Multi-agent Collaborative Mechanism and its Application in E-commerce SCM

Minru Yan

Fuzhou University, Fuzhou 350116, Fujian, China

Abstract
Supply Chain Management (SCM) is a kind of management thought and method to enhance enterprise competitiveness widely valued by international academia and business circles at present. Agent has the characteristics of autonomy, interaction, initiative and reactiveness, which is more suitable for developing the SCM system than traditional software methods. On the basis of the research on the conceptual framework and operational reference model of SCM, four steps to construct SCM system model was proposed: the analysis of entities in SCM; the confirmation of processing flow; the design of business process Agent and business process unit framework; and the proposal of multi-agent SCM system model and task-based MAS model. In this paper, with collaborative SCM system as the research object, the supply chain was collaborated by using game theory and multi-agent collaborative thought, and the collaborative supply chain system was designed by adopting data warehouse and multi-agent technology, collaborative SCM system based on multi-agent was put forward. This enables personnel in the related nodes of the supply chain to obtain, store, share and respond to market information data conveniently and quickly and has practical guidance for the realistic collaborative SCM.
Key words: MUTI-AGENT, COLLABORATIVE, GAME THEORY, SCM

1. Introduction

1.1 The Conceptual Framework of Supply Chain

Supply chain (SC) is a network consisting of suppliers, producers, warehouses, logistics, channels, retailers and customers, who gather together through the activities of acquisition, transportation, produce of raw materials which will finally be delivered to the customers [1]. Collaborative commerce further expands the supply chain and gradually turns the enterprises' operating strategy simply from product-centered to the commerce corpus (enterprise) and the coordination and integration of the whole process of commercial activity under network environment. It involves the collaborative operation between the whole supply chain and the related links, brings change to the enterprises' business model and operation and realizes win-win cooperation between enterprises and partners [2]. Collaborative commerce platform and related technologies integrate all the enterprises' apps and data to an information management platform, and provide them to employees, customers and partners of the enterprises with a unified interface, users can access to personalized information needed in the unified, integrated framework, such as enterprise business flows, customer relations and so forth [3]. Assuming that the enterprises in the supply chain are linked through the collaborative commerce platform and the related information systems (such as EDI or E – commerce, etc.), a business flow in supply chain starts with the customer's order request, customers can learn the enterprise's products catalogue(or product configuration table) through retailers [4]. After customers determine the required products, an order is signed and submitted to the retailers, and the retailers contact with the enterprise according to the order products; if the enterprise stock fails to meet the needs, get ready to produce the products listed in the order, and meanwhile contact with first and second level suppliers to get spare parts; and the suppliers contact with raw material suppliers to purchase materials for production; in the entire business flow, logistics enterprises should provide logistics channels [5]. A typical supply chain network is shown in Fig.1.

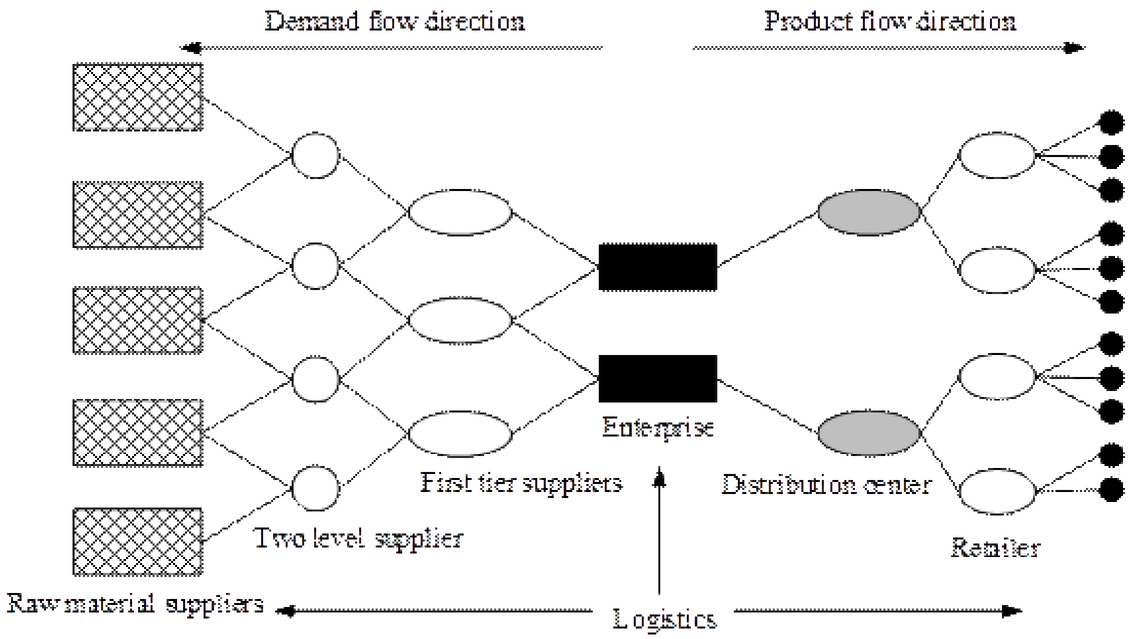

Figure 1. Supply chain network

1.2 SCM Model

Supply Chain Council (SCC) proposed a supply chain operation reference model (SCOR, as shown in Fig.2) based on "6R" goals in 2007 [6]. The so-called "6R" goals refer to the process to deliver the right product of right quantity, quality and status to the right destination at the right time, and achieve the cost minimization. Four strict operational processes [7], Source, Make, Deliver and Plan, were defined; in addition, the architecture of SCOR model was put forward [8].

