Multi-Agents Model and Simulation for the Evolution of Industrial Clusters

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***Abstract*—By using multi-agents system model simulation method, this paper tries to reveal the key driving force for the evolution of industrial clusters under the dynamic development of the external environment and internal innovation. Also, how important role of policy recommendations is proved for the regional industrial development. For the purpose of studying the evolution of industrial clusters, a multi-agent system model is constructed and the model's learning algorithm addressed on genetic algorithm. First, industrial clusters are formed as a conceptual system which corresponds to a virtual multi-agent system and the basic genetic algorithm is employed as an agent's intelligent learning algorithm. Then, simulation results are carried out by conducting the learning algorithm on Matlab7.0 to simulate the evolving behaviors of the multi-agent system. By mapping the corresponding simulation results back to the conceptual system, the evolving rules of the industrial clusters are revealed thereafter. The study by this method shows that the evolution of industrial clusters comes from the complex interaction of inner agents by themselves. The leading actions of initiative enterprises are the fundamental factors in the process of evolution of industrial clusters. Finally, the evolution trajectories of the agents are presented graphically that visibly verify and obviously describe the dynamic evolution process.**

***Index Terms*—multi-agents system; industrial clusters; genetic algorithm; dynamic evolution process**

I. Introduction

Industry cluster was first proposed in 1990 by American professor Porter, used to analyze these clustering phenomena from various aspects in details. He defines the industry cluster clearly as a group of some interactive relevance enterprises, specialization suppliers, service suppliers, financial institutions, relevant industry manufactures and other related organizations, all the members of the group settling in special region.

Economic globalization has led to the world division of labor and internationalization. In the global division of labor, the industrial cluster is a common industry approach and strategy selection in the world of regional economic development. In the past 20 years, many researches paid their attentions on industrial clusters, see [1] for details. In Asia, the phenomenon of industrial clusters in Guangdong, Jiangsu, Zhejiang of China, and other coastal provinces is particularly evident. The cluster has a strong vitality and it plays an important role in regional economic development. According to statistics, more than a third of its total industrial output value is produced by the current characteristics of industrial clusters in industrial output in Zhejiang Province of China. As it is known, industrial clusters effectively promote regional economic development in this way that it makes the regional economic integrate into the world so as to participate in the global division of labor markets and expand the global competition and collaboration.

Researches in management science have paid much attention to the controlling technologies on the business process of enterprise. In turn, the most corresponding results are employed in practical management by enterprises. Moreover, this controlling based type has a unique dominant position for the business management of one organization. Although much achievement has made in the micro-management field, the results are of little use for an enterprise at the macro decision-making level, i.e., the stratagem choice for one enterprise in a industrial clusters. From the macro-economic view, any enterprise in an industrial cluster is an independent subject which is called an "agent". The term was first proposed by Minsky in his well-known book in1986. Every enterprise is an agent in the cluster, with some intelligence. All agents form multi-agent systems acting interactively, a well introduction for multi-agent system can be found in [2] and more references therein.

This article focuses on multi-agent systems modeling and analysis of mechanism for the evolution of industrial clusters, mainly to explain the abstract concept of this model and system model framework for the potential cluster model, providing the basis for the evolution of the application framework.

Well then, it comes to our eyes that how this multi-agent system evolves, see [3], and how the agents interact in the system. A clear understanding on these rules has some practical content for the guidance of one enterprise to find its position among the industry clusters.

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Based on the evolution view point, the evolving rules of industry clusters are investigated by multi-agent system modeling method and the Genetic Algorithms is applied to describe the learning algorithm of an agent. All the results will be simulated by numerical experiments and the related analysis will focus on the manufacturing industry cluster in China.

II. Introduction Of Industrial Clusters

The nature of industrial agglomeration is the process of scale economies, scope economies and the joint effect of external economies. The importance internal mechanism formation of an industry gathering is cooperative and the importance external environment formation is systematic. Taiwan scholars used social network theory, see [4], to explain the phenomenon of clusters of SMEs in Taiwan. In the 21st century, the international industry is reflected in the emergence of new trends: the development of industry cluster grouping, ecological integration. It is the law of industry's development embodied in the practice of the three performance trends and it describes today's new features of industrial development uder the international economic changing for dynamic interpretation.

The industrial cluster network includes large, strong core enterprise groups which has leading management capabilities, business reputation, and excellent reputation in one regional business community. These core enterprises promote and maintain the appeal to the development of collaborative network members and makes the core businesses more harmonious.

