Research about Dynamic Evolution of Supply Chain Based on Agent

Yanhua Shao*, Zhao Min and Dawen Xia
College of Data Science and Information Engineering, Guizhou Minzu University, Guiyang, China

*Corresponding author email: yhshao@gzmu.edu.cn

Abstract. During the research with respect to the traditional supply chain, Enterprise autonomy is ignored. Within this thesis, from the perspective of CAS, the dynamic growth of supply chain was inspected by using CAS versus evolutionary game theory. Within supply chain, the corporate was viewed as agent. In the same way, the variety branches of the corporate were viewed as sub-agents. The agent-based model of supply chain was set up in this thesis. At the same time, supply chain dynamic evolution was simulated through swarm. The effective solution to coordinate the supply chain main body behaviour was explored too. Within this thesis, the evolutionary trait of supply chain is explored, and a reference for supply chain governance is provided.

Keywords: supply chain system; complex adaptive system; evolutionary game theory; swarm simulation platform

1. Introduction
Supply chain was an economic system, which was a complex adaptive system with a certain amount of swarm intelligence by the composition of many interaction enterprises. The entire supply chain had a strong ability to adapt, and each component unit in which influenced the evolution development of supply chain, rather than simply decided by a core enterprise, even the construction of the key corporate was the consequence of evolution too [1]. Within supply chain, the interplay of diversified logistics was in charge of energy exchange between inside and outside. So did the flow of information and cash.

Supply chain was view as CAS, its principal complexity manifested in: the construction complexity, which involved the complexity of substance relation and networks composition; substance’s behavior complexity, geographic dispersion complexity, various entity complexities. In addition, diversified logistics interaction resulted interactive complexity, so did the flow of information and cash within each corporate; the openness of the system, which mainly indicated the interaction between the enterprises. There was also interaction between each subsystem with the environment. The changes of the environment were reflected by every link, which reflected the energy switch with the outside environment [2, 3]. Furthermore, with the modification of environment, supply chain was evaluated; the component dynamics and system behavior resulted the dynamics of supply chain; the behavioral complexity of the system, which principally appeared in the behavioral characteristics not for a simplex company action through single aggregation. The root of complexity was the self-organizing traits and adaption of the system [4, 5].
2. Model of Supply Chain System Based on Agent

In complex supply chain system, the interaction between various sub-agents finally aggregated to agent. The interaction between various agents finally formed a higher level of the agent, namely the complex supply chain management system. As shown in figure 1.

![Figure 1. Architecture of supply chain.](image1)

![Figure 2. Agent’s structural model.](image2)

2.1. Agent Characters of Supply Chain System

In the process of supply chain evolution, agent’s conditions and behaviour pattern was depicted. The agent’s behaviour depended on its cumulative states. Simultaneously, the next state of agent was changed by its behaviour directly. Therefore a spiral relation would be formed by the agent status and behaviour. During the long-time trading, the agent’s behaviour pattern was sure to alter. Which caused the evolution of the agent through this mechanism, and then system would as evolution [6]. In the evolution development of supply chain model, the intelligent agent has the following properties and features of intelligence, interaction, learning, memory, preference and purpose.

Intelligence indicated each agent was capable of adjusting his trading strategy in line with environment of the market and other company management behavior. Each agent constantly improved in the evolution development, and took different management strategy according to different actual situation [7].

Interaction represented agent gradually filtered and stabled cooperation partner, and then a supply chain formed. After the formation of supply chain system, various enterprises through the different strategy would change, but what exactly done a change in the short-time is each node enterprise, instead of the corporation type, in the long-time the supply chain could also change followed the change of the corporation type.

Learning represented agent had the ability to learn based on the changes of himself and the evolution development of his economic system. Within supply chain, inside learning and outside learning was incorporated in agent learning. Each learning pattern indicated the agent’s strategy and pattern, which adjust to the market continuously [8-10].

Memory indicated the agent’s evolution, which possessed path dependence in the system. The present and future developments were influenced by the following decisions. In the process of adapting to market environment, the outcome of behavior and interaction was impeded by path dependence.

Within the supply chain, the characteristics of the company determined agent preferences, so did social and cultural background of the company's owners. The preferences would to a certain extent affect the management strategy and the choice of learning objects, which affected the behavior of agent subjecting to the market reaction.

Within the procedure of agent’s presence and evolution, purpose indicated agent possessed explicit choice tendency. In the thesis, the agent’s purpose was predigested, which was believed to obtain the more return exceed the average return of the market.