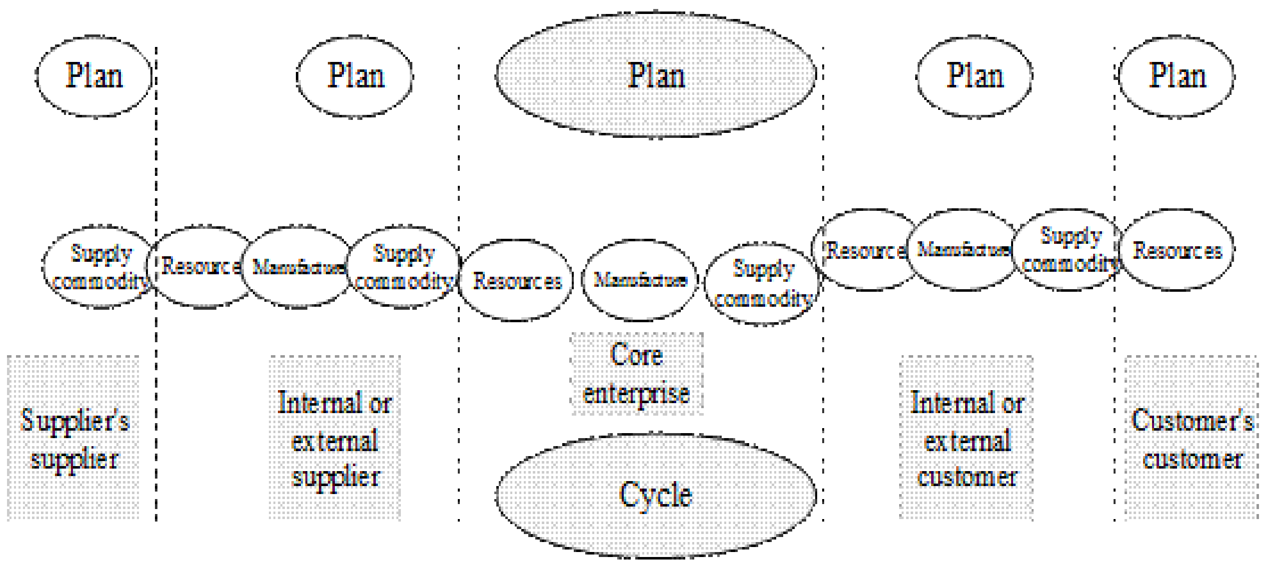

Figure 2. SCOR model

SCOR has become an actual industry standard. In fact, SCOR has been mainly applied in SCM [9], which provides a complete definition for four elements of supply chain, plan, source, make and deliver respectively [10]. It defines a complete supply chain framework tactically and strategically [11]. But SCOR model cannot substitute for the implementation of specific supply chain, which is only regarded as the theoretical basis of multi-agent supply chain model [12]. The relationship of the four elements is shown in Fig. 3.

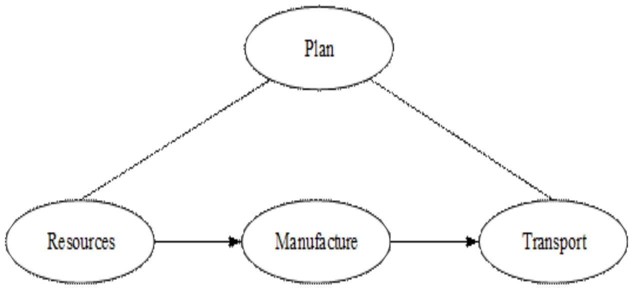

Figure 3. Supply chain four elements

1.3 The Analysis of Enterprise Level SCM System

Due to space constraints, we mainly introduce how the producers play game with the suppliers:

Assuming that there are enterprise producer M and supplier S in the supply chain, their respective demand function meet the following conditions:

$$P_M = a - bQ_M$$

$$F_M = (P_M - C_M - P_S)Q_M$$

$$F_S = (P_S - C_S)Q_M \tag{1}$$

Among them, P_M represents the product's market price, Q_M the producer's decision variable, namely the order quantity, F_M the producer's profit, C_M the producer's production cost, F_S the supplier's profit, P_S the supplier's decision variable, namely the price of product supplies, and C_S the supplier's supply cost.

