Self-organizing Evolution Mechanism of Regional Logistics System Based on Biology Community Theory*

Lingyun Zhou[1], Mu Dong[1]
1. School of Economics and Management of Beijing Jiaotong University, Beijing 100044, China
zlycsu@163.com; mueast@gmail.com
Yuehwern Yih[2]
2. School of Industry Engineering of Purdue University, West Lafayette, IN, 47906, USA
yih@purdue.edu

***Abstract*—the development of regional logistics system is a typical self-adapting and self-organizing evolution process. According to the structures and operation of regional logistics, the self-organizing characteristics of regional logistics synergetic evolution are analyzed. Moreover, the space evolution phases of regional logistics system are educed based on the complex system theory, and the enterprise community and industry evolution rules of regional logistics system are deduced on the basis of the comparability between biology community and regional industry community with the niche theory of biology community. Furthermore, the self-organizing evolution equations of regional logistics system are built to find evolution order parameters, and the synergetic development mechanism of regional logistics system is put forward for effectively adjusting the regional logistics industry structures and accelerating the synergetic evolution of regional logistics.**

Keywords-regional logistics system; self-organizing; biology community; synergetic evolution; complex system

I. INTRODUCTION

Synergetic development has been the aim and trend of human society and economy development. Nowadays, many enterprises often rely on the synergetic strategy in supply chains to win the marketing [1-3], and many countries, regions and cities are also implementing and perfecting the synergetic strategy of regional economy to accelerate the regional development [4-6]. Regional logistics system that is one of regional systems is the integration of all kinds of logistics systems and elements in one regional zone with the common economic attribute. Moreover, it is the artery of country and regional development, the accelerator of regional economy, the ligament linking the production and consumption, the basis of society development and human living level elevation and the symbol of evaluating the modernization level of one regional zone. The synergetic development of the regional zone needs the synergetic development of the regional logistics system. People must grasp the evolution law of regional logistics under the framework of regional synergetic development according to the characters of the regional station, industries, circulation, and then establish the synergetic development mechanism and platform; thereby people can accelerate the synergetic and orderly evolution of the regional zone.

The establishment of regional synergetic logistics system will play an important role in improving the efficiency and quality of regional logistics, and it is propitious to reduce the repeat logistics building and make full use of public infrastructure and information resources, moreover, it can accelerate the rationalization layout of regional logistics, reduce logistics cost, enhance the competition ability of regional logistics, and realize the synergetic and continual development of regional logistics. Some researchers have been paying more attention to the synergetic development of regional logistics system, and they have obtained some research achievements from different perspectives. Ralf Elbert and Robert Schönberger analyzed how regional value chains speed up global supply chains through logistics cluster [7], and Haasis and Elbert also analyzed the regional logistics effects and functions in global supply chains from logistics cluster perspective [8]. Moreover, autonomous co-operation and complex adaptive systems theory were applied in logistics and supply chain network research, and some the complexity and adaptability of regional logistics and supply chain were discussed [9-13]. Furthermore, the synergy connotation and mechanism of regional logistics system drawed some attentions, and Qingqing Xu and Lixin Miao put forward the synergy development modes of regional logistics [14], and Jianzhi Gao, Yao Zhao, etc., analyzed the coordinated development framework of regional logistics system including the internal coordination and the external coordination [15]. The paper will integrating use biology community theory and complex system theory and try to study the self-organizing evolution mechanism of regional logistics system based on the comparability between biology community evolvement and regional logistics development.

II. THE SELF-ORGANIZING CHARACTERISTICS OF REGIONAL LOGISTICS SYSTEM

The regional logistics system is a self-adapting and self-harmonizing system, which consists of all logistics industry subsystem in one region, including transportation, storage, distribution, load and unload, transit, packaging, circulation process, information service, etc. The regional logistics system is also a self-organizing system which is evolving from an old structure to a new structure. The nonlinear connection between logistics industries in a regional zone is a result of cooperation and competition of logistics industries, which is developing from an out-of-order state in the elementary phase to an orderly state in advanced phase. The regional logistics system has the following characteristics.

