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Emergence as a process of resources flowing in supply chain system

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Abstract: To accurately describe the resource values that agents possess in the complex supply chain system which is a result of the interaction among the agents and to make correct decisions regarding quantity, time and place of the resources, the characteristics of the resource values in the supply chain are analyzed. "Chromosome" is used to express a resource value in the supply chain, and eight random numbers are used to integrate the resources. The if-then rules and correlation chance constrained programming in the resource supply-distribution model are set up and they are used in a three-tiered-echo model which can describe the kinds of interactive behavior of the agents in the supply chain system. Simulation is done in the platform of Swarm with a genetic algorithm. The results show that the resources in the supply chain complex adaptive system are an organic whole that cannot be separated. The three-tiered-echo model can accurately describe the interaction of resource flows of agents in the supply chain system. The system can attain optimization by utilizing the resources in the supply chain if the agents in the system cooperate, compete and distribute resources according to this model.

Key words: resources flow; agent; simulation

The relationship among the agents in the supply chain mostly depends on the resources that are possessed by the chain. Furthermore, the management, the technology, the information, the ideologies of the corporation, and/or their inseparable combination, is the core band. The more effective the operating system, the stronger the core competitive capabilities[1]. In theory, a general equilibrium statement, every resource of any agents flowing in harmony with each other that makes the agents feel satisfied must be found. However, a quasi-equilibrium statement can be found because the complex environment concerning the supply chain system, in practice, can hardly be forecasted correctly.

In recent years, the complex system of supply chains has been studied to some degree[2-5]. The results of such studies point out that the major reasons for the complexity of supply chains are as follows: ① The mass of the supply chain; ② The complexity comes from the interaction among every flow of every node in the system; ③ The relationship among every agent and the form of the web are very complex; ④ The supply chain system is a dissipative system; ⑤ Emergency must be considered as part of the interaction among the agents in the supply chain system; ⑥ The supply chain system is a dynamic system. Most researchers think the complexity of a supply chain system comes from the uncertain changes in the following factors: politics, the economy, the culture, the society, competition and cooperation between/among the companies, the market demand, the intricate structure of the supply chain, parallel engineering in the supply chain system, and so on.

Overseas, it has been studied more deeply. The echo model[6] created by Holland gives us a good idea that describes deeply the rules guiding resource flows in the supply chain. However, it does not describe strictly the quantities of resources flowing in the net, which creates difficulties regarding the distribution of resources to every agent[7]. The faults must be improved in our study. These improvements are important. To modify these faults, the three-tiered-echo model, which regards all kinds of resources possessed by the agent as integrated, is created. In the next section, we will explain it in detail. In this paper, the author will research deeply the resources that flow in the supply chain system.

1 Resources and Their Environment in Supply Chain

1.1 Resources

In the complex adaptive system of the supply chain, equipment, commodities, funds and people are the material resources; however, the technology, information, culture, management, business philosophy and marketing are the intangible resources[8]. The resources in the supply chain system not only consist generally of

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all the material resources and the intangible resources, but also are the whole that integrates the two kinds of resources into a sum total.

Every member competes and cooperates with each other according to the basic mechanisms of heredity, selection and variance based on the principles of natural selection, and each member is constantly modifying the rules of interaction in order to make the rules optimize according to a new evolution theory whose major concepts are competition and cooperation with each other. In the end, all agents will become a complex adaptive system. The key to the exchanging of the resources is not the resources themselves; i. e., commodities, information, assets and technology, but the thoughts of management, business ideas, marketing and the business culture. Only when all resources have been considered systemically, described correctly by quantitative methods and introduced into the supply chain model, can we obtain the most effective resource flows.

1.2 Environment

The resources environment of the supply chain is defined as follows: ① The outside resources of the supply chain system; ② The inside resources of the supply chain system; ③ The resources that other agents possess; ④ The resources that the agent itself possesses[9]. The first and the second resources have been studied in many papers, so, we will study the others here.