$$F = F_M + F_S = (P_M - C_M - P_S)Q_M + (P_S - C_S)Q_M = (a - bQ_M - C_M - C_S)Q_M$$

So the gross profit is

$$F = F_M + F_S = (P_M - C_M - P_S)Q_M + (P_S - C_S)Q_M = (a - bQ_M - C_M - C_S)Q_M$$

In consideration of the maximization of the supply chain's overall interests, the supplier and the producer should fix the price jointly, then take the derivative of F:

$$\frac{dF}{dQ} = a - bQ_M - C_M - C_S - bQ_M = 0 \tag{2}$$

We get:

$$Q_M = \frac{a - C_M - C_S}{2b} \tag{3}$$

At this time, the overall maximum profit is:

$$F = \frac{(a - C_M - C_S)^2}{4b} \tag{4}$$

If both parties can cooperate with each other and set the max order quantity as $Q_M = \frac{a - C_M - C_S}{2b}$, the whole goal can be maximized [13]. It is found through the analysis that the interest at this time is greater than the sum of the interests of both parties in non-collaborative case, which shows that the producer and supplier can fully maximize the overall interests through collaboration. In this way, their mutual interests will naturally realize the maximum.

2. MAS-based SCM System Model

The supply chain models herein emphasize the information sharing and the cooperation among up stream and downstream firms [14], and make the corresponding decision according to the different information. The entire supply chain is of a three-tier structure, namely the supplier, the producer and the retailer, beyond that, there is transporters responsible for the connection among different layers. This supply chain is oriented by orders driving the operation of the whole supply chain. Retailers A, B, C are responsible for the selling of product X, adopting the quantitative order as the stock strategy, and adjusting the stock according to sale forecasting to ensure a safety stock; producers are in charge of making product X, formulating production plan according to sale forecasting, adopting the quantitative order as the stock strategy, and adjusting the stock according to the proportion of raw materials in production plan to ensure a safety stock; and suppliers A,B, C are responsible for providing three kinds of raw materials required by the production of X to the producers respectively; transporters are in charge of assisting the suppliers A, B, C and producers in replenishment from downstream firms. The delivery time of goods has certain randomness, for instance, the probability is 10% for two-day delivery time, 80% for three days and 10% for four days. The specific supply chain model is shown in Fig. 4.

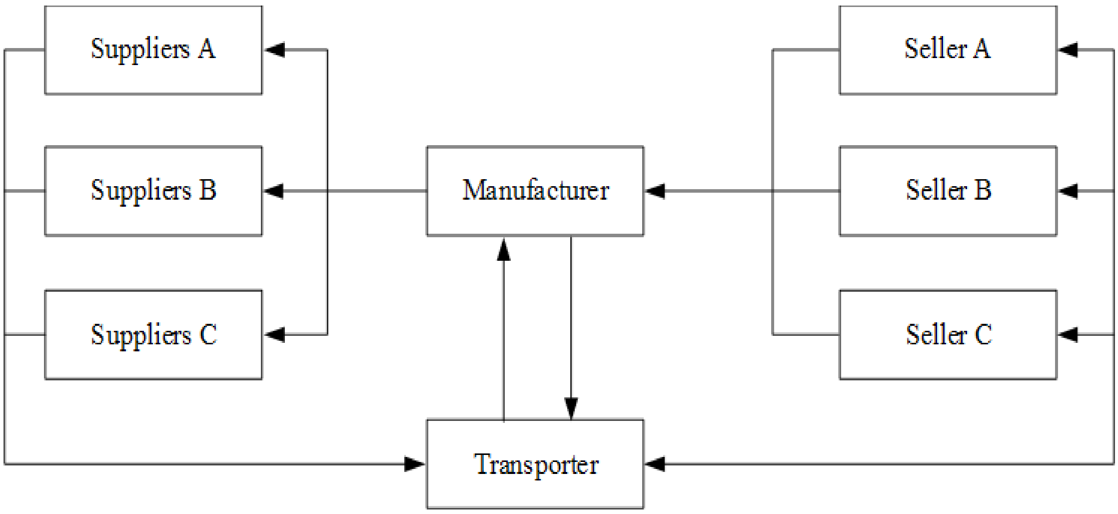

Figure 4. Supply chain model

Starting from its structural elements, the supply chain's autonomous or semi-autonomous entity can be abstracted into agent, the granularity of which should be moderate during the abstraction for easy development and reuse [15]. Customize the agent of different granularity according to the specific roles of these entities in the supply chain.

