Associate Professor Wei LIU，PhD

School of Management, Tianjin University, Tianjin, China
E-mail: ican001@126.com

Associate Professor Jing LI，PhD

School of Engineering, Nanjing Agricultural University, Nanjing China
E-mail: doctorlijing@gmail.com (Corresponding author)
Xue CHANG, Master
School of Engineering, Nanjing Agricultural University, Nanjing China
E-mail: 1136839628@qq.com

A MULTI-AGENT MODEL FOR STRATEGIES OF NEW PRODUCT DEVELOPMENT

Abstract: *This paper proposes a multi-agent simulation model of the optimal strategies for new product development (NPD) in a complex and changing industry environment. Three of the non-linear relations are considered, such as the relations between relational contracts and supply auctions, rapidly and slowly renewing firms, with and without mutation evolution strategies. An agent (a virtual firm) has one of six business strategies for introducing new products and pricing in each simulation period dynamically. A new agent will be substituted which selected from stochastic agent group when a failure agent turn-up. A number of experiments are conducted to the model with different settings of parameters, such as the experiments that manipulated by the genetic and evolutionary parameters. The model should be available as a toolkit for studying the optimal NPD strategies in different supply chains.*

Keywords: *multi-agent simulation, new product development, supply chain structure, procurement auctions, relational contract.*

JEL classification: **C15, O31, M11**

1 Introduction

Today, technological change and advances occur in an unprecedented rate. Hence, new methods, new materials and new processes become available more rapidly than ever before. Therefore, products are quickly renewed in certain industries, especially in IT industry, such products, for instance, cell phone, PDA, and personal computer etc. In an emerging market, like, China, India, Russia, Brazil, companies that develop an effective strategy of new product development to maintain market share is critical for keeping the company growth. Besides, the quality and reliabilities of NPD's components are key factors to result complexity of contractual transaction. And mostly, these transactions are processed through informal relational agreements (the relational contracts) with former partners (Tunca, 2006). In the paper, the manufacturer agent, who develops a new product, rely on getting NPD's parts from a set of preferred supplier agents. Most of the procurement of the NPD's parts is dominated by the relational contracts. However, the manufacturer agent can also purchase the NPD's parts by auctions under different bargaining scenarios. Based on this model, the multiple non-linear relations are studied, which are the relational contracts and supply auctions, high technology and low technology firms, with and without mutation evolution strategies. The evolution of the industry is researched by manipulating the genetic and evolutionary parameters. The different strategies of the industry can also be experimented in the model through changing the settings of parameters.

2 Review of the related research

Since the innovation is a complex process, it is difficult to capture all its relevant dimensions (Matei, 2010). This paper uses agent-based simulation to research the product innovation of IT industry. The competition relations in this paper have been studied in previous works. Tunca examined the competition between procurement auctions and long-term relational contracts by a mathematical model (Tunca, 2006). Since the non-linear relationships are modeled in our paper, it is implausable to make simplifying assumptions until the equations do become solvable. Computer simulation can be used to model either quantitative theories or qualitative ones (Gilbert, 2000; Brintrup, 2010). In our paper, the agent was used to optimal the product strategies of companies and the multi-agent model was built from bottom to up. The results of the experiment show the robustness of the multi-agent model for studying the evolution of the update strategies for NPD.

Scholars have applied various perspectives in order to resolve problems in the non-linear system. Scarlat et al. (2011) researched the complex decision-making process of choosing financial sources with multi-agent technology. The paper's model depended on the development of the former artificial model based on multi-agent system. Gilbert (2001) built a multi-agent model embodying a theory of innovation networks. A number of policy-relevant conclusions were suggested through experiments with the model's parameters. In our paper, many of experiments will be conducted with different settings of parameters. Shaw (2008) presented an individual-based simulator of species and community dynamics that allows experimenters to manipulate genetic and evolutionary parameters as well as parameters affecting the simulated environment and its inhabitants. The genetic and evolutionary parameters will be manipulated in our paper to experiment with the impact of these parameters. A general methodology based on robust optimization was assumed to address the problem of optimally controlling a supply chain subject to stochastic demand in discrete time (Bertsimas, 2006). These works were carried out by mathematical methods and the relations in the supply chain were not non-linear. However, some assumptions, such as the market, were useful for our paper. Since the evolution of the rapid renewing industry, a multi-agent model was proposed in our paper. Many scholars had given suggestions in this field. Since the dynamic context of supply chains, multi-agent technologies were used in an advanced planning system to improve partner's coordination (Kwon, 2007; Forget, D'Amous, Frayret, etc. 2009; Jiao, 2006). The multi-agent model was used in Cauvin's work to coordinate companies' behavior to minimize the impact of disrupting events (Cauvin, etc. 2009). The multi-agent model presented in our paper depended on the former works in this field. The following sections introduce the model of this paper.