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A. *Opening characteristic*

The regional logistics system is an opening system, which can exchange matter, information, energy with the environment. On the one hand, the environment put forward the all kinds of matters, information, people and capital for logistics system, and has an important effect on the business strategy of all enterprises in logistics system. On the other hand, logistics system outputs product, technologies, service, etc. Moreover, it can be suitable for the demands of the environment, try its best to change the environment, and establish the favorable development environment. The main characteristic of the opening is the input and output exchange between the logistics system and the environment. Nowadays, information and knowledge, in place of ground, matter and capital, become the dominant resources of logistics system.

B. *Non-balanced characteristic*

The regional logistics system is not an isolated or silent system. It connects the out environment nearly, and it varies by time. Moreover, its bosom has the characteristics such as heterogeneity and diversification, and its resource distributing, developing of its subsystems, etc. are non-balanced, so it is one kind of system apart from the non-balance status. The self-organizing theory emphasizes that the non-balance status is the source of balance status. In the developing process of regional logistics industries, only the establishment of the synergetic mechanism can break the balance status, make the logistics system be apart from the balanced status and keep the vitality of regional logistics system.

C. *Fluctuating magnification*

Achieving the order of systems through fluctuating magnification is the basis principle of self-organizing theory. In one open system apart from the balanced status, fluctuating is the inner factor of system evolution, which plays the constructive role. If there is no fluctuating, the system will not perceive the new order structure, and then there are not the nonlinear association magnification and the forming of the order parameter, so the evolution of the system will not operate. Because of the effects of inner and exterior factors in the logistics industry system, the fluctuating magnification is ubiquitous, for example, the differences between logistics industries, the heights of logistics technologies, the height of person ability, the fluctuating of capital, and so on.

D. *Nonlinear effects*

One main opinion of the self-organizing theory is that the mutual effect between elements or subsystems is the fundamental mechanism of system order evolvement. Depending on the nonlinear effects, one system brings the whole action. The mutual nonlinear effects include mainly the following aspects: the mutual effects between logistics industries, between logistics enterprises and between logistics organization departments; the mutual effects among logistics technology innovation, organization innovation and market innovation; the mutual effects among capital, technology and labor. Moreover, there are differences in these effects on the system, and these effects are imbalanced. After the dominating variables make the system pass through the critical instability spot, the kind of differences and imbalances will emerge.

III. THE SELF-ORGANIZING EVOLUTION PHASES OF REGIONAL LOGISTICS SYSTEM

The regional logistics system is a complex system, which locates in the complex exterior environment. The regional logistics system and its environment are affecting and depending on each other. During the exchanges between them such as information, energy, capital, knowledge, etc., the regional logistics system begins to ceaselessly evolve, so the regional logistics system is a dynamical complex system. The evolution of regional logistics system composes a dynamical evolution process, which includes the evolution of space system and industry system of regional logistics.

A. *Evolution Phases of Regional Logistics Space System*

Due to the non balance of region economy, the forming and developing phases of regional logistics space system in different periods are similar with the forming and developing phases of regional economy. The evolution phases of regional logistics system are illustrated as table Ⅰ according to the city economy evolution theory.

TABLE Ⅰ. COMPARABILITY BETWEEN CITY ECONOMY EVOLVEMENT AND REGIONAL LOGISTICS SPACE EVOLVEMENT

Evolvement of regional economy	Synergetic evolvement of regional logistics space system
Point region economy	Point convergence of regional logistics enterprises
Line region economy	Line convergence of regional logistics enterprises
Network region economy	Strip convergence of regional logistics industry
Circle region economy	Circle convergence of regional logistics industry

1) Point Convergency Evolution of Regional Logistics

Because of historical, factitious or haphazard factors, the cities and towns came into being, which made the point economy of city and town form. Logistics is the important supporting system for the development of city and town, and there are logistics demands in these cities and towns, so some logistics resources enter the new areas where the basic conditions of logistics are good and the economy develops well. With some relevant logistics enterprises entering the area, the point convergence trend of regional logistics comes into being in the area. Because of the economy of city and town is primordial, there are only few regional logistics enterprises in the development phase,, and the density and competence of regional logistics enterprises is low. Thereby, the point convergence phase is the beginning period of regional logistics system.