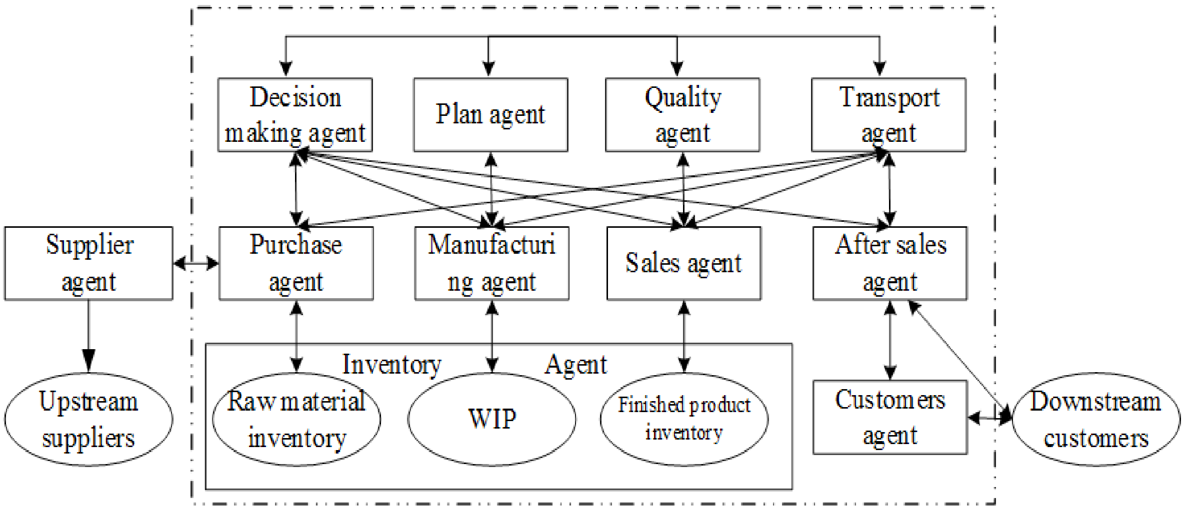

Figure 5. A multi-agent SCM system model based on the physical entity

SCM should coordinate the activities of all functional layers, but due to the complexity, heterogeneity of each link in the supply chain and rapidly changing market, it is difficult to execute the plan step by step. For example, the delayed purchasing links, the failure in production equipment, the change of customer order and other emergencies are likely to force enterprises to modify the original plan [16]. Such a modification will usually involve a number of functional units, so the modification should be coordinated and consistent with each other [17]. Multi-agent theory provides an abstract analysis method for distributed systems, which describes various activities in net work that work tasks are completed through interaction among human, organization and machine as the independent activities among agents. Supply chain is a typical distributed system, treating the supply chain as a network composed of multi agents, and each agent has a certain function and can collaborate with other agents. Fig.5 shows a multi-agent SCM system model based on the physical entity.

(1) Decision agent: after forecasting the market demand for the product, decision-making information is generated and passed to the plan Agent.

(2) Supplier agent: accepts the material demand information from the purchasing agent, completes the

handling of supply information from suppliers, and negotiates with the supplier and the evaluation to the suppliers.

(3) Customer agent: determines the price and delivery date of products in the order through negotiating with customers, handle the modifications or order cancel request proposed by the customers; reflects the demand information and the user feedback information of the whole supply chain.

(4)Sale agent: receives messages from the customer agent, checks stock agent. If the finished products can meet the order needs, send the results to the customer agent for customer's reply; if the stock fails to meet the order needs, send the demand information to plan agent for production, and the plan agent feedbacks the production results, and sale agent sends the relevant results to the customer agent who will negotiate with customer whether to modify or cancel the order.

(5) Stock agent: the distributed stock in supply chain manifests as all kinds of stock, which are distributed in different positions of the supply chain in various states (raw materials stock, finished goods stock, WIP stock). With timely delivery and reduction of stock as the goals, stock agent coordinates works with purchase, make, sale Agents.

(6) Plan agent: obtains market forecast information from decision-making agent, properly makes overall plan of the supply chain and develops purchasing, sale and produce plans and sends them to purchasing agent, sale agents and produce agent separately; coordinates the job activities of multi factories, multi suppliers and multi distribution centers in the whole supply chain; and adjust various plans according to other Agents' feedback information, and feedback the results to relevant agents. With improving the supply chain system's resource utilization as the goal, it is a Agent with multiple constraints.

(7) Purchasing agent: is responsible for the purchase of materials in the supply chain, determining the order quantity and period, and reducing the purchasing cost as much as possible. After the quality agent feedbacks the inspection results, it confirms or adjusts the purchasing quantity.

(8) Produce agent: completes the management of produce units, develops produce unit operation plan and schedule monitoring functions and sends WIPs or finished products of qualified acceptance to stock agent.

(9) Quality agent: is responsible for quality supervision and management of raw and auxiliary materials, finished products and produce process and feedbacks the results to purchasing Agent and produce agent to confirm the purchasing and produce. Another important feature of quality agent is to accept the information from after-sale service agent and coordinate with the relevant agents to make recommendations to handle the quality problem.

(10) Transport agent: obtains transport plan from plant agent and is responsible for the allocation and planning of resources, generating a series of transportation orders to meet the requirements of resource flow generated by plan agent.

(11) After-sale service agent: is responsible for accepting the after-sale quality feedback information from customers, sending the information to quality Agent, and the feedback quality problem is passed back to the after-sale agent after being treated by the quality agent, and after-sale service agent feedbacks the processing results to customer agent, and determines the solution through consultation.