3 The multi-agent model

The artificial supply chain is a multi-agent model containing heterogeneous agents which act in a complex and changing environment. The multi-agent model G ($G = <V, E, P>$) consists of N agents ($V = \{v_1, v_2, v_3, ..., v_N\}$), where each agent can be considered as a virtual company in the model. Figure 1 shows the framework of the multi-agent model.

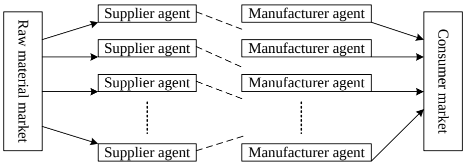

Figure 1. The framework of the multi-agent model

The relationship in the model is introduced by an adjacency matrix *E*, where an element of the adjacency matrix $e_{ij} = 1$ if the agent v_i sells his products to v_j and $e_{ij} = 0$ otherwise. If $e_{ij} = 1$, v_i is defined as the supplier agent and v_j is called the manufacturer agent in the model. The manufacturer agents buy material from suppliers and sell their product to end users. Agents try to improve its' profits by different strategies. Agents update their products based on different strategies of NPD.

3. 1 The supplier agent

A supplier agent (v_i) is a virtual company who buys raw materials (raw materials are assumed unlimited) and sells their product to manufacturer agents. The state of v_i is defined as $S_{v_i} = \{s_{v_i}, f_{v_i}\}$, where s_{v_i} is the business strategy of v_i, f_{v_i} is the capital of v_i (The initial value of f_{v_i} is $f_{initial}$).

Each supplier agent has NPD and price strategies. In the paper, the NPD strategy consists of three kinds of choices, radical, medium, and conservative strategy. Each agent chooses one of the three NPD strategies and the strategy will never been changed in the life of this agent. The agent with radical strategy produces a new product every *T* periods. The medium strategy agent proposes a new product every $T+T_1$ periods. Other agents produce the new product every $T+T_1+T_2$ periods. Supposed t means the current period, the product strategy can be explained by the following rules. If $0 \le t \bmod T < T + T_1$, only radical agents can produce the new product. If $T + T_1 \le t \bmod T < T + T_1 + T_2$, radical and medium agents can produce the new product. If $t \bmod T \geq T + T_1 + T_2$, all agents can produce the same product and now the product is called old products in the paper.

Moreover, supplier agents have two price strategies, high or low price. High price strategy means agents use the clearing price of last simulation period (p_c) as the initial price of this period. Low price means agents use $p_c * (1-\lambda)$ as the initial price, where λ is a system parameter. This means that s_{v_i} must has one of the six strategies, radical product and high price (*strategy1*), radical product and low price (*strategy2*), medium product and high price (*strategy3*), medium product and low price (*strategy4*), conservative product and high price (*strategy5*), and conservative product and low price strategy (*strategy6*). Figure 2 shows the different strategies for the agents.

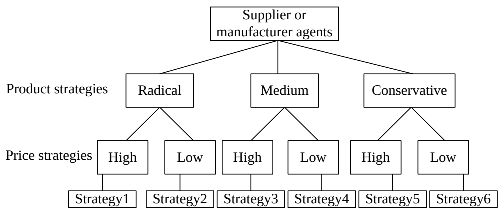

Figure 2. The strategy space of supplier and manufacturer agents

A finite set of actions for agent v_i is defined as $A_{v_i} = \{a_{sv_i}, a_{pv_i}, a_{cv_i}, a_{mv_i}\}$. a_{sv_i} means the action of v_i to choose his business strategy s_{v_i}. a_{pv_i} means the action of v_i to produce his products. a_{cv_i} means that v_i manages his customers to support his selling decisions. a_{mv_i} means the action of v_i to manage his capitals.