2.2. Agent’s Behavior Patterns of Supply Chain

Within the supply chain system, the agent’s behaviour pattern was defined the response to the variable
import of the external environment. With mathematical symbols described as:

\[ B = F_c(\gamma, s_{in}); \]

\[ \gamma \in EN = (EN_1, EN_2, EN_3, \ldots, EN_n) \]

The behavior patterns of agent reflected the supply chain system's response to the external environment stimulation, namely the system behavior. In the thesis, agent’s external environment was abstracted as the outward state set S. Among them, \( s (s \in S) \) indicated the external state of agent in a certain period. The logic structure of enterprise behavior was described by Entpr, that was \( \text{Entpr} := (Eid, Goal, P, I, A, \text{Infor}, \text{Next}, \text{Action}) \). Eid indicated the logo of corporate; Goal indicated the goal of corporate; P denoted the outward information set of companies; I indicated enterprise itself state collection in the supply chain; A denoted behavior state set of corporates; Infor and Action, went through three stages of external response: information acquisition, perception, and decision. The agent’s operation procedures of specific behavior were as described below:

In the premier stage, the agent acquired environment information of market in many aspects. The environment information imitated agent to the status of getting information. Enterprises would use rational analysis to change his internal state. At the same time, in viewed of his condition of acieration to market information and his inward condition, and consulted his behavior objective, enterprises would acquire the perception procedure of information. Enterprises would use rational analysis to change his internal state, which contributed to obtain the information perception, and referred to his behavior target too.

Eventually, the corporate decided to response to the motivate behavior results of environment on the light of the revised inward state.

2.3. Structural Model of Agent in the Supply Chain System

The agent was different during supply chain evolution from the view of principle. Due to network of supply chain was consisted of various different corporates, which involved full-scale product in circulation procedures between raw materials and the client. However, the fundamental attributes of agent in supply chain was the same in this research model. Agent hunted for return maximization. Agent had wise structure, which adjusted to fit for the development of system environment. Within supply chain, the corporate model dependent on agent model. Within the agent model, the diversities at the level of the fundamental operations of the corporate were neglected. The agent’s structural model was made known in figure 2.

Within the model, environment changes were probed through agent detector, which could acquire market information too. The process involved integral information from macro market to other agents within the system. After having obtained the information, the agent would analyzed the information according to his own management strategies and knowledge structure, and then adjust his behavior in response to these changes, so the agent would output his reaction to the environment through the effectors.

The if-then rule processor was an association of tactics and experience. The rule processor operated on the mechanism of building block and internal model to a certain extent. In case the programming theory was used to externalize rule processor, which would be the correspondence of one-to-one. The rules indicated the fundamental behavioral features of agent.

In the development of supply chain, the trade strategy in view of structural model was chosen by agent. The agent accepted the information of other agent at the same time made his own behavior information. The interplay between agent and environment was represented by agent model. Agent model was adjusted to adapt the environment. The process would be a spiral evolution procedure.

2.4. Agent’s Learning Model in Supply Chain

Within the CAS, an agent's apparent trait was learning. Agent’s learning behaviour helped to his adaptation ability.
The learning structure of agent could be divided into three modules during the evolution of the supply chain: input module, strengthen module and decision module, as shown in figure 3. Among them, environment information was transformed into the input information through input module. Hereafter, decision making module received input information. Environment status and agent behavior consequence was transformed into steady information through strengthen module. After that, the steady information was transmitted to the module of decision-making.

![Figure 3. Agents’ interaction within supply chain](image)

2.5. *Agents Interaction within Supply Chain*

Each agent’s behaviour was treated as a tactics. Agent’s evolution learning procedure was formalized by using advancement stable tactics. The interaction mechanism of agents was discussed from the game environment, the game rules and the game behaviour.

All agents’ space distribution constituted the topological diagram of agent game. In case agent kept static within the whole procedure of development, the relation and graph among agents would maintain. If the agent could be moved, each agent's game rivals would change, the game relation between the agents would continue to change, and the topological diagram would also dynamically. Within the procedure of game, because of the less return, the agent who used long-time irrational tactics would be clear away by environment. The rule of selection and elimination was as follows: After a game of all agents, according to the total profit of each agent, less than zero, gave fall into disuse. Randomly, new game agent was generated, to supplement the shortage of agent.

3. *Dynamic Evolution Simulation of Supply Chain*

Within modelling and emulation, agent was abstracted in view of different level. In the thesis, we would view each node enterprises of supply chain as the agent in CAS.

