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The Design of Agents Oriented Collaboration in SCM

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The Design of Agents Oriented Collaboration in SCM

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Abstract

In today's global marketplace, individual firms no longer compete as independent entities but rather as integral part of supply chain links. In order to cater for the increasing demand on collaboration between supply chain partners, the technology of intelligent agent has gained increased interest in supply chain management. However fewer researches have clearly investigated the mechanism about agent applications in this area. In this paper we are to study the way how to incorporate intelligent agents into supply chain management from the perspective of agent-oriented system analysis and design. A multi-agent framework for collaborative planning, forecasting and replenishment in supply chain management is developed, in which supply chain collaboration models are composed from software components that represent types of supply chain agent, their constituent control elements, and their interaction protocols.

1. Introduction

Supply chain management system is an integrated system of suppliers, factories, warehouses, distribution centers and retailers. In today's global marketplace, individual firms no longer compete as independent entities but rather as integral part of supply chain links, and there have been increasing attentions on the collaboration in supply chain management. With the increasing research work on collaboration in supply chain management systems, the technology of intelligent agent has been widely applied in this area. A supply chain can be looked as a network of autonomous or semiautonomous business entities collectively responsible for procurement, manufacturing and distribution activities associated with one or more families of related products [1]. There have been a number of researches exploring the agent application in supply chain management and collaboration. However, the approaches involved in most applications are somewhat special, and more efforts are needed to investigate the mechanisms how to incorporate multi-agent technology into supply chain management and collaboration.

In this paper, we will investigate the mechanism how to apply the technology of intelligent agents into the collaboration in supply chain management. The agent-oriented methodology is used for the analysis and design of agent-based systems for supply chain collaboration. In this multi-agent framework, we propose a society of agent integrated with legacy supply chain systems to cater for the increasing demands on supply chain collaboration between partners and strategic adaptation to dynamic environment. Each agent carries out a specific function; they work together to perform tasks in supply chain collaboration in an autonomous and collaborative fashion. The rest of the paper is organized as the follows. Section 2 briefly reviews the relevant literature on supply chain collaboration and the application of agent technology in supply chain management. The methodology of agent oriented analysis and design is briefly introduced in section 3. Following this methodology, a multi-agent framework for supply chain collaboration is developed in section 4. Finally, some conclusions are addressed in section 5.

2. Literature review

2.1 Collaboration in SCM

Supply chain is a set of activities that span enterprise functions from ordering and receipt of a raw materials through the manufacturing of products and the distribution and delivery to the customers. In today’s competitive environment, single enterprises acting alone can no longer provide maximum value to many of today’s demanding customers. The new competitive realities are causing suppliers, manufacturers, wholesalers, and retailers alike to rethink their strategic initiatives with their supply chain partners [2]. In recent years, a number of collaborative-based initiatives are addressed for supply chain management. Vendor Managed Inventory (VMI) is probably the first trust-based business link between suppliers and customers. It is an arrangement where the supplier, not the customer, decides when and how much of the customer's stock is replenished. We can also see some similar trends such as Supplier Managed Inventory (SMI) or Joint Managed Inventor (JMI), which are different ways of looking at the same thing [3]. Today, the focus is shifting toward programs like Collaborative Planning, Forecasting and Replenishment (CPFR). CPFR is a collaborative initiative aimed at “making inventory management more efficient and cost-effective, while improving customer service, and leveraging technology to significantly improve profitability” [4]. Nowadays, CPFR has won the support of companies in the drug, grocery, general merchandise, and apparel industries.