Within the model, there are two settings for a_{sv_i}. With the first, v_i adopts the Boltzmann soft-max distribution to select s_{v_i}. The probabilities of Boltzmann soft-max distribution are generated by the percentage of current agents' strategies. The alternative setting is that the choice of the strategy for the new agent has a mutation operation after the first choice with the probability of *mp*. Under the second setting, a_{sv_i} is similar with Genetic Algorithm. The implementation of the model allows for switching between these settings in order to experiment with the two evolution conditions. a_{sv_i} is shown in dashed line (Figure 3).

a_{pv_i} is one of the most complex actions for v_i. v_i uses the product auction or relational contracts for the different kind of products. Figure 3 shows the dynamic process of the supplier agent's operation. The actions of a_{pv_i} are shown in the dashed line. In the figurer, *t* means the current period of the simulation.

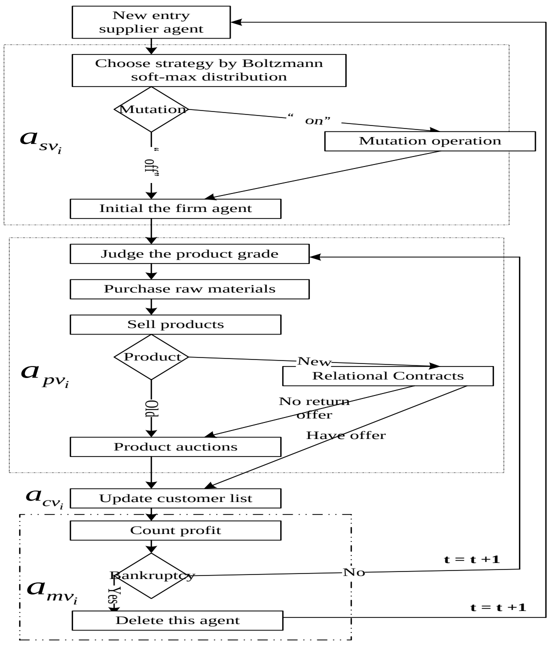

Figure 3. The dynamic process of v_i (supplier agent)

If v_i produces the new product in the current period, the new product will be sold to customers with relational contracts (The initial price depends on s_{v_i}). The target profits of the new products were higher than that of the old ones. v_i sells his products to the manufacturers agents in the customers list firstly. The first manufacturer agent in the list will get the offer firstly. If no customer wishes to accept the new product offer, the new product will be proposed to product auctions with other agents' new products. Manufacturer agents bid with the high/low price in the first auction cycle. The new product's price will be decreased with Δp_n for every simulation period until it is sold. In product auctions, v_i gives his selling prices and outputs. Then manufacturer agents give their purchasing prices and demands. As in the stock market, the minimum price supplier agent cooperates with the maximum price manufacturer agent firstly.

If v_i produces the old product in the current period, the old product will be sold on product auctions. Manufacturer agents bid with the high/low price in the first auction cycle. The old product's price will be decreased with Δp_o every simulation period until it is sold.

a_{cv_i} is used to manage the customer list of v_i. The position of manufacturer agents depend on the previous contacts experiences. If agent v_j make v_i get the biggest profit by the relational contract, v_j will be the first agent in the list. All of customer agents were ordered by the previous contacts experience.

v_i uses a_{mv_i} to manage his capital and creates new agents. v_i computes his profits at each simulation period and updated his f_{v_i}. The initial numbers of supplier and manufacturer agents are defined as n_s and n_m in the model. If $f_{v_i} \le f_{dead}$, v_i will be deleted from the model and a new agent will be created randomly.

