rated price, flowers will be sold at expected price. If there is no discount price, flowers will be sold at rated price.

Because of the special trading scenario, we need to define an ontology in order to keep agents have consistent understanding of the information. The ontology indicates the vocabulary of the symbols used in the content. Both the information sender and the receiver must ascribe the same meaning to these symbols for the communication to be effective. On JADE platform, code of ontology realizing, and code of sending and receiving information, are independent of the content language. In the Flower trading system, we define a vocabulary named

FlowerTradingVocabulary.

D. Result

Figure 7 shows flower search interface. Figure 8 shows the logistics order information and then the logistics company arranges the delivery.

Because mobile agent is applied in the SCM of flower trading, all participates can share the information efficiently. Therefore, supply chain gains a short lifecycle and high response ability to the dynamic business market.

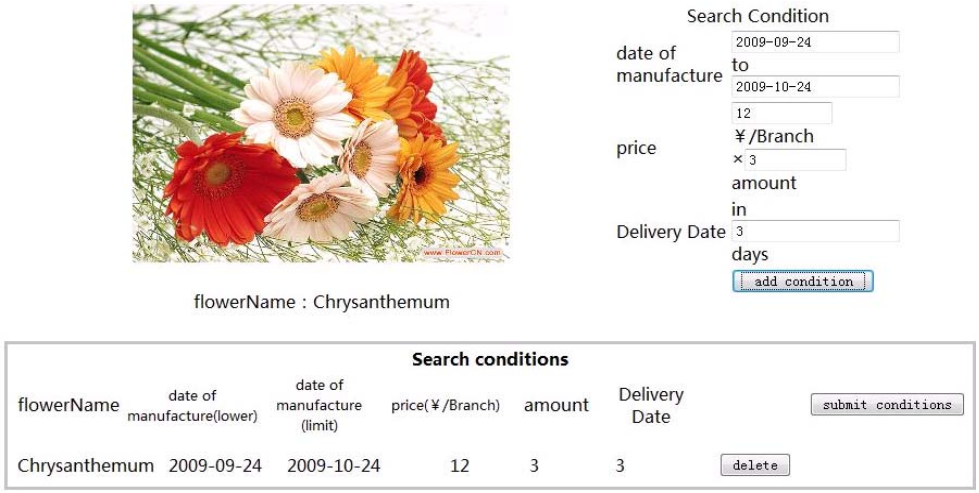

Figure 7. Search interface

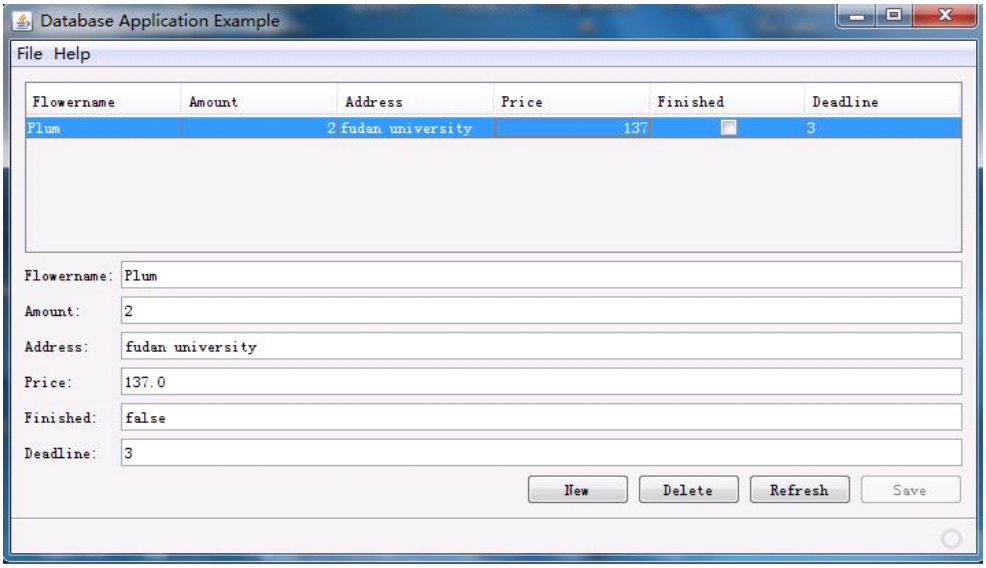

Figure 8. Information for logistics

V. CONCLUSION

In dynamic business environment, agile capability and flexibility have been the new requirements in SCM. How to improve the efficiency of intelligent activities has become the “bottleneck” in today’s agile SCM. In this paper, we explored the application of mobile agents to fulfill those activities intelligently and automatically, and presented a mobile agent system for agile SCM with the case of flower trading.

Further researches are designed to improve the agent capability with a perfect knowledge base and enforce the security of mobile agents to protect the carried sensitive information.

ACKNOLEDGMENT

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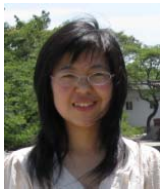

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