2.2 Intelligent agents in SCM

Intelligent agents can be seen as software agents that enjoy such properties as autonomy, co-operativity, reactivity, pro-activity, and mobility. Actually, an agent is a computer system that is situated in some environment, and that is capable of autonomous action in order to meet its design objectives [5]. A generic agent has a set of goals, certain capabilities to perform actions, and some knowledge about its environment. To achieve its goals, an agent needs to reason about its environment (as well as behaviors of other agents), to generate plans and to execute these plans. In recent years, there has been considerable growth of interest in the design of a distributed, intelligent society of agents capable of dealing with complex and distributed problems, and vast amounts of information collaboratively. Software agents offer a convenient way of modeling processes that are distributed over spaces and time. They are good candidates for domains that require constant adaptation to changing environment or demands. Endowed with extended communication capabilities by the advances in network technologies, multi-agent systems are being used in an increasingly wide variety of applications involving inter-enterprise collaboration, extending the boundaries of strategic partnership to wherever the network technologies can reach.

A supply chain encompasses all activities associated with the flow and transformation of goods and services from the raw material stage, through to the end user, as well as the associated information flows. Intelligent agents with their cooperative properties are suitable candidates for collaborative activities in business organizations [6,7]. They can carry out intelligent such tasks as joint decision on orders, monitoring on product activities, and adjustment on replenishment policies, in an autonomous and collaborative way [8, 9]. The combination of supply chain process definitions with an advanced infrastructure in terms of multi-agent systems has the potential to make possible a real strategic competitive advantage for the entire supply chain and will enable new forms of business and work [10]. Nowadays there is an increasing number of researches exploring the agent application in supply chain management, in which the multi-agent paradigm is utilized for modeling and analysis of supply chains. However, the solutions involved in most applications are somewhat special, and more generic approach is needed to support agent application in supply chain management. Furthermore, more efforts are needed to clearly investigate the collaboration mechanisms and collaboration processes in supply chain management, especially at strategic level with respect to multi-agent technology.

3. Agent-oriented system analysis and design

Traditional software development techniques fail to adequately capture an agent's flexible, autonomous problem-solving behavior, the richness of an agent's interactions, and the complexity of an agent system's organizational structures, and software engineering techniques are specially tailored for the analysis and design of agent-based systems based on agent-specific concepts [11]. The agent-oriented analysis and design process is concerned with how a society of agents cooperate to realize the system level goals, and what is required of each individual agent in order to do this.

In agent-oriented system analysis, we view an organization as a collection of roles, that stand in certain relationships to one another, and that take part in systematic, institutionalized patterns of interactions with other roles. Thus, the organization model is comprised of two further models, role model and interaction model. The *roles model* identifies the key roles in the system, and can be viewed as an abstract description of an entity's expected function. Such roles are characterized by some attributes, e.g. permissions/rights and responsibilities associated with the role. The inevitable dependencies and relationships between the various roles in a multi-agent organization are central to the way in which the system functions. Such links between roles are captured and represented in the *interaction model*, which consists of a set of protocols definitions, capturing the recurring patterns of inter-role interaction.

The design process involves generating three models followed. The *agent model* aggregate roles into agent types, and refine to form an agent type hierarchy, as well as document the instances of each agent type using instance annotations. The *services model* identifies the main services that will be associated with each agent type. For each service that may be performed by an agent, we can document its properties, such as inputs, outputs, pre-conditions, and post-conditions. The *acquaintance model* documents the acquaintances for each agent type; it defines the communication links that exist between agent types.

4. Agent-oriented collaboration in SCM

Based on the above methodology of agent-oriented analysis and design, we will investigate the mechanism how to apply the technology of intelligent agent into the collaboration of supply chain management. A multi-agent framework for collaborative planning, forecasting and replenishment in supply chain management is to be developed, in which supply chain collaboration models are composed from software components that represent types of supply chain agent, their constituent control elements, and their interaction protocols.

4.1 Domain analysis

In this paper, we focus on collaborative planning, forecasting and replenishment in supply chain management. With such collaboration, a customer sends data about sale activities and inventory status to a supplier, and the supplier then uses the data to generate replenishment forecast that will be shared with the customer before it is executed. The kind of collaboration between suppliers and customers can be applied in different kinds of partnerships, such as component suppliers and product manufacturers, manufacturers and retailers (or distributors), distributors and retailers. For purpose of simplifying the discussion, we focus on the collaboration between manufacturers and retailers.