The resources that other agents possess in the supply chain: Every agent can be regarded as a sub-system of the complex adaptive system of the supply chain, a dissipative system. Because different profits are produced by different kinds of resources, and different potential energies are produced by different profits, the resources can flow freely in the system. Every agent can study the advantages of the others' in the process of resource exchange. As a result of this, the system will become a more creative system that can stand on the edge between chaos and order, which will make the supply chain system become more competitive.

The resources the agent itself possesses: Because of its sociality, intelligence and autonomy, the experience and ability can be varied (increasing and/or decreasing) with the development of the system, these will be the greatest and most important resources among them all[10].

1.3 Evaluating and data filtrating the resources

Because of the complex adaptive system, more or less, the resources have some complicated characteristics, which barely quantify their true values, so it is necessary to analyze the characteristics of the system and set up an appropriate filtrating system that adjusts the values of the resources.

The agents in the supply chain system as a whole consists of social, intelligent and autonomic agents. Because of the behavior of the human beings that exist in the system, the resources that all agents possess ultimately satisfy the rule about the labor force value. However, they have some different characteristics because there exist complex attractors in the system, which makes all kinds of resources adaptable.

1) Structure asymmetry

As with other systems, the resources in the supply chain system satisfy the marginal utility regression rule, and its actual values cannot be described in cardinal number utility. In the same way, the same quantity of resources have different values in different dynamic environments in the progress of their flowing.

2) Nonlinearity

Because of its own characters, the resources that flow in the complex adaptive system of the supply chain represent nonlinearity to a heavy degree (the most outstanding example is the Ellsberg paradox: the sum of all parts' value is unequal to the whole value).

3) Dynamics

As time passes, the resources take on a dynamic character that can be changed depending on the resources continuously flowing. Each resource and every flow progress make the building blocks changeable, which produces the diversity of the true utility value.

4) Changeability with time and place changing

The values of same quantities of resources change with the development of the environment of the system, especially with time and place changing. This accounts for the fact that the system is a dissipative system that stands on the edge of the chaos system and the order system, which makes the initial values of all critical parameters sensitive and creative. If we change some parameters to a little degree, especially for time and/or place, the system will surpass its original structure, which can improve its capability drastically.

Provided that $f(x)_t$ is the value decided by the average production time in society, $g(x)_t$ is the adaptive function of the initial value of the resources in the system, here, $\frac{\mathrm{d}^2[g(x)_t]}{\mathrm{d}x^2} < 0$; $h(x)_t$ is the adaptive probability density function of the initial value of the resources in the system based on loss because of nonlinearity from the moment $t-1$ to the moment t, here, $\frac{\mathrm{d}^2[h(x)_t]}{\mathrm{d}x^2} < 0$; furthermore, $-1 \leqslant h(x)_t \leqslant 1$, when $h(x)_t \leqslant 0$, can be described by a complex function[11] of complex entropy; the payoff that occurs in formal time can be described by a random function. The effect that is affected by the phase $t-1$ can be described by the function $j(x)_{t-1}$. Here, $\frac{d^2[j(x)_{t-1}]}{dx^2} < 0$; $k(x)_t$ is the adaptive function of the operating environment of the system, that is, $\frac{d^2[k(x)_t]}{dx^2} < 0$. The true value can be adjusted in the supply chain to a new one:

$$\int_{\Omega} f(x)_t g(x)_t h(x)_t j(x)_{t-1} k(x)_t \, dx$$

In the function, all parameters can be attained by statistical methods.

1.4 Evaluating values of resources

1.4.1 Create the multiagent organelles

A new method to modify and adjust the resource-value is introduced in this paper: Standardizing all vectors of the resource-value, translating the number-values into the DNA-values, making the one resource in a series with the others and becoming a multiagent organelle of this complex adaptive system, i. e., $(x_1, x_2, \ldots, x_8)$, where x represents the variables (x_1 = materiel, x_2 = financing, x_3 = information, x_4 = technology, x_5 = management, x_6 = operating thought, x_7 = talent, x_8 = marketing); x_i is the "chromosome" for the DNA-value of the agent[12], which makes the resources that the agent possesses become an inseparable and interdependent whole one, so we can research the rule of resources flowing in the supply chain from the aspect of the system and analyze the rule more deeply. The "chromosome" has all the characteristics of a complex adaptive system, such as social, intelligent and autonomic characteristics.