2) Line Convergency Evolution of Regional Logistics

With the development of city and town, the goods interchanging demands between cities and towns increase rapidly, so the logistics channels such as roads, railways and inland came into being. These logistics channels can improve the economy and attracts the economy resources and elements to get together along theses logistics channels. Furthermore, there are more specialization work subdivisions between logistics enterprises, and thereby the line convergence of regional logistics enterprises comes into being. Theses logistics channels connect cities and towns each other, the line convergence characteristic of regional logistics enterprises become more obvious with the economy development of these cities and towns. In the phase, regional logistics enterprises get together, and all logistics subsystems compete with each other. Therefore, the phase is the fast developing period of regional logistics enterprises.

3) Network Convergency Evolution of Regional Logistics

With the development of regional economy, there are more regional logistics demands, which accelerate the constructions of logistics channels and nodes. Under the niche conditions of the logistics industry, the agricultural logistics infrastructural network is gradually taking form and being perfected, and moreover the line convergence of regional logistics industry can self-evolve as one new state because of many exterior and interior factors, such as the demands of exterior environment, the construction of interior infrastructure, all kinds of random fluctuating, etc. On the basis of the line convergence of regional logistics and regional economy, all kinds of regional logistics channels, nodes and logistics subindustry begin to emerge. Thereby, the line convergence of regional logistics upgrades, moreover, the line convergence of regional logistics enterprises can self evolve as the network convergence of regional logistics industry.

4) Circle Convergency Evolution of Regional Logistics

With the development of regional logistics network, more and more regional logistics networks come into being, the superposition reaction and synergistic effect of regional network go into effect, and the radial force of regional logistics network upgrades, therefore, the network convergence of regional logistics can enter one synergetic development state through the driving of the network city economy, namely when parameters of outfield and interior control parameters reach critical values, the network of regional logistics can enter the regional logistics circle convergence phase. The circle convergence of regional logistics is with the characteristic of high homogeneity and has the powerful attractive force and radiation force, so it can make the regional economy enter the integration development.

B. Evolution Phases of Regional Logistics Economy System

Due to the comparability between biology community and regional industry community [16], the forming and developing phases of regional logistics system in different periods can be deduced based on the niche theory of biology community in bionomics [17]. The evolution phases of regional logistics system are illustrated as table 1 according to the ecosystem evolution theory.

TABLE I. COMPARABILITY BETWEEN BIOLOGY COMMUNITY AND REGIONAL INDUSTRY COMMUNITY

Evolvement of biology community	Synergetic evolvement of regional logistics system
inbreak phase	inbreak convergence of regional logistics enterprises
ecesis phases	community of regional logistics enterprises
development phase	regional logistics industry cluster
evolution phases	regional logistics creative network

1) Inbreak Phase: Inbreak Convergency Evolution of Regional Logistics Enterprises

The inbreak convergence of biology community denotes that biology species leave the initial circumstance and move to a new environment for living because of natural and human factors [18]. The transfering and scattering is the precondition of biology species. Because of historical, factitious or haphazard factors, some logistics enterprises enter the new area in which the niche conditions of logistics are good. The logistics niche attracts some relevant logistics enterprise to get together, and then the convergence trend of regional logistics enterprises comes into being. In the development phase, there are few regional logistics enterprises, and the density of regional logistics enterprises is low, so there is almost no competence in logistics market. Besides, there is no specialization of work subdivision in the logistics area, so the usage rate of logistics resources used by logistics enterprises is very low.