With the emergency of new telecommunications and computer technology, the way products are bought and distributed is dramatically affected. The collaboration between manufacturers and retailers can be web-based, EDI based or through other network technology, as shown in Figure 1. According to related issues about collaborative planning, forecasting and replenishment [3], the basic transactions in such collaboration process are outlined in the Figure 2. ***Collaboration Planning,*** the first step for collaboration, is to make a collaboration plan, which may contain replenishment policy (e.g. inventory levels, fill rates), monitoring policy (e.g. critical inventory, shipment delay), performance measures (e.g. forecast accuracy rate, on-time delivery), communication process, and so on. ***Product Activity Reporting*** is the backbone of collaborative supply chain management, in which the manufacturer's sale and inventory information is typically sent to the manufacturer on a scheduled basis. Based on the report of product activities, the manufacturer may perform ***replenishment forecasting*** and create order suggestions if necessary. The retailer can review the order suggestions and then determines if the order suggestions are proper or need modifications. Subsequently, an order may be generated based on such ***joint decision*** from both sides.

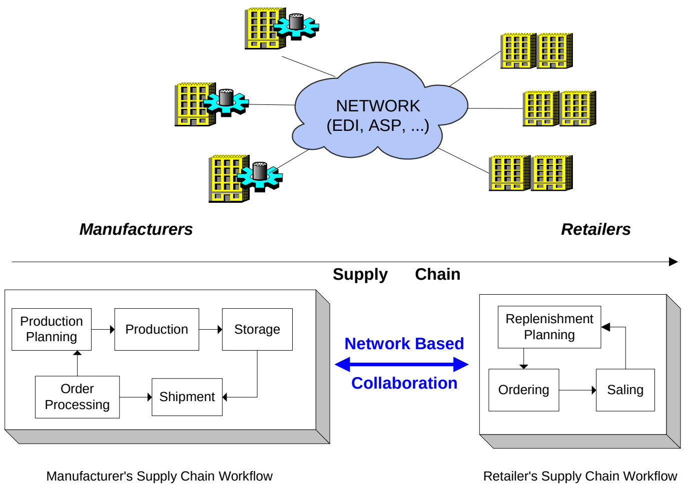

Figure 1. Network-based Collaboration in Supply Chain

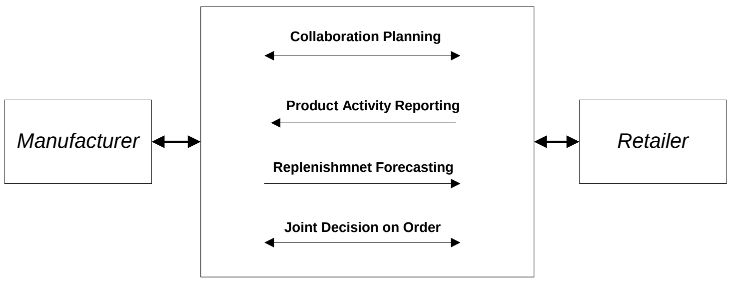

Figure 2: Transactions in the Collaboration Process

After an order is generated based on the consensus from both sides, the manufacturer will inform the retailer what product to expect from him. There are several kinds of message being used for this transaction. The *Validated Order* used as purchase order acknowledgment contains the product numbers and quantities ordered on the retailer's behalf. Then, the manufacturer picks and ships the order and transfers a *Shipment Notice* to tell the retailer exactly what is being sent and when it is shipping. When the shipment is received, the retailer transfers a *Receipt Advice* to tell the manufacturer exactly what was received. The manufacturer can then match this to his purchase order to determine any potential problems and send out an *Invoice* to the retailer for payment.

4.2 Agent hierarchy

Moving from the above analysis on supply chain collaboration, we design the agent model and present it as agent hierarchy in Figure 3. We classify these agent roles into three classes, task agent, user agent and information agent; each class contains several sub-classes as the follows.