3.1. *Design of Simulation*

The principal view of emulation and layout was: within a structured setting to put up lots of agents, which in this environment to conduct their actions. These agents had the attribute of their individual tactics and behaviour, and they were left alive in supply chain system. Hereafter, they changed themselves, and other agents and environmental factors. A number of characteristic and behaviour was analysed by means of the interaction among agents.

Buy orders was handled by supplier agent. Supplier agent was in charge of allocating raw materials. Within supply chain, so as to cut down the product design period, and promote product design efficiency, agent of supplier should take part in congregate products design. Supplier agent would monitor raw materials character. Suppliers agent input involved buy orders, collaborative product design and serve management. The output factors included raw materials, credibility and long-term cooperation.

Manufacturer agent accepted production orders, then arranged production plan and organized production according to the order. Manufacturer agent placed buy orders to supplier agent according to the raw material reserve and the order rules. Finally, the product was sent to the finished goods inventory by manufacturer agent. Manufacturer agent input involved manufacturer orders, raw
materials purchase, fabrication, and quality monitor. Manufacturer agent output comprised finished products, product percent of pass, ordered fulfillment rate. Distributor agent was responsible for sales, arranged daily incoming orders, and integrated the orders. In case the order requirements could be satisfied by the present reserve, manufacturer agent would receive manufacture instruction from distributor agent. In addition, distributor agent should respond to the need of retailer agent. If the current inventory couldn’t meet the requirements of the order, distributor agent sent all products in inventory to retailer agent, and informed retailer agent of placing an order for goods a few days later. Distributor agent’s import involved order handling, reserve management, order fulfillment, advertising, and channel construction. Distributor agent output included brand. Distributor agent output also included channel and products distribution too. Retailer agent was in charge of the growing of market and the goods sell, and served client. The import of retailer agent involved market prediction, goods procurement, and client service. The output involved the goods sell and client contentment. Logistics agent was in charge of building connection to all others, first and foremost engaging in carriage and allocation services. The import of logistics agent involved carriage means, staff, and packaging, processing and other appreciation services. The output included logistics services and cost savings.

3.2. Analysis of Simulation
The interaction relation among picking tactics of supply chain system and productive environment was made known by the price of market. First of all, the return of supply chain was influenced by market price. Supply chain suitability was accordingly influenced by market price. Market offering was decided by supply chain management tactics. In turn, market price would be influenced through market offering.

In general, the dynamic evolution of the supply chain not only reflected the changes of business strategy, but also had a close interactive relationship with the development space of macro industrial environment and life cycle. In the simulation, the simulation experiment progressed in time steps, and one time step represented a week's time. We researched the evolution of market prices over time, as shown in figure 4.

It can be seen from the price of market in Figure 4, at the initiating of the evolution emulation, the supply chain chose trade strategy randomly, since the agent had no special trade experience. Under this circumstance, the market offering was extremely lower, and so the price of market was relatively high in the beginning stage. However, along with the accumulation of market innovation experience, innovation risk gradually decreased, so did the innovation cost. At the same time, the excess profit would tempt part of imitation agents to change their imitation strategy into innovation strategy. At this time, the market price was the highest. With the increase of market innovation behavior, the imitation agent had more to imitation space. The existence of imitation agent made the market price begin to decline. Since the quantity of mimicry agent increasing, the offering of market promoted too, and the price of market decreasing quickly. When the market price dropped to a certain value, the market supply tended to be stable. But with the further simulation, the market price began to decline and some fluctuations emerged. This marked the innovation behavior in the market further towards maturity. Due to the existence of the innovative agent, the whole industry was still able to continue development of 100 cycles in evolution.

![Figure 4. Market price of supply chain.](image1)

![Figure 5. Key choice of the supply chain.](image2)
Figure 5 performed supply chain key choice. In the initial period, an upward trend produced within emulation of innovation supply chain. The number of imitation supply chain was the maximum, as market price increased to the highest. Although the yield of imitation supply chain was not high, the high market prices still allowed him to obtain high profits. When market price tended to be stable, the ratio of supply chain also tended to be stable. Yet, the innovation supply chain took up the market within the simulation, which represented the superior extent of innovation circumstance in the market.

4. Conclusion
The thesis regards the supply chain system as a complex adaptive system, and studies it through Agent modelling and simulation. The evolutionary trait of supply chain was explored. In the next research, we will enhance the learning ability of the agent and make the system more intelligent.

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