2) Ecesis Phase: Evolution of Regional Logistics Enterprise Communities

The ecesis phase of biology community denotes that one biology species begin to grow, develop and propagate in the new environment after transfering. In the phase, some biology species can live and propagate after transfering, but other biology species have not the competition ability and may disappear because they are exclude by some resident biology species, thereby the ecesis phase is also called the interactional phase. The regional logistics enterprise community denotes the colony that centralize and work together in the specifically area for jointly completing the regional logistics service production and tasks, and it is formed due to the self multiplying and work subdivision specialization of regional logistics enterprises. The phase is the middle development period of regional logistics in which every logistics enterprise must face the keen competition, and the obvious characteristic of the phase is the accessibility of zone space and logistics speciality.

3) Development Phase: Evolution of Regional Logistics Industry Cluster

The development phase of biology community denotes that the survival biology species develop well together by sharing and taking full use of natural resources. In the phase, these good characteristics of biology community are remained by evolutionary genetics [19], and the amount of

biology community and density are increased, and the relative balance between biology species is realized through the biology competition. Enterprise community can evolve into an industry cluster through the competition and co-evolution [20]. The regional logistics industry cluster denotes that regional logistics subindustry leaded by one or several dominant agents aggregate and form the regional logistics system of industry cluster, and it is evolved from regional logistics enterprise community into a new steady phase with such characteristics as reasonal layout and synergic development, namely under the nonlinear effects between regional logistics enterprise community subsystems, the order parameters are produced to compel logistics enterprise community to evolve into a more efficient and reasonable system. The regional logistics industry cluster has such characteristics as the comparability in space, industry and society, the synergy between agents, etc., so it is the advanced phase of regional logistics economy development.

4) Synergy Evolution Phases: Evolution of Regional Logistics Creative Network

The synergy evolution phase of biology community denotes that one biology species can evolve into a new species to adapt itself to the change of other biology species. The synergy evolvement of biology species make them adapt to each other and jointly develop well, and the compose and amount of biology species are more reasonable. Under the driving of random fluctuation and the domination of order parameter, industry cluster may a more advanced system [21]. Thereby, a regional logistics industry cluster can evolve into a regional logistics creative network with the highest stabilization and rationality through the synergy of study, technology, service and operation. The regional logistics creative network denotes that all regional logistics agents and subsystems form a synergic service network through the creative resource flow and allocation, and it has such obvious characteristics as the comparability of space, industry and society between agents, the regularity of competition synergy and dynamic innovation, so it is the most advanced phase of regional logistics industry cluster.

IV. THE SELF-ORGANIZING EVOLUTION MECHANISM OF REGIONAL LOGISTICS SYSTEM

A. Evolution of the Communities of Regional Logistics Enterprises

With the convergence development of logistics enterprises, there are more specialization work subdivisions between logistics enterprises, and thereby the community of regional logistics enterprises comes into being. During the evolution process, there are interchanges of matter, energy, information and capital between regional logistics system and its external environment, so the regional logistics system is affected by the interfering of its external environment and interior fluctuating; thereby the state of regional logistics subsystem, namely X, is random variable. If X_0 is average stationary state value of X, the real state of regional logistics system in the time of t is X_t, so the state variable of regional logistics system is expressed by

$$X(t) = X_t - X_0 \tag{1}$$

If the logistics system consists of n subsystems, according to the synergetic theory and nonlinearity dynamics theory [22], the state change of the whole logistics system is expressed by

$$\dot{X}_i = \frac{dX_i}{dt} = K_i(X_1, X_2, \cdots, \mathrm{X_n}) + \Re_i(t) \tag{2}$$

where $i = 1, 2, \cdots, n$, and X_i is state variable of logistics subsystem i, the damp force K_i is the nonlinearity function of all subsystems, namely $\{X_1, X_{2,} \cdots, X_n\}$. $\Re_i(t)$ is the random force of logistics subsystem i. In order to analyze the equation expediently, the random force $\Re_i(t)$ is ignored at first, and then according to (2), there is

$$\dot{X}_i = \sum_{j=1}^{n} \alpha_{ij} X_j + f_i(X_1, X_2, \cdots, \mathrm{X_n}) \tag{3}$$