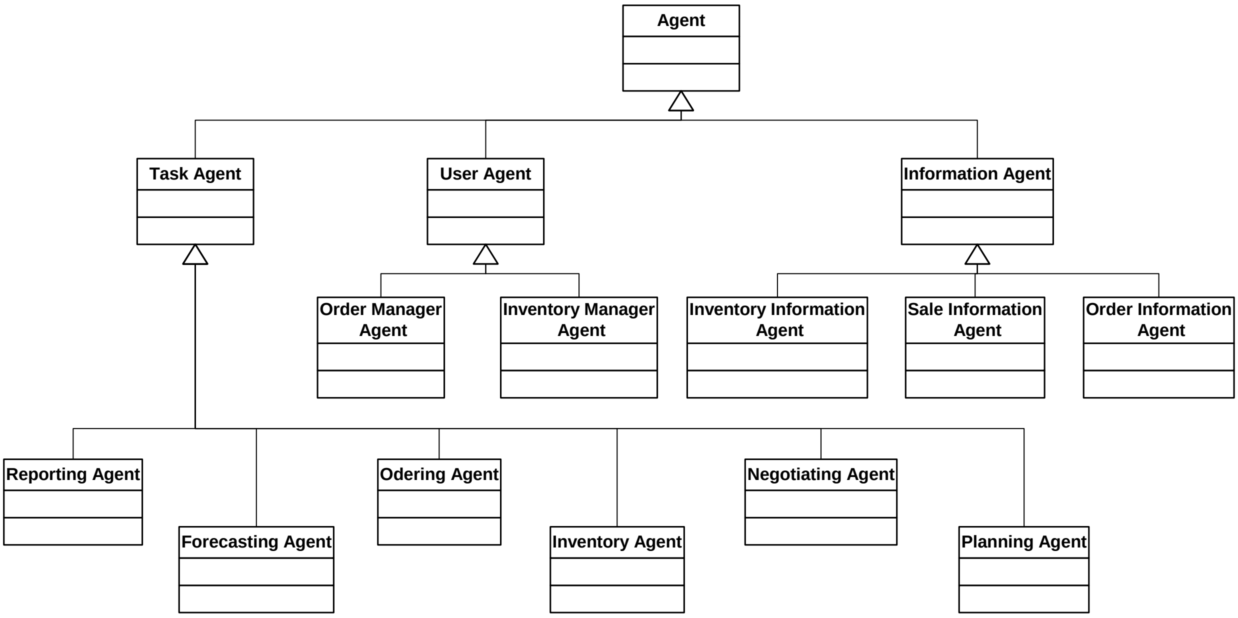

Figure 3. Agent hierarchy for supply chain collaboration

4.2.1 Task agent

Several kinds of task agent are proposed to carry out business operations involved in the supply chain collaboration.

- The **Reporting Agent** is to send the retailer's sale history file and current product activity reports to the Forecasting Agent of the manufacturer on a scheduled basis.
- The **Forecasting Agent** is responsible for conducting data analysis on retailer's sale history and current product activity reports to generate replenishment forecast or order suggestion. The order suggestion is made on the calculation of reorder point according to the replenishment agreement between partners.
- Once receiving an order suggestion from the Forecasting Agent, the **Ordering Agent** will ask the order manager for check and modification, and then send it to the Inventory Agent for review and confirmation. If the order quantity is over pre-defined limitation, the Inventory Agent will ask the inventory manager for validation. After validation, the order is sent back to the manufacturer side for confirmation and execution. Subsequently, the Ordering Agent will start to monitor the process and progress of this order.
- If the order suggestion is not accepted by the retailer side, a **Negotiating Agent** can be activated to guide both sides to make an online discussion in order to achieve some consensus for the joint decision. Also, the manager of both sides can start this agent for negotiation on other issues, e.g. adjustment on collaboration plan.
- The **Inventory Agent** is charged with the inventory management for the retailer. Besides reviewing order suggestion from the manufacturer, this agent will keep track on inventory status, raw materials/components shipment and receiving. For example, if one kind of raw material in the inventory is detected in a critical status, the Inventory Agent will ask the Forecasting Agent to generate a replenishment order suggestion in a real time fashion.
- The **Planning Agent** is proposed to make collaboration plans for supply chain partners. It can also make suggestions about collaboration adjustment based on its planning knowledge and analysis on supply chain performance, and send it to managers for reference. When the managers decide to adjust the plan, the Planning Agent can help distribute the content of the adjustment to related agents. For example, the modified replenishment policy will be sent to the Forecasting Agent and Inventory Agent to adjust their activities.