Any one of the core business in a industrial clusters group represents an independent individual that has its own individual characteristics. The business activities of these individuals together promote the evolution of the entire industry clusters and their evolution. The evolution of industrial clusters leads to the changes and the evolutions of macro- industry.

III. Multi-Agent Systems Model

Multi-agents system, in short “MAS”, is composed of a number of agents which can interact mutually. Theories souring from the field of artificial intelligence, especially the ideas of agents and multi-agents systems produce broad influences in economics, sociology, bionomics and other fields.

Multi-agent systems theory is a new discipline developed in the last 20 years and the main research area focus on the behavior of complex systems and how it affects the overall system’s characteristics. As it is known, individual’s micro-action can lead to the system’s complex exhibitions, see [5], and this phenomena is named after the emergence property of the system. The reason for this is that the MAS is just a nature metaphor for human beings and biotic populations. Employing the multi-agents views can then naturally give a proper description for these systems and the method is called agent based modeling, i.e., ABM.

Shortly, multi-agent system is composed of two or more interacting systems. Features of a multi-agent systems are characterized by a limited perspective, see [6], that is, each subsystem owns incomplete information, limited capacity and has no global control ability. Furthermore, the data dispersion and calculation of the subsystems could not be in a parallel way, namely asynchronously.

Thus, MAS is actually an abstract intelligence community. Many real-world groups have these characteristics. In multi-agent system, each agent is autonomous entity and has relatively independence and the system’s complex relationship may appear from the interactive communication of different subjects.

Models based on the multi-agent are often solved by simulation experiments which microcosmic real properties, the decision-making logic and the behavior characteristics can be revealed through the interaction among the agents and between the agent and the environments.

Generally, agent’s microcosmic characteristic can hide the system’s macro features and thus, to reveal the system’s characteristics, there must build a model as the bridge of microcosmic and the macroscopic. Since the multi-agents models have the alternations that the member’s properties and behaviors have no limit at any levels in the systems, ABM method soon becomes a novel tool for studying the complex systems that composed of individuals with intelligence.

As it is well-known, economics is a science that studies human being using scarcity recourses to produce goods and distributing warfare’s among different populations. But, modern economics, as pointed by some economists, e.g., appears that the 1900’s economics are suffering from schizophrenia. This means the disconnections between microeconomics and macroeconomics in recent two decades. Fortunately, the multi-agents model system methods and its simulating provides a potential tool for filling up this gap between the two economics. Since a single enterprise in an industrial clustering owns all the specialties such as autonomies, interacts, preliminary acts, environment fitting and the selfish motives for profits, multi-agent based models, i.e., ABM, can be a well tool for the study of industry colony settlement.

Figure 1 describes a multi-agent system architecture diagram: The main system consists of several relatively independent main bodies; each body can partly affect the environment at least, and at the same time, there are complex interactions among the subjects.

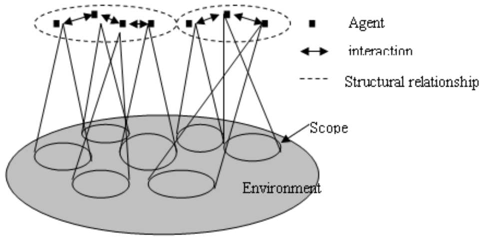

Figure 1 The standard structure of multi-agent systems

Multi-agent systems research consists of two intertwined aspects: one is about the realization of the subject and the other is the interaction between subjects.

For the purpose of studying multi-agent systems, the subject is the basic component and we must achieve a single subject. From the calculation view, the subject is a calculated entity with its own resources which is able to sense environmental information. The implementation of the subject's behavior, it will impact its own state and the environment, to achieve such a body, different structures can be employed. So, the basic structure is the definition of the main ingredients as well as the relationships and interactions between components of the mechanism. Using the appropriate structure for a particular application would be more natural and easier to understand.

Any agent has different levels of abstraction, from the most general level to the highest level abstraction, as shown in Figure 2. The main factors constitute the environment and each body interacts with the environment. In the top-level abstraction, the main action has a decision-making component, sensing the environment in some way to get environmental perception, and then input perception to the main target. Making component selection by one action or a group action will produce action output. Implementation of the action impacts on the environment will lead to the changes of the environment state. So, the main body and the environment interacts repeatedly and evolutes continuously.