2.1 Task-based MAS Model

Supply chain is a loose combination of a group of enterprises with their own goals around the core enterprises, holding an essence to complete some core businesses, so as to maximize the interests of the entire supply chain. But there is a global controller in the system. Completely centralized coordination refers to the Behavior that master control Agent fully controls the subordinate, and internal planner of main-control agent ensures that the Behavior among subordinate agent can be coordinated together. This coordination method has been applied in the world of machines. Centralized coordination method reduces the complexity of the system, decreases the communication expenses for coordination, but it requires that the central planner should have an extremely strong processing capacity, to handle all kinds of conflicts to form a global consistent solution. Therefore, this coordination is not suitable for the application in dynamic and open environment. Thus, it has been seldom used in multi-agent system. In completely distributed coordination methods, various agents are equal, the coordination of Behavior interacts with one another through internal inference mechanism of various agents or among agents, and consultation should be carried out to realize it in necessity. This coordination method is applicable to the research on multi-agent system of rational agents; actually, it better simulates the human society. However, this method also brings great communication pressure and dramatically increases the cooperative tasks to MAS, so it is necessary to create a MAS structure more suitable for the construction of SCM system, as shown in Fig. 6.

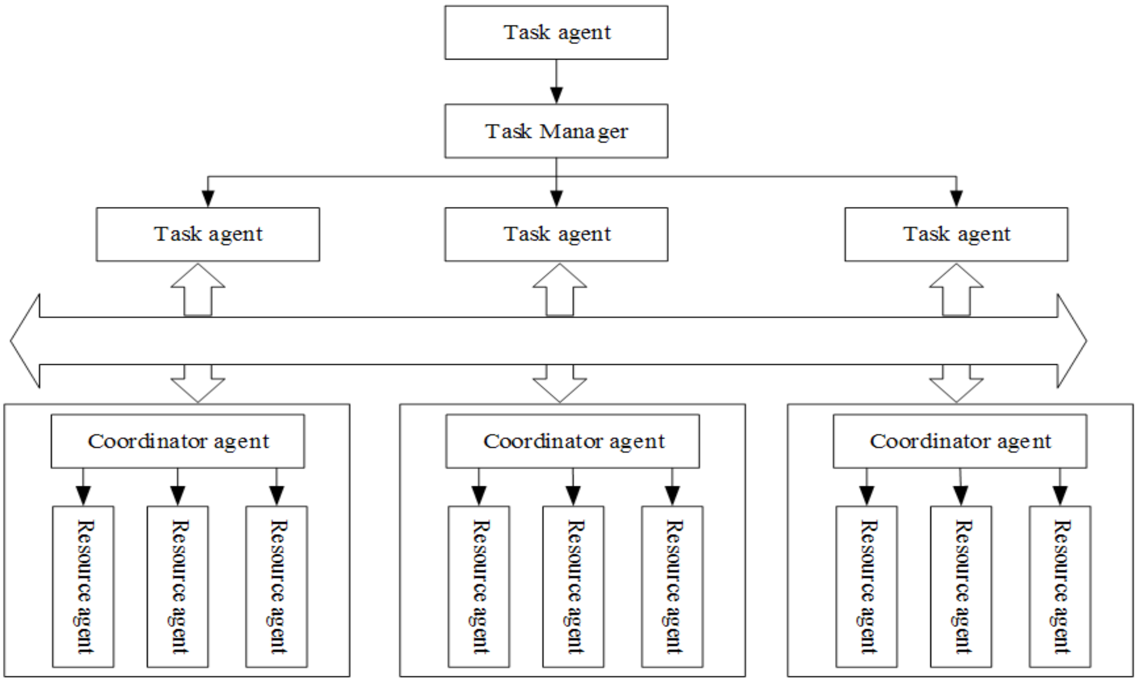

Figure 6. A MAS structure more suitable for the construction of SCM system

2.2 Behavior Class Inheritance Structure

Behavior class inheritance structure is as shown in Fig. 7 below, Behavior abstract base class defined by JADE derived two abstract subclasses, simple Behavior and composite Behavior, in which simple Behavior derived one shot Behavior and cyclic Behavior belonging to abstract class; composite Behavior derived FSM Behavior, sequential Behavior and Para11e1Behaviou belonging to abstract class, and their examples can be directly created.