4.2.2 User agent

User agents act as effective bridges between the users and the system in order to make the human-computer interface more intuitive. There are two kinds of user agent in this system; each represents a type of user who interacts with the system. The **Order Manager Agent** enables the order manager of the manufacturer to read replenishment forecast, check order suggestions, validate orders, control progress of orders, and negotiate with the retailer through the help of several task agents. The **Inventory Manager Agent** enables the inventory manager of the retailer to review and validate order suggestions, check inventory status, negotiate with partners, and etc.

4.2.3 Information agent

Information agents are responsible for operations on multiple, heterogeneous and distributed information sources with a view to controlling resources of business processes. Although there is no need for centralized storage of all knowledge regarding supply chain collaboration, there could be consistent knowledge repositories that maintain and integrate all information related to collaboration tasks. In this way, the various agents that make up the system can exchange knowledge regarding entities involved and deal with supply chain management in a collaborative manner. In our system there are three types of information agent, **Order Information Agent**, **Inventory Information Agent**, and **Sale Information Agent**, each responsible for access to the corresponding information resource. Moreover, such information resources may form an important base for agents' collaboration in supply chain.

4.3 Agent architecture

Based on the above description of various agents in the system, we are to design the internal structure and operations of each agent as its service model. Generally, the design of agent architecture considers an agent knowledge base, its operational facility and its external interface. Knowledge is required by each agent to perform its internal and external activities. It consists of resource status information, rules for particular tasks, information about other agents, and so on. The operational facility can execute different functions and provide collaboration with other agents. The external interface envelops an agent and provides access to it via a well-defined interface. It is also the primary conduit for communication between agents.