1.4.2 Random number of resources that agents interact with

As an agent of the supply chain system, its resources should be an organic whole that consists of all the facets mentioned above. Every resource does not operate solely but interpenetrates and interacts with the others. To satisfy this, 8 random numbers are introduced into the multiagent organelles, which are distributed randomly into the "chromosome"[9]. This allows us to describe the inter-acts more precisely and high light the similarities to the actual actions taking place in the process of interacting.

Suppose that

$$x_{i+1} = ax_i + c(\bmod m) \qquad i = 1, 2, \ldots, n-1 \quad (1)$$

where a is a positive number, which is called a coefficient; c represents a non-negative integer, which is called the increment; $0 \leqslant x_i < m$, x_1 is a germ; m is a modulus, which is the length of a sequence of pseudo-random numbers. So, for every initial number of x_1, by the formula mentioned just now, we can create a new vector $\{x_1, x_2, \ldots, x_n\}$. Through the following formula, we can obtain the 8 pseudo-random numbers that are a stochastic distribution in the interval of $[a, b]$, then

$$u_i = a + \frac{x_i}{m-1}(b-a) \qquad i = 1, 2, \ldots, n \qquad (2)$$

Using the pseudo-random numbers, we can describe more exactly the true rule of resource flows that agents interact with in the supply chain system, and we can describe more exactly that the core of the resource is a whole that cannot be separated from the resources of management and information and thoughts that make a role effective in the system; i. e., the resources that are adjusted can describe the entity more correctly.

2 Action Rule and Resources Flowing Mode of Agent

2.1 If-then rule of resources flowing among agents

The if-then resources flowing rule of the agent in the complex adaptive system in the supply chain is shown in Tab. 1.

If a sub-agent receives a sign of *Tell-constraint* from another subagent, it will enter working status to some degree. The sub-agent, in the first step, shall judge whether its owner' s resources satisfy the demands of the instructions from the former. If it is not satisfied, it will refuse the information or make a counterproposal to the other. Furthermore, it should be redirecting its attention to others in refused status, counter-proposal status or working status continuously. If it is satisfied, it will consider whether the next sign is feasible or not. So, this sub-agent shall enter a sub-course, as the sub-agent translates the sign of *Tell-constraint* to the sub-agent that will act on it. Finishing a sub-action in harmony, it will face two choices: returning to the main process or entering the next sub-action. Furthermore, it classifies and packs away all kinds of resources, and enters working status again. On the other hand, if it succeeds in reaching harmony, it will consider whether the following instructions are harmonized or not: if there are some instructions that have not been harmonized, it shall enter a new sub-course. When all the transmitting instructions are in the status of success, it will transmit the instruction of *Accept-constraint* and enter the instruction of *Satisfied* on the main course. Whether the sub-agent is in the status of *Satisfied* or in the status of *Failed*, if the last conclusion is not adjusted, the sub-agent will classify and pack away all kinds of resources in the process of harmonization, and finally enter the status of finished.