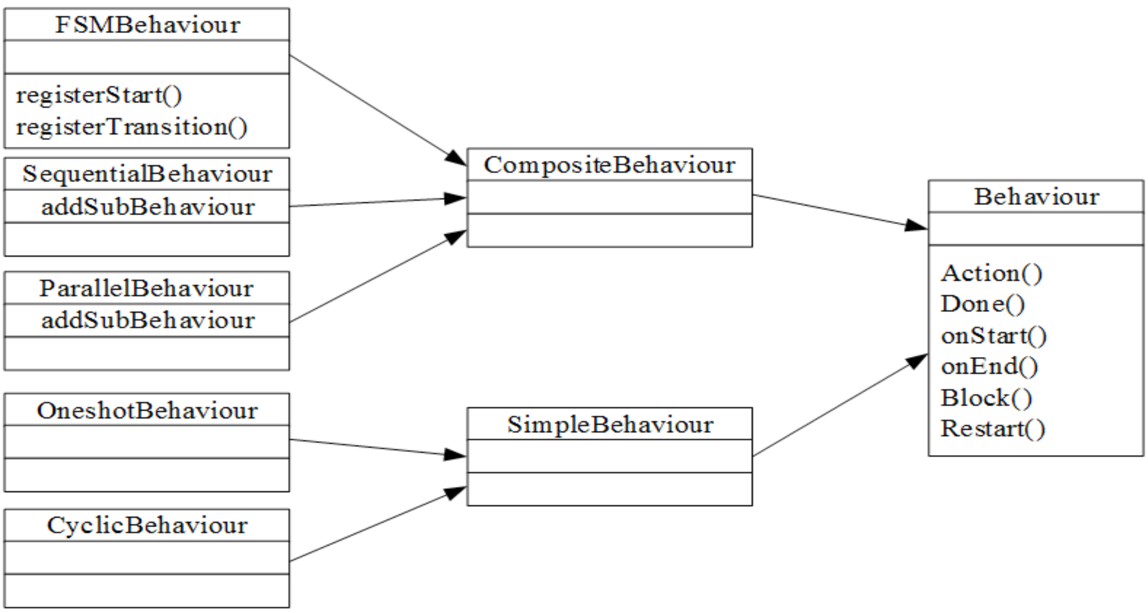

Figure 7. Behavior class inheritance structure

The algorithms for main Behaviors in the system are as follows:

(1) Sale Behavior, the sale Behavior of the retailer' sale agent, the simulation of the daily sales. It is assumed that the daily customer demand is relatively stable; the demand fluctuation around a certain value is only related to the seasonal element. Simulate the demand by taking a random number in a certain numerical section, after that, compare the demand with the stock, if it is smaller than the stock, the sale vol-

ume of the day is equal to the demand, or the sale volume equal to the stock.

(2) Sale Behavior, the sale Behavior of producers, producer' sale Agent to stimulate the replenishment to downstream enterprises. The replenishment quantity to i downstream enterprise:

$$R_i = \begin{cases} D_i(\sum_{i=1} D_i \le S) \\ S \times D_i / \sum_{i=1} D_i(\sum_{i=1} D_i > S) \end{cases} \quad (5)$$

Among them, D_i means the order demand of i downstream enterprise, S the stock volume of the product.

(3) Statistic Behavior, the statistical Behavior of the sale agent for the average sales of the current month, namely the accumulation of all daily sales.

(4) Forecast Behavior, the Behavior of sale agent to forecast the sales of the next month with forecasting methods based on time series:

$$\begin{cases} F_1 = S_t / R_t \times R_1 (t = 12) \\ F_{t+1} = (\sum_{i=1}^{t} S_i / R_i) / t \times R_{t+1} (t \ne 12) \end{cases} \quad (6)$$

Among them, the forecasted sales volume of the month F_t; the actual sales volume of the month S_i; R_t is the impact factor of seasonal element.

(5) Outstock Behavior, instock Behavior, stock Agent' in and out storage Behavior, the simulation of stock changes. New stock = original stock – outstock volume, new stock = original stock + instock volume.

(6) Order Behavior. Stock Agent's purchasing Behavior, the simulation to place orders to upstream enterprises. When stock of a certain product is less than the safety stock and the transporter hasn't yet delivered the product to the enterprise, place an order to the corresponding upstream enterprises.

(7) Safety stock Behavior, the safety stock Behavior of stock Agent, the simulation of setting up a safety stock. The safety stock $S = F / D \times d$, in which F is the predicted value of the next month; D the days of the next month; the safety stock level (unit: day)

(8) Produce Behavior. The produce Behavior of produce agent, the simulation of daily production. In principle, it produces according to the daily volume in production schedule, but if the stock of raw materials in the warehouse cannot meet the requirements of production schedule, product as many as possible according to the stock of raw materials.

(9) Schedule Behavior, the produce agent's schedule Behavior, the simulation of making production schedule. The scheduled production volume of the next month $S_m = F \times \sigma + S_a - S_t$, scheduled daily production volume of the next month $S_d = S_m / D$, among which F is the predicted sales volume of the next month; σ the production coefficient; S_a the product safety stock; S_t the existing stock; and D the days of the next month.

(10) Receive Behavior, transport agent's Behavior of receiving a transport task, the simulation of receiving transport tasks and confirming the transport time. Assuming the probability of arrival of a batch of goods is 10% for two days, 80% for three days and 10% for four days,

r = random() // is used to simulate the arrival probability

if r≤0.1 then D=2;

else if r ≤0.9 then D=3;

else D= -4;

De=Ds+D

Among them, r is the arrival probability; D the arrival days; Ds the receiving date of goods; De: arrival date of goods.

(11) Arrive Behavior, transport agent's goods arrival Behavior, the simulation of informing the receiving party upon arrival of goods. If the arrival date is the same as the expected date, inform the receiving party's stock agent in receiving the goods.