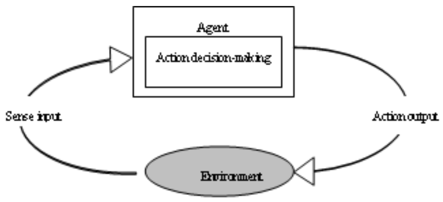

Figure 2 The high-level abstraction of the Agent

IV. Multi-Agent Model And Algorithm Of Industrial Clusters

A. Concept Model

Elements of multi-agent system model for industrial clusters are defined as follows:

Subject: enterprise in the industrial clusters

Environment: the society which is composed by the people, regime, finance, policy, government etc.

Interaction: Competition, cooperation, symbiosis, etc.

Structural relationship: according to [7], the subjects have same function and in the same industrial.

Table 1 shows the correspondence between industrial clusters and the concept for multi-agent system.

TABLE 1:
INDUSTRIAL CLUSTER---MULTI-AGENT SYSTEM

Multi-agent system	Industrial cluster
subjects	enterprise
environment	totally free market economy
Interaction	Competition, cooperation, symbiosis, etc. for enterprise
Structural relationship	The same function, in the same industrial

According the definition, it is clear that the subjects have all characteristics of subject weak concept, which is autonomy, social ability, and responsiveness, pre-mobility, see [8]. These characteristics deciding behavior mode of subjects must have the following symptoms:

Intelligence: each enterprise operates independently and adjusts their business strategy under the role of the market is the marketing environments and other enterprises activities. We assume that enterprises follow the principle of maximizing their own interests to guide their business behaviors. So, enterprises are going to study, summarize and change their business way according to revenue.

Learning ability: by [9], enterprises' learning ability is reflected in the summarizing of their business experience. They adjust themselves behavioral strategies to adapt to market environment based on market activity law in the past.

According to the above description, we present multi-agent system structure by Figure 3 of industrial clusters:

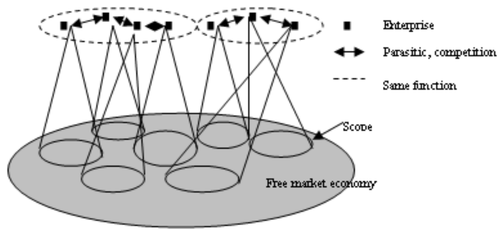

Figure 3：Multi-agent system structure picture of industrial

We classify the subjects based on business strategy:

Active R&D enterprise is defined as proactive agent, named Agent 1 and this type of agents will produce R&D action output by sensing from the environment.

Passive enterprise is defined as following-up agent, named Agent 2 and this type of agents will produce imitated action output by sensing from the environment.

Subjects' sense for environment is achieved by some learning algorithm, hence high-level abstraction of industrial clusters will dominate the behaviors of the multi-agent system, as shown in Figure 4.

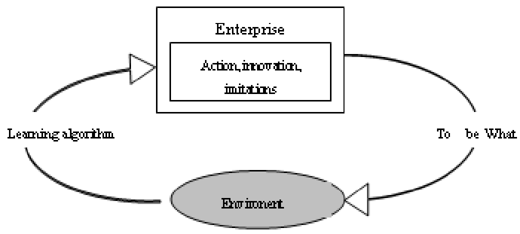

Figure4 High-level abstraction of industrial clusters' multi-agent system

For high-level abstraction of industrial clusters system, we must emphasize the following three points:

First, Top level stands for the enterprise's strategy space. Each strategy is target of enterprise's decision-making autonomy, which is a possible solution. Strategy space represents the set of all solutions, see[10].

Second, according to [11], every enterprise will improve its business strategy through business processes; the enterprises have an important characteristic of intelligent learning. Continuous repeated interactive modifying behavioral strategy helps the enterprise achieve the purpose of improving their performance. The learning algorithm is used to describe the process, and different system model have different learning algorithm.

Third, repeated modifying of subjects' behavioral strategy, see [12], leads to evolution of industrial clusters, overall system performance be reflected through modifying and changing of micro-behavioral strategy.

In the following step, we will employ SGA algorithm as the agent's learning algorithm which is described in details forthcoming.

B. Algorithm

In this paper, Genetic Algorithms is used to analyze the agent's behaviors. Since the pioneer work on genetic algorithms by Holland, it has been extended to other methods by a number of authors such as evolution strategy by Rechenberg and Schwefel, evolution programming by Fogel and genetic programming without doubt by Koza. Certainly, there are studies focusing on mixing these elementary methods to form the mix genetic algorithms, see[13], and the art of state as well as more references on this problem can be found therein.