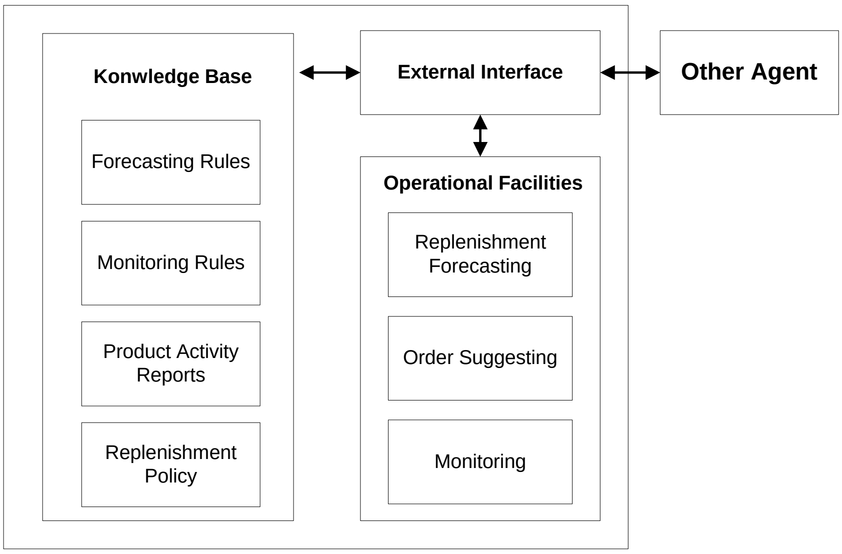

Figure 4. Architecture of a Forecasting Agent

In the interests of brevity, we only present the architecture of the Forecasting Agent as an example. As presented in Figure 4, the **external interface** enables the Forecasting Agent to communicate with outside, i.e. receiving product activity reports from the Reporting Agent and sending order suggestions to the Ordering Agent. The **operational facility** is represented by a set of functions followed. The replenishment forecasting function is responsible for conducting data analysis on current product activity reports as well as retailer's sale history to generate replenishment forecast. The order suggesting function works based on the calculation of reorder point specified in the replenishment policy, e.g. stock level, fill rate, and etc. The monitoring function is proposed to keep track on product or sale activities to detect unexpected events happened in the retailer side. **Knowledge** is required by the Forecasting Agent to perform its internal and external activities. There are several types of knowledge for this agent to perform various tasks, including forecasting rules, monitoring rules, product activity reports, and so on. Furthermore, the Forecasting Agent can access the sale information through the Sale Information Agent to assist its forecasting activity.

4.4 Agent communication and collaboration

Interaction among agents, an important aspect on research of multi-agent system, is set up on the base of lower-level data communication that takes charge of transferring data without semantic from end to end. Unlike data communication, interaction among agents is mainly control information with semantic and knowledge. KQML (Knowledge Query and Manipulation Language) is a language that is designed to support interaction among agents [12]. Message transferring with respect to information flows models the exchange of information and contributes to the collaborating processes between supply chain agents. For instance, after a purchase order is created based on the joint decision between the manufacturer and the retailer, several types of message may be transferred between the two sides, such as "validated order", "shipment notice", "receipt advice" and "invoice". All the messages are structured documents based on KQML language, and can be dealt with by each agent according to the event selection mechanism that is subject to some control rules such as first in first out (FIFO).

Our collaborative multi-agent environment is to provide the application independent framework to meet the infrastructure needs of everyone involved in supply chain collaboration. With the multi-agent environment, collaboration goes beyond the simple, serial exchange of information between varied disciplines or domains. It ensures that knowledge can be shared and used at the moments when it can best impact the work. The interaction and collaborations among agents in our system are described in Figure 5.