Where $f_i(X_1, X_2, \cdots, \mathrm{X_n})$ is a nonlinear function. Because the stationary state is steady, the coefficient matrix of the linearity item of (3), namely (α_{ij}), is absolutely negative, so a new set of variables is introduced to make (α_{ij}) diagonalizable [23], thereby, there is

$$\dot{Y} = -\gamma_j Y_j + g_j(Y_1, Y_2, \cdots, \mathrm{Y_n}) \tag{4}$$

Where $j = 1, 2, \cdots, n$, and $\{g_j(Y_1, Y_2, \cdots, \mathrm{Y_n})\}$ is a set of nonlinearity function related to the state variables all logistics subsystems, and the damp coefficient $\{\gamma_j\}$ often varies with the environment conditions. In the stage, all logistics subsystems compete with each other; their movement is not only associated but also disorderly. If the affection of random force is taken into account, these subsystems only fluctuate disorderly.

B. Evolution of the Cluster of Regional Logistics Industry

With the development of communities of regional logistics enterprises, more and more regional logistics enterprises get together, and there all kinds of logistics sub-industries, such as transportation, storage, distribution, load and unload, transit, packaging, circulation process, information service, etc. Therefore, the community of regional logistics enterprises can enter one synergetic development state through the nonlinearity reciprocity between all logistics subsystems, namely when parameters of outfield and interior control parameters reach critical values, the community of regional logistics enterprises can enter the critical state. During the process, the state variables

$\{Y_1, Y_{2,} \cdots, Y_n\}$ of all logistics subsystems include order parameter u which dominates the future development of the community of regional logistics enterprises. According to synergetic theory, when the control parameters of one system reach critical values because of environment change, order parameter u can bring the phenomenon of critical slowing down, and its damp coefficient will move to zero. Therefore, make $Y_1 = u$, then when the community of regional logistics enterprises enters the critical state, there is

$$\gamma_1 \to 0 \tag{5}$$

And the other γ_j is more than zero, namely $\gamma_j > 0$ ($j = 2, \cdots, n$). Here, u is independent variable; the other variables such as $Y_2, Y_{3,} \cdots, Y_n$ are dependent variables. According domination element of synergetic theory, the dependent variables can be processed with adiabatic approximation way [22], namely

$$\dot{Y}_j = 0 \qquad (j = 2,3, \cdots, n) \tag{6}$$

Consider (6) and (4), there will be:

$$\begin{cases} \gamma_2 Y_2 - g_2(u, Y_2, Y_3, \cdots, Y_n) = 0 \\ \gamma_3 Y_3 - g_3(u, Y_2, Y_3, \cdots, Y_n) = 0 \\ \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\ \gamma_n Y_n - g_n(u, Y_2, Y_3, \cdots, Y_n) = 0 \end{cases} \tag{7}$$

After solving (7), the gained solutions are as following

$$\begin{cases} Y_2 = h_2(u) \\ Y_3 = h_3(u) \\ \cdots\cdots\cdots\cdots \\ Y_n = h_n(u) \end{cases} \tag{8}$$

Equation (8) shows that variables such as $Y_2, Y_{3,} \cdots, Y_n$ vary with u , namely the movement of all region logistics subsystems are dominated by order parameter in region logistics systems [24]. The domination brings the coherent movement which shows the order characteristics in time, space and function, thereby, forces the community of regional logistics enterprises to evolve into the state of regional logistics industry cluster.

