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Research Article

Measure Analysis for Order Degree of Complex Manufacturing Collaborative Logistics Network

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Abstract: In order to more effectively study the resource optimization problem of complex manufacturing collaborative logistics network, the study combines the features of complex manufacturing, has a system analysis for complex manufacturing collaborative logistics network and expect to have a better understand about its internal composition. Therefore, under the guidance of Synergetic and dissipative structure theory, the study introduces the hyper cycle dynamical concurrence idea, measures the orderly operation of complex manufacturing collaborative logistics network from synergy degree, stability and self-organization three angles.

Keywords: Collaborative logistics network, dynamic alliance, order degree, self-organization, synergy degree

INTRODUCTION

Collaboration which derives from the Latin text "collaborated", expresses that the process of work together to create (Audy *et al.*, 2011). Haken's definition is that: it's a self-organizing process to realize disorder-orderly and orderly-orderly changing among a large number of complex opening subsystems which have different nature (Haken, 1983). In supply chain management, collaboration refers that the process or ability of consistently completed certain target by coordinating two or more different resources or entities (Camarinha and Afsarmanesh, 2005). As an effective organizational model for logistics activities in a network business environment, collaborative logistics network will break through the traditional model of point to point, integrates multiple entities with different logistics functions and resources, Omni directional realizes heterogeneous systems' sharing cooperation.

Logistics network based on Internet technology is actually a collaborative system, it can be said that collaborative network is the highest development level of logistics network (Camarinha *et al.*, 2009). Its development shows as Fig. 1. The connotation of collaborative logistics network can be explained that: it aims at providing customer satisfaction services on the premise of the whole work value, realizes sync coordinate among material flow, information flow, data flow, capital flow and knowledge flow (Miranda *et al.*, 2009), through integrating the different members which have the features of space dispersed, independent organization, interests conflicted in network, so as to achieve resource optimal allocation of logistics nodes and efficient operation of the logistics network operation systems. Say in brief, collaborative logistics network is essentially a directing-type collaborative logistics system, which is made up of cooperation firms, logistics nodes, path and relationship between the nodes and has competitive flexibility and dynamic self-organization ability.

Complex manufacturing collaborative logistics network is constructed by logistics collaborative groups including different virtual organizations and dynamic alliances of complex manufacturing; it is a large-scale and relations criss-cross open complex system. Obviously, there are a lot of uncertainty, disorder, ineffective and complexity in the entire network (Arne, 2011). The order degrees of logistics resource planning, acquisition, evaluation, sharing and integration are directly related with synergy effect and response speed in complex manufacturing collaborative logistics network. The original intent about order degree in physics refers that: the particle distribution in space of object internal structure has the regularity of periodic repetition (Markus and Robey, 1988). The existence of isolated organizations in network will lead to the increase of disorder degree. Therefore, its order degree analysis measures that the network overcomes space-time chaos and logic disorder and realizes resources more effective operation and dynamic restructuring, which includes the collaborative level between network members, the stability of dynamic alliance, the self-organization degree of whole work. It can be said that the pros and cons of operation effect for complex

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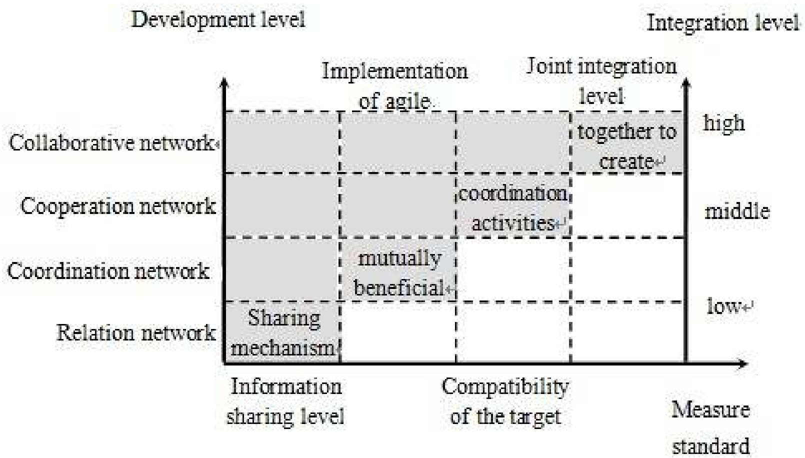

Fig. 1: Development of ladder diagram of logistics network

manufacturing collaborative logistics network is directly depend on its order degree. Based on above analysis, objective of the study is mainly about that: how to measure the order degree of complex manufacturing collaborative logistics network, through synergy, stability and self-organization.

COLLABORATIVE LOGISTICS NETWORK ELEMENTS

The main basic elements of collaborative logistics network include that: collaborative firm, logistics node, link road of nodes and nodes relationship.

Collaborative firm: The relationship of collaborative firms in collaborative logistics network isn't just short-term transactions and more is long-term, stable alliance. With the evaluation of cooperative relations between the depth and corresponding evaluation mechanism, collaborative firms can reach a strategic development collaborative joint according to their needs and the external environment changes, thus achieves the goal of "win-win".