Tab. 1 Harmonized rule of the agent

Step	If	Then
1	Receive the sign *Tell-constraint* from other agent	Thinking
2	Thinking	Transmit the sign *Accept-constraint* to other Agent
3	Receive the sign *Satisfied* from other agent	Thinking
4	Receive the sign *Failed* from other agent	Thinking
5	Thinking	Transmit the sign *Loose-constraint* to other Agent
6	Thinking	Transmit the sign *Decline-constraint* to other agent decline-constraint
7	Receive the sign *Tell-constraint* from other agent	Thinking
8	Receive the sign *Confirm-decline* from other agent	Thinking
9	Receive the sign *Confirm-loose* from other agent	Thinking
10	Receive the sign *Decline-Loose* from other agent	Thinking
11	Thinking	Transmit the sign *Tell-constraint* to the agent that will act on
12	Receive the sign *Accept-constraint* from other agent that will act on	Thinking
13	Receive the sign *Decline-constraint* from other agent that will act on	Thinking
14	Thinking	Transmit the sign *Tell-constraint* to the agent that will act on
15	Thinking	Transmit the sign *Confirm-decline* to the agent that will act on
16	Receive the sign *Decline-loose* from other agent that will act on	Thinking
17	Thinking	Transmit the sign *Decline-loose* to the agent that will act on
18	Thinking	Transmit the sign Failed to the agent that will act on
19	Thinking	Transmit the sign *Confirm-loose* to the agent that will act on
20	Thinking	Transmit the sign *Tell-constraint* to the agent that will act on
21	Thinking	Transmit the sign *Accept-constraint* and *Satisfied* to the agent that have finished following action
22	Receive the sign *Tell-constraint* from other agent	Thinking
23	Thinking	Transmit the sign *Tell-constraint* to the agent that will act on
24	Receive the sign *Satisfied* and *Failed* from other agent	Thinking
25	Receive the sign *Tell-constraint* from other agent	Thinking

Notes: *Tell-constraint* means the restriction of some action; *Accept-constraint* means that accept the restriction imposed upon all actions; *Satisfied* means harmonize successful; *Failed* means harmonize failed; *Loose-constraint* means the agent need to loose restriction; *Decline-constraint* means the agent does not satisfy the restriction; *Confirm-decline* means the agent assures the action is not feasible; *Confirm-loose* means the agent assures the restriction; *Decline-loose* means the agent refuses the restriction.

2.2 Supplying-distributing rule of resources of agent

To make the research convenient, we introduce a special supply chain system, which has the following structure, as shown in Fig. 1.

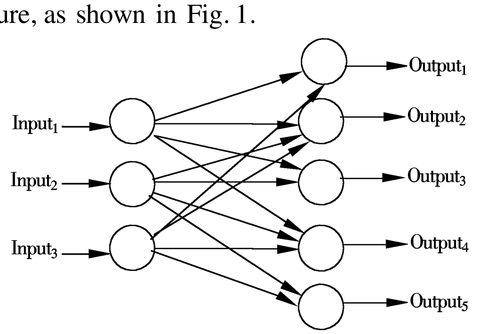

Fig. 1 Structure of complex adaptive system in supply chain

2.2.1 Hypothesis of random environment

1) The random variables $\xi_1, \xi_2, \xi_3, \xi_4$ express the maximum quantity of something that 4 supplier agents can provide to the dealer, assuming that the probability density function of every random variable satisfies ϕ_1, ϕ_2, ϕ_3, ϕ_4. Here, $P_r(\xi_i)$ $(i = 1, 2, 3, 4)$ represents the probability of i attaining ξ_i units of resources from the suppliers.

2) Decision variable (x_1, x_2, x_3, x_4) is a series of random variables dependent upon each other which flow out from the Input$_1$, it will depend on the states of the other implements, and each of them is a function of x_1, x_2, x_3, x_4. In the same way, the decision variable (x_5, x_6, x_7, x_8) are dependent upon each other which flow out from the Input$_2$. The decision variables $(x_9, x_{10}, x_{11}, x_{12})$ are dependent upon each other which flow out from the Input$_3$.

3) The hypothesis of the dealer: c_i, the reliability of the dealer i can obtain is $P_r(c_i)$.

4) Because of some reasons, either economic and/or political and/or geographical, we hypothesize that an object is min(input$_3$).