As the broadest applied random searching method of evolution algorithms, genetic algorithm is the most powerful one which has been employed to solve various engineering problems and got great success. There are a great many of results reported in the applied areas on these hotshots of study. An elementary introduction book on genetic algorithm can be found by Alander. Since genetic algorithm is due to the evolution theory and genetic mechanism, some concepts of genetics and evolution are then employed in this algorithm, see [14]. The main concepts are as follows:

(1) Genetic code DNA arrangement of the genetic information;

(2) Chromosome: carrier of genetic substance composed a number of genes;

(3) Individuality: entity with some specialty being the basic structure treated by the genetic algorithm;

(4) Populations: number of chromosome generations;

(5) Fitness: parameter of the fitting degree for the environments.

For the composition of genetic algorithm, Michalewicz sums up in five parts as following:

(a) Genetic presentation of the problem's solutions;

(b) Method of creating the initial populations;

(c) Justifying superior or inferior of an entity according to the fitness value, i.e., fitness function;

(d) Genetic operator;

(e) Parameters.

Simple genetic algorithmic short "SGA", according to [15], is a genetic operation that acts on all populations and this operation uses only the basic genetic operators: selection, crossover and mutation. SGA provides the framework for all other genetic algorithms and its genetic operation process is simple and easy to understand. SGA can be formulated simply as "C-EP-M-S-Co-Mu-E", here

C: genetic method for coding
E: estimation for individuals
P: initial populations
M: mass of populations
S: selection operator
Co: crossover operator
Mu: mutation operator
E: ending conditions

Pseudo-code of SGA can be described as follows:

```
begin
    initialize P(0);
    t=0;
    while (t=T) do
        for i=1 to M do
            Evaluate fitness of P(t);
        end for
        for i=1 to M do
            Select operation to P(t);
        end for
        for i=1 to M /2 do
            Crossover operation to P(t);
        end for
        for i=1 to M do
            Mutation operation to P(t);
        end for
        for i=1 to M do
            P(t+1)=P(t);
        end for
        t=t+l
    end while
end
```

In the following section, we choose the SGA as the learning algorithm of the multi-agent models employed for investigating the evolutions of the industry colony settlements.

With the above descriptions, the article takes SGA as the tool to simulate the agent behaviors. According to the previous suggestions, each agent in the concept system of ABM is an intelligent entity with decision-making and learning abilities. That is each agent can adjust its business management so as to fit in the environments. Corresponding to the multi-agent system, each agent is a chromosome which can learn others in the system and we choose, as describe by [16], the SGA as its learning algorithm.

Accordingly, we have to give the detail description for the learning SGA.

chromosome coding:

TABLE 2.
CODING AGENT 1

Agent No.	role	resource	daily input	res. input

and

TABLE 3.
CODING AGENT 2

Agent No.	role	resource	daily input	imi. input

Here the left row means the number of agent,” role” means ”agent 1” or ”agent 2” and identifies each by ”1”or”0”, respectively, ”resource” means all the enterprise’s wealth, daily input means the producing input, ”res. input” means research input and ”imi. input” means imitation input. All the resource and input we present here by money amount.

Example:

TABLE 4:
A CHROMOSOME

23	0	50	20	15

This means an agent with No. 23, being ”Agent 2”, it owns all resource 50, daily input 20 and research input 15.

Fitness estimation: naturally, we choose the current profits of an enterprise as the fitness estimation function. According to the hypothesis (H2) and the complete free economics environments, the market requirement curve is linear with negative slope. Other assumptions are (H3) initial wealthy of the two agents are the same, e.g., S ; the unit cost for each product being the same, e.g., k .(H 4) the research cost of each product for agent 1 is C_c , see [17], and the imitating cost for agent 2 is a constant s .