Collaborative firms in networked manufacturing environment can be divided into two kinds: supply supporting and assembly manufacturers. Supply supporting firms provides assembly manufacturers a variety of materials, equipments and parts; assembly manufacturer is mainly responsible for the final product assembly.

Logistics node: Logistics activities of collaborative logistics network (such as: warehousing, packaging, sorting, distribution, processing, etc.) mostly need to rely on the logistics nodes, it can be said that the logistics nodes is an important part of collaborative logistics network. The level of the entire network operation efficiency largely depends on complex professional functions, information processing capabilities and the level of collaborative scheduling of logistics nodes.

Logistics nodes according to carrier the function can be divided into two types: real nodes which can a variety of logistics activities, virtual nodes which can monitor the network by attached the logistics virtual interface. Real nodes have storage, transformation, circulation and transport four types. Virtual nodes have information sharing; process monitoring, organization and coordination three types.

Link road of nodes: Route between logistics nodes is called link road of nodes in collaborative logistics network, logistics activities in the link road are all types of transport activity. The real nodes liking logistics infrastructure and geographic are the key of link road, the nodes determine the link road. In general, the different levels of nodes in network are connected, which basically represents the most economical mode of transport between any two nodes.

Nodes relationship: Nodes relationship in collaborative logistics network refers to the organic links between nodes. Nodes and link roads in network aren't isolated and static, the nodes through vertical complementary and horizontal competing, forms a competitive and collaborative dynamic collaborative logistics network. Therefore, nodes relationship has become one of the elements of collaborative logistics network.

SYNERGY DEGREE ANALYSIS BETWEEN MEMBERS

With the order parameter and servo principle in Synergetic, it can be concluded that the co-evolution in complex manufacturing collaborative logistics network is controlled by order parameter, the stable structure of evolution and ordering degree also depends on order parameter. The description of order parameter is mainly about system macroscopic ordering degree and the fast relaxation variables obey slow relaxation variables in this system, so order parameter is in a dominant and decisive role (Susanne and Monica, 2003). Collaboration between order parameters can make system have an emergence qualitative change in critical point which appears synergistic effect, this effect is the comprehensive group effect of order parameter interaction in complex open systems (Donald, 2008) and it is the external characterization of system self-organization phenomena. Complex manufacturing collaborative logistics network wants to achieve orderly operation, it must be become a non-linear far from equilibrium in open systems, while a small amount of order parameters can dominate and regulate other variables behavior, they determines the direction of system evolution.

Synergy degree refers to the degree of logistics resource rational used and coordinated of network members in complex manufacturing collaborative logistics network, it is the measure of synergy effect in the order parameter collaborative process. There are a large number of sub-organizations compose of the complex manufacturing collaborative logistics network, uses multivariable $q_1, \ldots, q_n$ to describe these sub-organizations' state at a given moment and these variables are called "state variable", all variables can be represented by the vector q:

$$q = (q_1, \cdots, q_n) \tag{1}$$

The vector q obeys the nonlinear stochastic partial differential equation such as Eq. (2):

$$\dot{q} = N(q, a, \nabla, x, t) \tag{2}$$

where,

N : Nonlinear function, a represents external control parameter

∇ : Spatial derivative

x & t : Space and time

Based on the adiabatic approximation in the servo principle of Synergetic, the vast majority of variables in q can be represented by order parameter; the form of order parameter equation is shown as Eq. (3):

$$\dot{u} = \lambda_u u + f(u) \tag{3}$$

where, λ_u represents Eigen value of u and $f(u)$ represents polynomial of u.

Synergy degree of complex manufacturing collaborative logistics network is the comprehensive characterization measure index of group effect between collective collaboration effect among order parameters and discrete effect of individual order parameters. Group effect is a macro-state generated by micro-order parameter coupling interaction, functional complementation and reflects the orderly trend of whole system. Discrete affect a macro-state generated by micro-order parameter centrifugal mutually exclusive, function offset and reflects the confusion degree and disorder trend of whole system. The mathematical express about synergy degree is shown as Eq. (4):

$$\begin{cases} C_{\deg} = I(u) - S(u) \\ I(u) = N(u_1, \cdots u_n) \\ S(u) = P(u_1, \cdots, u_n) \end{cases} \tag{4}$$

where, C_{deg} represents synergy degree of complex manufacturing collaborative logistics network, $I(u)$ represents group effect function of order parameters collaboration, $S(u)$ represents discrete effect function of order parameters exclusion.

Synergy degree can be divided into five types (Georgi, 2012).

Strong positive synergy degree: $C_{deg} > 0$, it is a positive synergy effect of strong performance, indicates that the overall benefits outweighs the loss, which is the performance of system stability. In other words, group effect of order parameter collaboration brings strong and irreversible value-added to overall system. This value-added mainly presents as follows: contract development norms of network rules, integrated optimization of logistics resource, a high transparency in information sharing, the improvement of infrastructure utilization and operational efficiency, shorten collaborative response time and network costs reduction and so on.