3.2 The manufacturer agent

The manufacturer agent purchases parts from the supplier agent. If the manufacturer agent can’t buy the new part from the supplier agent, they can’t produce the new product for the consumer market. In the part market, the manufacturer agent compares the supply and demand in the last period if the agent needs the new part. If the supply is less than the demand, the manufacturer agent will accept the relational contract offered by the supplier agent. If there is no offer of the new part, the manufacturer agent has to buy it from the auction. However, if the supply is more than the demand, the manufacturer agent will refuse all of relational contracts and buy the part by the auction. Of course, the auction is only one method for the bargain of the old part. In the consumer market, the manufacturer agent schedules the price of his products by one of the six strategies (in Figure 2).

The differences between supplier agents and manufacturer agents are the product action (a_{pv_i}). The agent state ($S_{v_i} = \{s_{v_i}, f_{v_i}\}$) and actions (except a_{pv_i}) in $A_{v_i} = \{a_{sv_i}, a_{pv_i}, a_{cv_i}, a_{mv_i}\}$ are same between supplier and manufacturer agents. Figure 4 shows the dynamic process of the manufacturer agent (v_i). In the figure, t means the current period of the simulation.

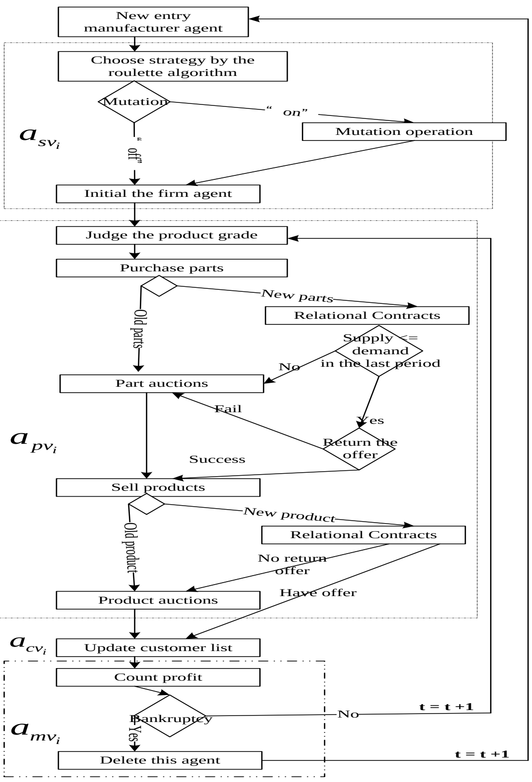

Figure 4. The dynamic process of manufacturer agents

The radical or medium manufacturer can produce the new product only if they can purchase the new parts (the suppliers' new products). If the new parts' output exceeded the demand in the last period, the manufacturer agent will purchase the parts by procurement auctions in this period. If the new parts' output was less than the demand in the last period, the manufacturer agent will return the producers' product offers in this period. All of the manufacturer agents with the demand of old parts will purchase their parts by procurement auctions in every simulation period.

On the selling market, the manufacturer agents have one of the six strategies same with the supplier agent (Figure 3). The manufacturer agents' different product will be sold on the market with high/low price depended on his business strategies.

3.3 The market

The end product is sold in the consumer market. There is a continuum of K consumers indexed by their values, r, and in each period each consumer purchases either one or no units of the product. If $0 \le t \bmod T < T + T_1$, the consumer will purchase it if the new products' price is less than $(r+v_1+v_2)$, where (v_1+v_2) is the new product premium consumers are will to pay for a very new product (only the radical agent can produce this product. $v_1>0$. $v_2>0$). The old products will be sold if the price is less than r. If $T + T_1 \le t \bmod T < T + T_1 + T_2$, the consumer will purchase it if the new products' price is less than $(r+v_1)$, where v_1 is the new product premium consumers are will to pay for a new product (only the radical and medium agent can produce this product.). The old products will be sold if the price is less than r. If $t \bmod T \ge T + T_1 + T_2$, all agents can produce the same product and the products will be sold if the price is less than r.

4 The Implementation

The multi-agent model is programmed by JAVA and run on WinXP. In order to show the validity of the model, the paper conducts two experiments of the framework. The parametric settings for the experiments are proposed in Table 1.