From the well-known theory of manufacture’s creation, it follows that Agent 1 will get the profits by the decrease cost for each product:

$$x = \sqrt{2C_c / \alpha} \quad \text{.....................(1)}$$

where α is a random number applied to the β distribution $B(p,q)$ .In practical operation, there is a magnifying action on this cost reducing, let the magnifying coefficient be m . So, the unit cost in current period is given by

$$C_p = k - mx \quad \text{..................(2)}$$

Then, noting (H 3), we can get the production amount for agent 1 is

$$Q_c = \frac{S - C_c}{C_p} \quad \text{..................(3)}$$

For Agent 2, it follows that the unit cost in current period is given by

$$C_m = k - wmx \quad \text{...............(4)}$$

Where $w \in (0,1)$ be a parameter for the imitating degree, and the output production

$$Q_m = \frac{S - s}{C_m} \quad \text{...............(5)}$$

Assume that the number of Agent 1 is j and Agent 2 is n , it follows that the market requirement function given by

$$P = P_0 - l(\sum_{c=1}^{j} Q_c + \sum_{m=1}^{n} Q_m) \quad \text{...(6)}$$

where P_0 being a constant and l being the slope of the market requirement curve.

By (2), (4) and (6), it follows that the profits of Agent 1 and Agent 2 in current period, respectively, as

$$TR_c = (P - C_p)Q_c \quad \text{...............(7)}$$

and

$$TR_m = (P - C_m)Q_m \quad \text{...............(8)}$$

So, for any agent with No. i, (7) or (8) is employed to estimate the fitness of the agent. Let U_i denote the fitness value for agent i defined by previous equations.

Genetic operators: this part contributes to the main genetic operators employed in SGA, that is, the selection, crossover and mutation, see [18].

Selection operator: Using Holland’s roulette rule, suppose the amount of population is n , then the i th agent is chosen with probability

$$P_i = \frac{U_i}{\sum_{j=1}^{n} U_j} \quad \text{........................(9)}$$

Crossover operator: Let S_i be the wealthy of the i th agent. Crossover means for two agents, e.g., agent i and agent j , how they will reapportion their wealth in next business programming. Here, we give the alignment proportion for the i th agent as follows.

$$S_i = \frac{U_i}{U_i + U_j} S_i + \frac{U_j}{U_i + U_j} S_j \quad \text{......(10)}$$

Mutation operator:

To produce new agents and then create new populations, we add a random number to all the agents’ wealth and choose a mutation probability to control the mutation proportion in the previous populations.

IV. SIMULATION AND ANALYSIS

This section gives the simulation results which are conducted on Matlab and the analysis about the results. We first give all the parameters appearing in the previous section and choose the mutation probability, crossover probability shown in the following table.

TABLE 5:
PARAMETERS

amount of population	60
percent of agent 1	0.3
initial resource	8000
unit cost	600
p	3
q	7
P_0	1200
l	1200
m	3
n	0.6
w	0.9
crossover probability	0.05
mutation probability	0.5
ending generation	100

Two simulation visualization graphs come out. One is Market price fluctuation diagram and the other is agent character selection chart. Output of the experiments is the role choice of agents in the market, as shown in diagram by the following Figure 5.

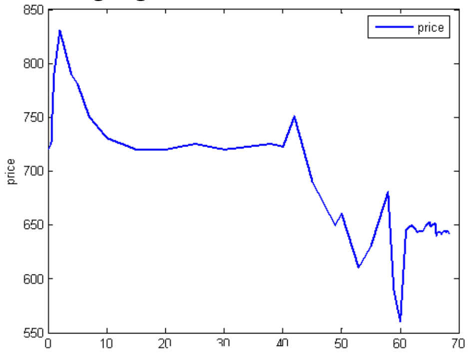

Figure 5 : Fluctuation of Market Price

From Figure5, it is easy to see the following results being guaranteed.

At the beginning of the industrial development, without experience of business strategy for reference, the enterprises usually randomly adopt management strategy to enter the market. Because of the significantly lower market supply, the market price is on the high side. All the enterprises in market can acquire higher profits, because the earlier technology and experience of the industry are not very mature. Since the cost of R & D and the risk is very high, there will be a part of the active research and development enterprise to change its role to a passive type enterprise and then market supply of products is reduced further, market prices continuing to rise finally.

With the active enterprise changing the role of quantity, market supply is reduced to the extreme; the market price gets to the peak. But with the accumulation of market experience, as well as the market active enterprises excess profit and development results of the technical progress, the initiative innovation enterprise market supply will be released, plus passive business output, the supply increases rapidly, and the market price starts to fall. In this process, some passive companies will also change the role to the active one. Thus the market initiative in enterprises and passive enterprises ratio tends to be stable, and the market supply is stable. So when the market price is reduced to a certain value, a smooth phase in the price chart will appear.

With the further growth of industry, research and development maturity is further improved. Innovative market environment has been formed. The market supply gushes out, so the market price goes sharply lower and appears drastic fluctuation.