2.2.2 The flowing rule about resources that every agent possesses

Considering the forecited hypothesis, the model that describes the judging rule of resources flowing among agents in the stochastic process must involve a multi-object planning of supply and distribution, which involves a correlation chance restricted planning, as shown in Eq. (3):

$$
\begin{aligned}
&\max f_1(x) = P\{[x_1 + x_9] = c_1\} \\
&\max f_2(x) = P\{[x_2 + x_5 + x_{10}] = c_2\} \\
&\max f_3(x) = P\{[x_3 + x_6 + x_{11}] = c_3\} \\
&\max f_4(x) = P\{[x_4 + x_7] = c_4\} \\
&\max f_5(x) = P\{[x_8 + x_{12}] = c_5\} \\
&\min f_6(x) = x_9 + x_{10} + x_{11} + x_{12} \\
\text{s.t.}\quad & g_1(x) = P\{x_1 + x_2 + x_3 + x_4 \leqslant \xi_1\} \\
& g_2(x) = P\{x_5 + x_6 + x_7 + x_8 \leqslant \xi_2\} \\
& g_3(x) = P\{x_9 + x_{10} + x_{11} + x_{12} \leqslant \xi_3\}
\end{aligned} \tag{3}
$$

3 Interacting Rule of Multi-Agent

We need to reconsider the resources in the supply chain system, and subsequently, an appropriate model reflecting the resources flowing among the agents. Here, the resources that every agent possesses can be interpreted by the following model, and the interaction among the agents shall be followed according to the echo model in the process of interaction. The attacking sub-model of one agent does not always interact on the other sub-models of another agent, which is a cycle something like a turntable operating, until all the other sub-models are satisfied. Otherwise, they do not interact at all (see Fig. 2).

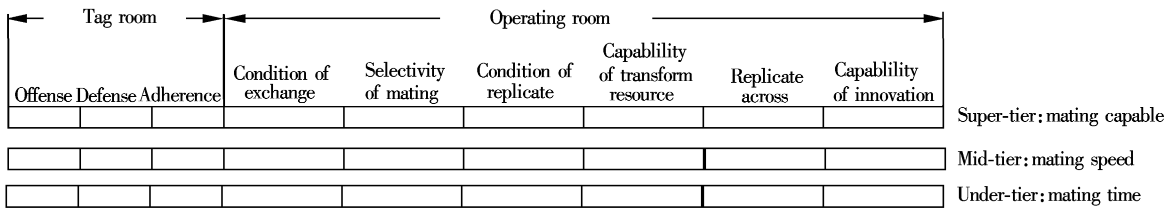

Fig. 2 Three-tiered-echo model of complex adaptive system in supply chain

Here, we introduce the echo model that Holland created as the prototype of our model, ① Add the capability of replicating across and the capability of innovation to the prototype, which can describe the basic phenomena that tangle with the complex adaptive system concerning the management organization represented; ② Not only consider the mating capability of the resources of the agent, but also consider the mating speed, which can simulate more correctly the rule of the organization coordination action taking place in practice which has emerged in the process of interaction: quick response, two-win/multi-win/co-win; so we create the two-tiered sub-model, i. e. mating speed; ③ Considering the change about the structural stability of the supply chain and the dynamic properties of the mating capabilities as time flows, add the variable of time. Thus, we create the three-tiered sub-model. The above-mentioned model is called the three-tiered-echo model of the agents in the complex adaptive system in the supply chain system which is interactive. This is the basis of the interaction among agents.

By conforming all resources effectively, simulated in the computer, we can draw conclusions more correctly concerning the resources in the three-tiered-echo model of the complex adaptive system in supply chain management. Furthermore, we can analyze the following key rules in the system.