Table 1: Parameter Settings

T	T_1	T_2
10	5	3
λ	Δp_n	Δp_0
0.05	0.01	0.01
$f_{initial}$	f_{dead}	n_s
300000	10000	12
n_m	v_1	v_2
10	10	10

In the paper, the experiment environment is set so that the supply of products is more than the demand. We supposed all agents have the same product ability and the number of supplier agents is more than the number of manufacturer agents. The market's demand is less than the manufacturer agents output too. Under this condition, some companies will be bankrupted after some periods and new firms can join this simulation. Under the standard settings, the following figures were generated.

Firstly, the evolution condition of mutation operation is switched as 'close'. Figure 5 to Figure 7 were developed under this condition. The top of the Figure 5 shows the percentage of the supplier agents with different strategies. In the figure, *strategy1* and *strategy2* are the winners of the evolution. This scenario may be caused by the evolution of the strategy of the manufacturer agents in the bottom of the Figure 3. For the manufacturer agents, *strategy1* is the only winner under these settings. This means the experiment market is prefer to the new product and the people in the market has more moneys.

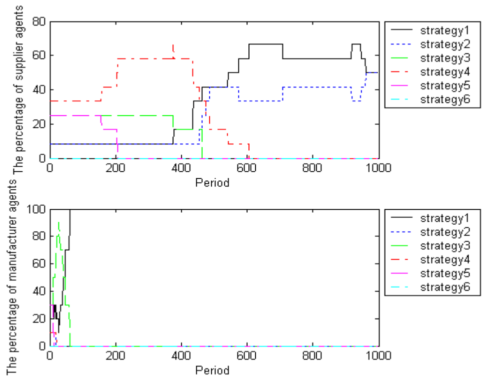

Figure 5. The percentage of different strategy agents

Figure 6 shows the profits of all supplier and manufacturer agents. Since the manufacturer agents were controlled by the supplier agents with parts supply and the market is fixed, the profit of manufacturer agents keep stable in a low level. The profit of the supplier agents rises at the beginning and decreases quickly with the evolution of systems. This means few winners with different strategies were not beneficial to the profit of the group of all agents. However, some special agents may success in spite of decreasing of the group's profits. Figure 7 shows the profit of the twelve supplier agents. It is clear that *supplier4* has a very successful strategy.

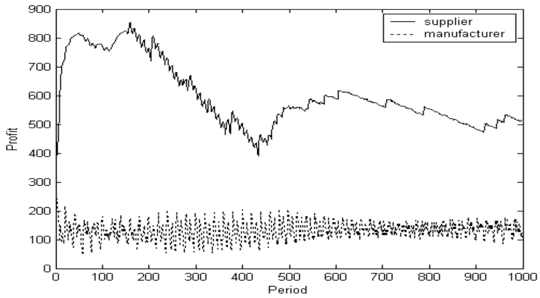

Figure 6. The profit of all supplier and manufacturer agents

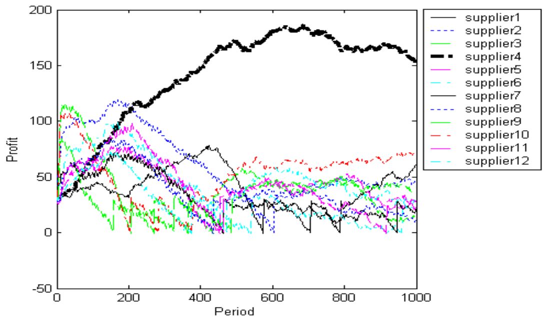

Figure 7. The profit of each supplier agent

After the previous experiments, the evolution condition of the mutation operation is switched as 'on'. Figure 8 was generated under this condition. Figure 8 shows the profit of the manufacturer agents were not influenced by the mutation operations. However, the mutation operations were beneficial to increase the profit of the supplier agents. This means new supplier firms that use different business strategies from (those of) previous successful enterprises might make more contributions to the development of the whole industry.