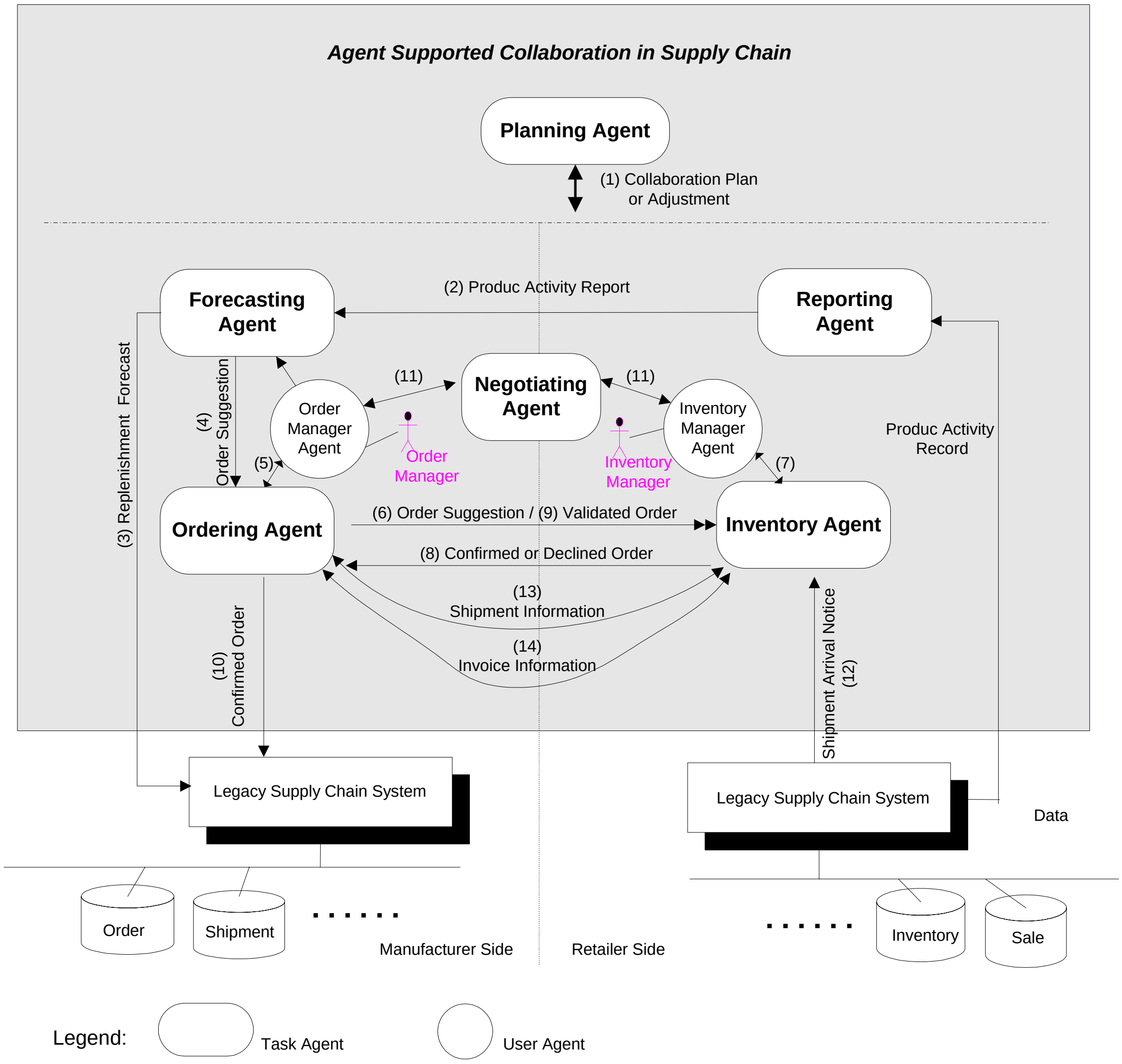

Figure 5. Agent interaction in supply chain collaboration

As shown in Figure 5, the first step for supply chain collaboration is to make a collaboration plan between partners, which may include replenishment policy, communication process, monitoring policy, performance measures, and etc. The managers can submit the collaboration plan to the Planning Agent and let it distribute the plan to related agents to initiate their activities (1). The Reporting Agent sends current product activity reports to the manufacturer on a scheduled basis (2). Then, the Forecasting Agent conducts data analysis on these reports and generates replenishment forecast (3) or order suggestions (4). After receiving an order suggestion from the Forecasting Agent, the Ordering Agent will ask the order manager to check or modify this suggestion (5) and send it to the Inventory Agent for automatic validation (6). If the order quantity is over pre-defined limitation, the Inventory Agent will ask the inventory manager for check and modification (7). After such process, the order is sent back to the manufacturer side (8) for confirmation (9) and execution (10). If the order suggestion is not accepted by the retailer side, a Negotiating Agent can be started to facilitate both sides to make a discussion for some consensus if possible (11). When the products are to be delivered to the retailer (12), the Ordering Agent will transfer a shipment notice to the Inventory Agent (13). Then, the Inventory Agent will check the matching of the product order and the shipment notice, and send receipt advice for payment while receiving the expected products (14).

5 Conclusions

In this paper, we applied the methodology of agent-oriented analysis and design to the system development of supply chain collaboration. Based on the analysis on supply chain collaboration paradigm, a multi-agent system framework is developed, in which various types of agents are proposed with their internal services and external interactions to perform collaborative activities in supply chain management. The key concepts in this methodology are agent roles, which have associated with them responsibilities, permissions, and can interact with one another in certain ways specified in the protocols of the respective roles. We believe this work is not only of pragmatic value for supply chain collaboration applications, but also assists a precise understanding of some concepts and terms in agent-oriented system development.

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