2.3Agent Behavior Design

Agent Behavior design includes the following content, based on JADE platform, select the relevant defined JADEBhaviour class to design the agent Behavior. As mentioned above, you can take Behavior abstract base classes or their abstract subclasses as the parent class to realize the self-defined Behavior class before creating the examples of the Behavior; or you can directly create the specific examples of FSMBehavior, SequentialBehavior and Para11e1Behavior. Of course, you can also adopt the above two methods together to create self-defined CompositeBehavior: Behavior class. At this stage, determine which method various agents can select to create their respective Behavior examples, and adopt the corresponding methods to describe their Behavior flow. Which method to be selected for the description depends on the personal habit.

The mutual transformation between objects and message can be realized by setting the ontology and language attributes of message in JADE, so the message content becomes more meaningful. Below we explain how to realize the process with an example of sending order message:

First of all, obtain the order message Ontology class OrderOnto from the Ontology class inheritance, and define order containing the class of order content, after that, register the attributes in Order class to Ordemnto through the class in schema.

The Behavior herein is a an abstract class providing a basic task framework, which gives two methods: action() and done(), in which action() means the task that can be fulfilled by Behavior class, and done() is used in the scheduling mechanism by agents, when a Behavior is completed, it returns to the truth value, which can be removed in the Behavior queue; when a Behavior isn't completed, it returns to the false value, action() should be recalled. Use addBehavior() method to add the Behavior to the agent. Furthermore, each agent can perform several actions at the same time. Agent Behavior execution flow chart is shown in Fig. 8.

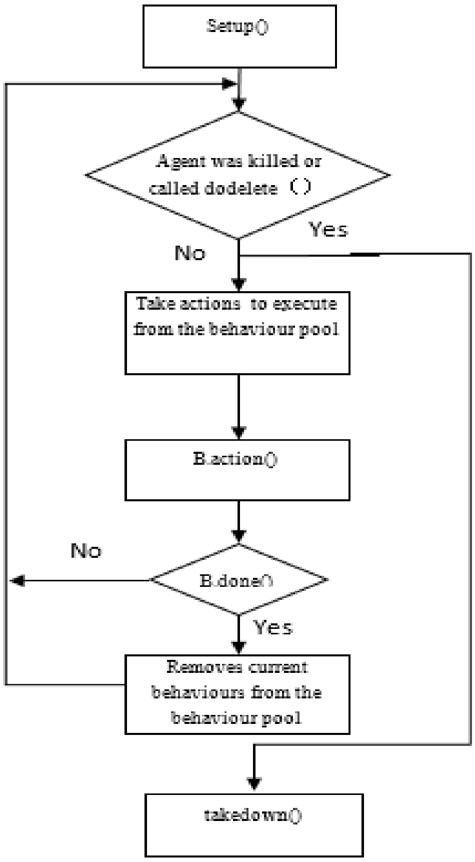

Figure 8. Agent Behavior execution flow chart

2.4 The Establishment of Multi- agent Simulation Model

With the development of supply chain, its selection and optimization has become one of research focuses, and the simulation, as a powerful tool for selecting and optimizing, has been paid more and more attention. The current simulation modeling methods adopted mainly include: object-oriented simulation modeling, simulation modeling based on system dynamics, and simulation modeling based on Petri network and etc.. These simulation methods have been fully developed and are of great help for the research of supply chain.

According to the supply chain model, we combined the agent technology with the simulation technology to construct a multi-agent simulation system as shown in Fig. 9 (the arrow direction in the figure is the message transferring direction among agents).

Similarly, the model is composed of four parts: supplier agent, produce agent, sale agent and transport agent. Among them, the supplier agent is divided into three groups respectively used in the simulation of three suppliers. Each supplier is stimulated by three agents, produce agent, sale agent and stock agent. The produce agent develops its own production schedule and manages the daily production according to the producer's production schedule; sale agent is responsible for meeting the producer's order requirements; and the stock agent is in charge of the instock and outstock management.

Producer is also simulated by three agents: produce agent, sale agent, sale agent and stock agent. Among them, produce agent makes production schedule, manage the daily production and carry out monthly output statistics according to the prediction of sale agent; sale agent is responsible for meeting the order requirements of retailers, carrying out monthly output statistics and forecasting of sales of the next month; stock agent is in charge of the instock and outstock management, and determining the safety stock of various raw materials and replenishment in time according to the production schedule.

Retailer's agent can be divided into three groups respectively for the simulation of three retailers. Each retailer is stimulated by two agents, sale agent and stock agent. The sale agent is responsible for simulating the daily sales, carrying out monthly output statistics and forecasting of sales of the next month; and the stock agent is in charge of the instock and outstock management, and determining the safety stock of various raw materials and replenishment in time according to the production schedule.

Transporter is simulated by transport agent and responsible for receiving goods, simulating the transport of goods so as to send the goods to the destination on time.

3. Conclusion

Based on the analysis and summary of SCM, the paper firstly pointed out some problems existing in SCM and believed that the supply chain organization structure needs to be reorganized and optimized, secondly, it analyzed the research status and existing problems of SCM system model, and on this basis, a multi-agent SCM system model was put forward, the simulation research was carried out to the model by using the software component technology, and finally simulated test was conducted to practical problems.