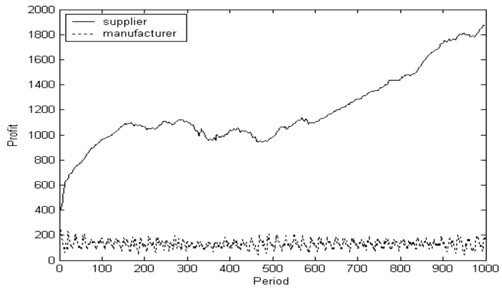

Figure 8. The profit of all supplier and manufacturer agents (with mutation)

The two experiments show the multi-agent model can simulate the evolution of product renewal. Virtual enterprises can achieve their optimal target under different experiment environments. It is found that mutation operations show different influences on different companies. These conclusions show significance on enterprises within the supply chain (Products are renewed quickly). Based on this model, researchers can carry out studying on the optimal strategies of product renewal in different supply chains.

5 Conclusion

This paper describes multi-agent model for simulating the evolution of product strategies between supplier and manufacturer agents in a complex and changing industry environment. The model presented in the paper is an attempt to improve our understanding of the complex processes going on in the update strategies of NPD. In the paper, six strategies and two kinds of evolution conditions were proposed. Under different experimental settings, the percentages of the six strategies were compared by some figures. Moreover, virtual companies' profits under different conditions were analyzed too. Under those experiments, the model shows significance on the studying of the evolution of the update strategies for NPD. For different supply chains, optimal strategies of NPD can be proposed by the multi-agent model. Through the setting of the parameters, the model is also beneficial to the researching of the management problems in the other fields for the future works.

Acknowledgments

This research was supported in part by: (i) Basic Research Program of National Science & Technology (China, Grant Number: 2012IM040500); (ii) Natural Science Foundation of Jiangsu (China) under Grant BK2011652; (iii) NSFC (National Natural Science Foundation of China) program under Grant 71301077.

REFERENCES

[1] **Bertsimas, D. (2006)，*A Robust Optimization Approach to Inventory Theory*；** *Operations research*, 54(1), 150-168；

[2] **Brintrup,A. (2010)，*Behaviour Adaptation in the Multi-agent, Multi-objective and Multi-role supply chain;*** *Computers in Industry*, 61,636–645；

[3] **Cauvin, A.C.A., Ferrarini, A.F.A., Tranvouez, E.T.E. (2009)，*Disruption Management in Distributed Enterprises: A multi-agent mMdelling and Simulation of Cooperative Recovery Behaviours,*** *International Journal of Production Economics*, 122, 429–439；

[4] **Forget, P., D'Amous, S., Frayret, J., Gaudreault, J. (2009)**, ***Study of the Performance of Multi-behaviour Agents for Supply Chain Planning;*** *Computers in Industry*, 60,698–708；

[5] **Gilbert, N., Pyka, A., Ahrweiler, P. (2001)**, ***Innovation Networks - A Simulation Approach.*** *Journal of Artificial Societies and Social Simulation*, vol. 4, no. 3；

[6] **Gilbert, N., Terna, P. (2000)**, ***How to Build and Use Agent-based Models in Social Science.*** *Mind & Society*, 1, 57-72；

[7] **Jiao, J., You, X., Kumar, A. (2006), *An Agent-based Framework for Collaborative Negotiation in the Global Manufacturing Supply Chain Network.*** *Robotics and Computer-Integrated Manufacturing*, 22, 239–255；

[8] **Kwon, O., Im, G.P. Lee, K.C. (2007)**, ***MACE-SCM: A Multi-agent and Case-based Reasoning Collaboration Mechanism for Supply Chain Management under Supply and Demand Uncertainties.*** *Expert Systems with Applications*, 33, 690–705；

[9] **Shaw, K. L., Wagner, K. (2008),** ***Cricketsim: A Genetic and Evolutionary Computer Simulation;*** *Journal of Artificial Societies and Social Simulation* vol. 11, no. 1, available on line at http://jasss.soc.surrey.ac.uk/11/1/3.html；

[10] **Tunca, I. T., Zenios, S. A. (2006)，** ***Supply Auctions and Relational Contracts for Procurement;*** *Manufacturing & Service Operations Management*, 8, 43-67.