3.1 Reconsidering resources

We analyze the ways of attaining the values of resources; however, it is a simple method without considering the interaction that is described in the three-tiered-echo model. First, 9 characteristics should be considered: offense, defense, adherence, exchange, selection of mating, condition of replication, the capability of transforming resources, replication across, the capability of innovation. Secondly, the mating speed must be considered. Last but not least, the mating time must also be considered. So, resources in the supply chain must be described by

$$
\begin{aligned}
&\{y_{111}, y_{112}, \dots, y_{118}\}\{y_{121}, y_{122}, \dots, y_{128}\}\dots\{y_{191}, y_{192}, \dots, y_{198}\} \\
&\{y_{211}, y_{212}, \dots, y_{218}\}\{y_{221}, y_{222}, \dots, y_{228}\}\dots\{y_{291}, y_{292}, \dots, y_{298}\} \\
&\{y_{311}, y_{312}, \dots, y_{318}\}\{y_{321}, y_{322}, \dots, y_{328}\}\dots\{y_{391}, y_{392}, \dots, y_{398}\}
\end{aligned} \tag{4}
$$

where y_{ijk} is the j-th character that the k-th resource's value has been coded by the DNA technology of an agent. And $i = 1, 2, 3$, which is the capability of the mating, capable of 9 kinds resources, mating speed and the dynamics and/or stability in the process of mating. The agents act as the three-tiered-echo model, whose rule of interaction as shown in Tab. 1. The transforming of the resources that the agents that are interacting possess is shown in Eq. (3).

3.2 Arithmetic of the model

In the process of simulation, the data of this paper come from a tobacco company of Heilongjiang province. For reasons of secrecy, the raw data is omitted.

3.2.1 Modeling in Swarm

Add the genetic algorithms in the simulation of Swarm modeling. In the simulation model (ISA, industrial shift and agglomeration), we set up two agents: an enterprise agent and supply chain agent, whose properties and ways are given as shown in Tabs. 2 to 4.

Tab. 2 Properties and ways of enterprise agent

Main properties	Main ways
Satisfaction	GetSatisfaction( )
IdealExpectation	SetIdealExpectation( )
Influence	SetInfluence( )
RandomMoveProbability	SetRandomMoveProbability( )
	EnterpriseMove( )

Tab. 3 Properties and ways of supplychain agent

Main properties	Main ways
MaxExpectation	AddResource( )
TypeofInvestmentLow	FindTypeofInvestment( )
TypeofInvestmentHigh	FindTypeofInvestment( )

Tab. 4 Properties and ways of modelswarm

Main properties	Main ways
NumberofEnterprise	EnterpriseModelSwarm( )
EvaporationRate	AddEnterprise( )
DiffuseRate	BuildObjects( )
MiniIdealExpectation	BuildActions( )
MaxIdealExpectation	ActivateIn( )
MiniInfluence	ActivateIn( )
MaxInfluence	ActivateIn( )

The model is edited on the basis of the essential model of Swarm: Heatbugs, whose correlative variable can be found in www. swarm. org.

In the process of modeling, we have considered five ideas: ① The interaction among the agents has run in the two tiers(enterprise agent and supply chain agent). In other words, their actions have been run between homogeneous agents and heterogeneous agents; ② The action based on inter-transforming resources that happen in the same tier consists of 4 kinds: between the agent and the environment, among multi agents, between agent and itself, and between two agents; ③ The interaction of the agents comprises the following facets: between the agent and the environment, among multi kinds of agents, two agents existing in the same tier, and among agents and themselves; ④ To embody the integrated character of all the resources in interacting in the supply chain system, the resources flow that the agent runs are actually the multiagent organelles of the resources of the agents that have been coded in DNA and are series-connected in the 8 kinds of resources according to the above-stated order, in which the uncertain place of interaction can be decided on by a random number; ⑤ The interaction process is a process of natural selection, which satisfies the rules of the theory of evolution, so the concept of the genetic algorithms must be added in the modeling.

3.2.2 The results

By running simulations of the three-tiered-echo model, we can attain the simulation results of 200, 2 500 and 4 500 steps, as shown in Fig. 3 to Fig. 5.