The modeling and simulation of SCM system needs large workload, because of the limitation of time and conditions, the steps of the method for modeling and simulation of supply chain were described, and simulation realization was mainly carried out to the structure function of logistics distribution center. The comprehensive research on the SCM system should be further conducted.

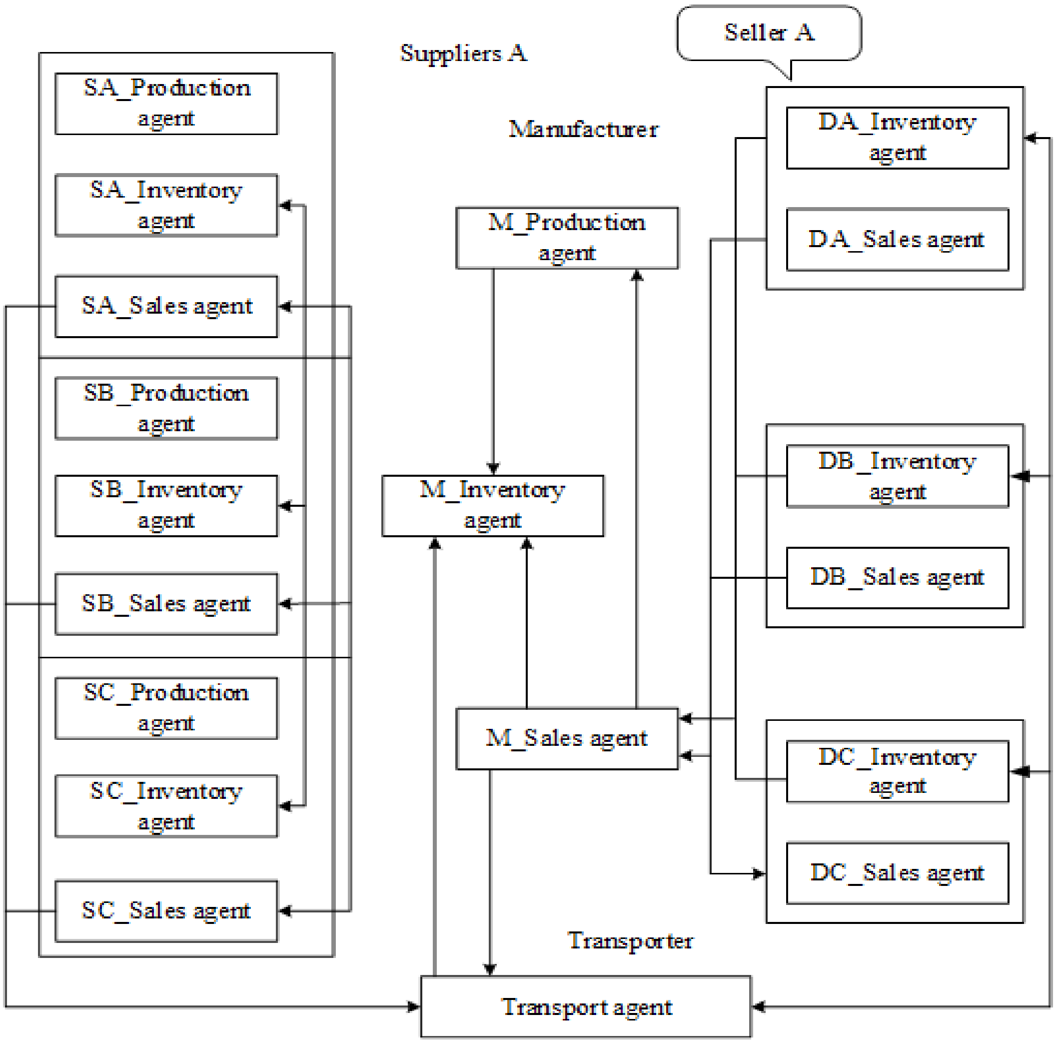

Figure 9. A multi-agent simulation system

Seeing from the domestic and overseas researches on the application of agent in SCM, most of the researches still stay in theoretical and mathematical proof stage, while the practical researches and system development are in their initial stage and many problems exist, such as single agent function; low efficiency of the communication system; insufficient intelligent degree of the system; unable to adapt to the dynamic changes in the market; the lack of flexible negotiation mechanism between supplier and demander, etc.. These problems have seriously hindered the development of MAS in SCM, in addition, SCM has different requirements on various technologies of cross subjects and multi fields. It needs people from different fields and subjects who are interested in exploring agent-based SCM to make common efforts to seek an effective way for the research and application of SCM actively.

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Analysis on the Correlation between Energy Consumption Cycle and Economic Cycle

Weidong Yu

School of Economics, Capital University of Economics and Business, Beijing 100070, China

Abstract
Economic development has shown periodic oscillation and has certain regular pattern. With the economic development, the national energy consumption has been also promoted. Energy, as the material foundation to develop economy, is closely related with the development of national economy. It has a strong positive correlation relationship between energy consumption and economic cycle fluctuation. This paper studies the relation between energy consumption and