C. Evolution of Rregional Logistics Creative Network

Under the niche conditions of the logistics industry, regional logistics industry cluster can self-evolve as one new state because of the changes of exterior environment, the influences of interior factors, all kinds of random fluctuating, etc. Consider (5), (8) and random fluctuating, (4) can be switched to

$$\begin{aligned} \dot{u} &= -\gamma_1 u + g_1(u, Y_1, Y_2, \cdots, Y_n) + \Re(t) \\ &= -\gamma_1 u + g_1(u, H_2(u), H_3(u), \cdots, H_n(u)) + \Re(t) \\ &= K(u) + \Re(t) \end{aligned} \tag{9}$$

Equation (9) is evolution equation of order parameter in regional logistics systems where $K(u)$ is the nonlinearity function related to u and $\Re(t)$ is random fluctuating force. The equation shows that the development and evolution of the whole region logistics systems is dominated by the order parameter in region logistics systems. The order parameter u is one subsystem of region logistics systems, and it represents the dominative logistics industry. The order parameter u is a scalar quantity, also a vector. If u is a scalar quantity, it shows that there is one dominative industry in logistics systems; If u is a vector which is m m dimensional array, namely $\vec{u} = (u_1, u_2, \cdots, u_m)$, it shows that there is m dominative and acting industries of logistics systems at the same time.

According to the synergetic theory and nonlinearity dynamics theory [22,23], the order parameter equation of region logistics systems can be view as the random motion equation of nonlinearity damp oscillator from the view of generalized sense. $\Re(t)$ is the stochastic driving force, and $K(u)$ is the restoring force of damp oscillator. $V(u)$ is the restoring force potential of $K(u)$, it satisfies the following requirements:

$$K(u) = -\frac{\partial}{\partial_u} V(u) \tag{10}$$

Here, the evolution equation of order parameters of region logistics industry cluster system turns into

$$\dot{u} = \frac{du}{dt} = -\frac{\partial}{\partial_u} V(u) + \Re(t) \tag{11}$$

As a result, the development and change of region logistics industry cluster system is under the leading of restoring force potential $V(u)$ and the driving of stochastic fluctuating force. So the shape of $V(u)$ and its leading trend ultimately dominate whether the region logistics industry cluster system will evolve into more advanced system, or fall into a decline. In the specific logistics region, the shape of $V(u)$ and its leading trend are affected by the niche conditions of logistics industry, region industry field, exterior control parameters, etc. When industry field and exterior control parameters reach critical values, the regional logistics industry cluster system can enter the critical state under the certain niche conditions of logistics industry, equation (11) will bifurcate solutions, namely bifurcating phenomena. Here the regional logistics industry cluster system may evolve into regional logistics creative network system if the leading trend goes upwards, thereby the region logistics systems will extend its functions. On the contrary, the regional logistics industry cluster system may

fall into regional logistics enterprises community system if the leading trend goes upwards, thereby the region logistics systems will reduce its function grade.

V. CONCLUSION

The forming and developing course of regional logistics system is the evolution process from one system structure to another system structure. The synergetic evolution simulation of regional logistics system is important, and it can provide the decision support of regional logistics industry development with relevant decision makers.

According to the evolvement of biology community theory, the evolution phases of regional logistics system in different phases should include such four phases as convergence of regional logistics enterprises, community of regional logistics enterprise, regional logistics industry cluster and regional logistics creative network.

At the beginning, some logistics enterprises enter some new areas with good logistics niche conditions because of historical, factitious or haphazard factors, and the logistics niche attracts relevant logistics enterprise to get together and produces the convergence phenomenon of regional logistics enterprises.

With the convergence development of logistics enterprises, there is more specialization work subdivision in logistics, and thereby the community of regional logistics enterprises comes into being.

Moreover, the communities of regional logistics enterprises can evolve into the state of regional logistics industry cluster through the nonlinearity reciprocity between logistics subsystems when parameters of outfield and interior control parameters reach critical values.

Under the niche conditions of the logistics industry, regional logistics industry cluster can self-evolve as one regional logistics creative network system because of the changes of exterior environment, the influences of interior factors, all kinds of random fluctuating forces, etc. But the regional logistics industry cluster system may fall into regional logistics enterprises community system if the logistics niche conditions are not good, and parameters of outfield and interior control do not reach critical values. So logistics niche, outfield environment are also very important for the development of regional logistics industry.

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