Along this market's volatility, market can continue to perform industrial distillation of enterprises that will be transformed into active R & D. At this time the industrial group evolution becomes relatively stable. With the reaction in the market prices rising, price will have a slight fluctuation but range is not big. The smooth running of the stable development of industry form appears in the economic arena.

Also, some information can be afforded to us from the Figure 6 in the following.

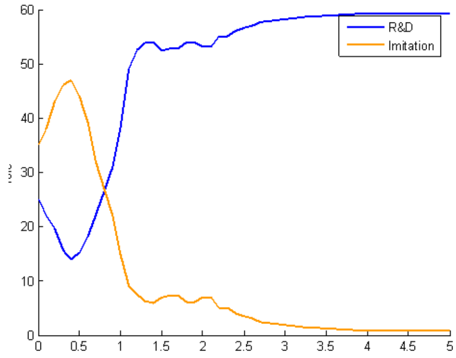

Figure6 : Role of Enterprises vs. time

The beginning of industrial development market in the passive follow-up enterprises presents a rapid increase trend. With the market price trend in full compliance, the overall market price becomes higher. The passive follow-up of the profit lets large enterprises make this choice. Conversely, as the primary industrial development R & D cost is high, market risk, active enterprises shows a rapid decline trend. By comparison of two graphics, information can be easily found: when market price reaches the highest the market in the passive role also gets the maximum.

When the market price tends to be stable, the market proportion between active enterprise and passive enterprise will be stable. This is the first segment of the market price of smooth curve to form reason; with the industry's further development, active enterprises will rise sharply, and the industry supply appear to emerge in large numbers. A fluctuation period of violent price in figure 5 appears. According to the later of figure 6, the number of active enterprises has a gentle increase. At the same time, fully matured industry development, reflection in the market price of the second half appears as the Figure 5 shows. At the later of this stage the passive enterprises gradually tend to zero but not equal to zero, because the profit space of this type market is compressed but voids or some.

V. CONCLUSION

Much study focused on the industrial clusters has been an active research in the field of economic management more than ten years. Industrial clusters economically operate breaking down their regions and this mode has a broad distribution over the field of China. Different types of industrial clusters there are over different regions of China, especially the developed regions.

Any key enterprise of industrial clusters has some special characteristics as an independent individual. The business activities of these individuals jointly promote the evolution of the entire industry clusters which then inspires the evolution of the entire macro-industries.

All along, research area of management science has paid much attention to the controlling technologies on the business process of enterprise and the most corresponding results, in turn, are employed in practical management by enterprises. Moreover, this controlling based type has a unique dominant position for the business management of one organization. Although much achievement has been made in the micro-management field, the results are seldom used for an enterprise at the macro decision-making, the stratagem choice for one enterprise, by the controlling based method.

From the macro-economic view about an enterprise's management, any enterprise in industrial clusters is an independent subject. Every enterprise like an agent which has some intelligence, and thus a system of agents is formed. Well then, it comes to our eyes that how this multi-agent system evolves and how the agents interact in the system. A clear understanding on these rules has some practical content for the guidance of one enterprise to find its position among the industrial clusters.

From the evolution view point, the evolving rules of industry clusters are investigated by multi-agent system modeling method and the genetic algorithms is employed as the learning algorithm of an agent.

Operation of industrial clusters is a cross organizational and geographic boundaries economic mode, operated enterprises in the cluster are independent business entities, each enterprise is an independent subject, and these subjects composed interactive multi-agent system. The evolution of industrial cluster stem from mutual adaption of enterprise and environment, and system evolution process of interaction among enterprises. The evolution of enterprise in cluster is a process of learning and accumulation, R & D and innovation is the fundamental driving force for the evolution of the cluster, and determinant for maintaining continuity of industrial clusters

Because considerations are not comprehensive enough, in the paper, we made a great simplification for evolution model of industrial cluster; actually, actual economic environment may be more complicated. For example, the impaction of information flow and capital flow for evolution in the cluster has not been taken into account. And we analyze the autonomy of the enterprises in the cluster maximatily. These problems will be new topics for the future research of evolution of industrial clusters.

The study in this paper shows that the evolution of industrial clusters comes from the complex interaction of agents so as to adapt to the environment. The fundamental power for the evolution of industrial clusters is the leading action of initiative enterprise. It is the case that the innovations of these enterprises drive the whole industry as well as the development of industry clusters.

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