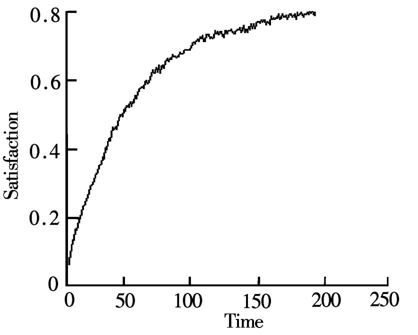

Fig. 3 State of the 200th simulation step

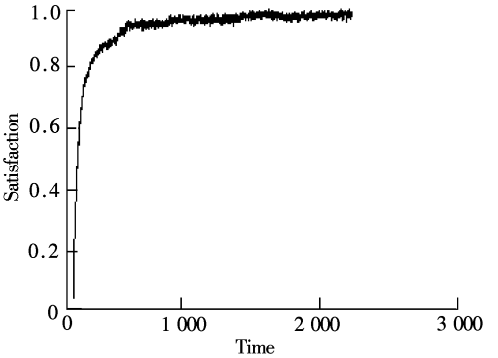

Fig. 4 State of the 2 500th simulation step

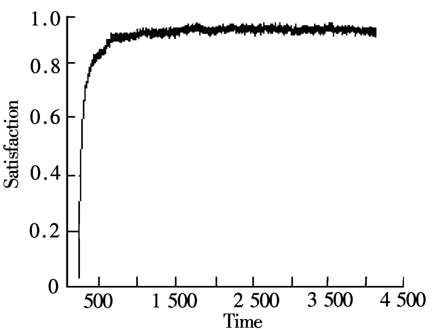

Fig. 5 State of the 4 500th simulation step

We simulate the interaction among the agents that possess various kinds of resources while considering the resources flowing in the three-tiered-echo model, and attain a series of results shown in the simulation curves from Fig. 3 to Fig. 5. Here, the x-axis represents the disperse time coordinates, and the y-axis represents the values confirmed in formula (4). The value expresses the whole competition capability and the payoff capability of the supply chain system. Fig. 3 expresses the whole value of the system that the interaction plays at the 200th step. Fig. 4 expresses the whole value of the system that the interaction plays at the 2 500th step. Fig. 5 expresses the whole value of the system that the interaction plays at the 4 500th step. From the figures mentioned, we can know that, with the inter-model, the system can reach the pre-optimization level: pre-idealization level, i. e. carry out the aim of co-win.

4 Conclusion

The resources in the supply chain comprise the nonlinear sum of materiel, financing, information, technology, management, operating thought, talent and marketing. We adjust the single resource's value with the formula $\int_{\Omega} f(x)_t g(x)_t h(x)_t j(x)_{t-1} k(x)_t \mathrm{d}x$, and transform every value into an integration with the three-tiered-echo model. Putting the rules to agents and simulating it, we can argue that: If an agent always adjusts its owner action under the environment of the supply chain system, that is interact (1) between the agent the environment, (2) among multi kinds of agents, (3) two agents existing in the same tier, and (4) between the agent and itself, the system will be optimized and become stabile and mature over time; otherwise, the system will become brittle, leading ultimately to collapse. If and only if these are considered, the results of emergence of resources can conform more exactly to the states observed.

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供应链系统资源流动过程中的涌现

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摘要: 为了准确描述由于交互作用行为所涌现的巨大复杂性供应链 agent 携带资源的真实价值,进行资源数量、时机和地点的正确决策,分析了供应链系统资源价值特点. 用“染色体”表示主体资源价值,采用 8 个随机数确定主体相互作用点并将各个资源进行整合,对资源供给–分配进行 if-then 规则及相关机会约束规划准则的设置,并将其应用于供应链复杂适应系统主体交互作用的三层–回声模型中,在 Swarm 平台建模过程中融入遗传算法进行模拟仿真. 结果表明:供应链复杂适应系统中各个资源是一个不可分割的有机整体,三层–回声模型是描述基于资源相互作用的供应链主体间较为实用而准确的内部模型,系统主体按该模型进行合作、竞争与资源分配,并达到系统总资源利用的最优化效果.

关键词: 资源流;agent;模拟仿真
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