Weak positive synergy degree: $C_{deg} \longrightarrow 0$, it is a positive synergistic effect of low-intensity performance and it is the trend performance from the steady state to critical state, which indicates that the overall benefits is slightly greater than the loss in this process, it shows that the group effect is weakened or the discrete effect is increased. This trend shows that: reduction in the number of collaborative logistics activities between members, less transparency in information sharing, the binding and attraction of public relation for members in collaborative logistics network and so on.

Zero-sum synergy degree: $C_{deg} = 0$, it indicates that both collaborative and independent operation have the same effect, it is also considered that the discrete effect of order parameter in individual mutually exclusive is offset by the group effect of order parameter collaboration, which is a critical point of system sudden metamorphosis, the system may tend to orderly, but also may tend to disorder. This offset mainly refers that: the cancellation between increasing communication cost among its members and the value-added of synergy-effective, the offset of interests reverse in logistics collaboration and so on.

Weak negative synergy degree: $0 \leftarrow C_{deg}$, it is negative synergy degree of low-intensity performance and is a trend performance from unstable state to critical state. In this process the overall loss slightly greater than the interests, which indicates that system is ended the chaotic state and trended orderly. This mainly refers that: contractual rules tend to be reasonable, new members continuously join collaborative logistics network to enhance the competing mechanism, the attractiveness of collaborative public relations is increased, the frequency of private collaboration between members is decreased.

Strong negative synergy degree: $0 > C_{deg}$, it is a negative synergy effect of strong performance, indicates that the overall loss is greater than the interests, which is the performance of system unstable state. It also can be said that the group effect of order parameters collaboration causes the overall depreciation. At the same time, the strong discrete effect of order parameter will lead to disintegration of system. This depreciation mainly refers that: the underutilization of logistics infrastructure, the lack of transparency in logistics information sharing, the communication cost is higher than collaborative interests and so on.

In summary, synergy degree of complex manufacturing collaborative logistics network has uncertainty. The strong positive synergy degree is the pursued goal, but the synergy degree in critical point or near critical point also should be concerned. The measures should be taken to guide it changing to favorable direction and try to avoid strong negative synergy degree which can lead to the emergence of network disintegration.

ALLIANCE STABILITY ANALYSIS

The alliance between sub-organization members in complex manufacturing collaborative logistics network is depended on constrains of contract rules in network, information-sharing mechanisms and mutually beneficial value-added, the alliance relation is dynamic and open in collaborative logistics network. Openness is necessary condition of order evolution of complex manufacturing collaborative logistics network, but it isn't sufficient condition. Open of network is influenced by network members join or quit alliance relations change. The transform of energy and material exchange can be reduced network orderly, but also can be caused its falling into disorder and chaos (Benoit, 1977).

Therefore, it must be formed a self-stabilizing mechanism, in order to reasonably control and constraint dynamic alliance relationship in the network.

As an open nonlinear system which far from equilibrium, when external control parameter reaches a certain threshold, under the internal driving and random fluctuation force, the system can mutate into new, more orderly stable state. New steady-state is known as a bifurcation phenomenon in mathematics, it can achieve transition from a disorder chaos balance to orderly stable non-equilibrium through the bifurcation system. Therefore, if someone wants to better understand the alliance stability of complex manufacturing collaborative logistics network, it must be clear to the steady-state of system bifurcation.

Steady-state of alliance equation in complex manufacturing collaborative logistics network can be expressed as Langevin equation:

$$dq = N(q,a)dt + dF(t,q) \tag{5}$$

where $\mathrm{N}(q,a)$, represents system internal driving force function, $\mathrm{F}(t,q)$, represents system random fluctuation force.

Based on the find-determine mechanism of new system steady-state in Synergetic, the probability distribution function of new steady-state can be described by the solution $\mathrm{f}(u,t)$, of Fokker-Planck (Haken, 1983). Combined with the principle of detailed balance and time reversal, it can be derived the Fokker-Planck equation such as Eq. (6):

$$\frac{\partial f}{\partial t} = [\sum_i (\frac{\partial}{\partial u_i} C_i + \frac{\partial}{\partial u_i^*} \tilde{C}_i) + \sum_{ki} Q_{ki} \frac{\partial^2}{\partial u_k \partial u_i^*}] f \tag{6}$$

where, Q_{ki} represents diffusion coefficient matrix:

$$Q_{ki} = \delta_{ki} Q_i , Q_i = Q_0$$

$C_i, \tilde{C}_i$, must have the following form:

$$C_i = \partial B / \partial u_i^* + I_i^{(1)} \quad (7)$$

$$\tilde{C}_i = \partial B / \partial u_i + I_i^{(2)} \quad (8)$$

And these must meet the following conditions:

$$\sum_i \left(\frac{\partial B}{\partial u_i} I_i^{(1)} + \frac{\partial B}{\partial u_i^*} I_i^{(2)}\right) = 0 \quad (9)$$

$$\sum_i \left(\frac{\partial I_i^{(1)}}{\partial u_i} + \frac{\partial I_i^{(2)}}{\partial u_i^*}\right) = 0 \quad (10)$$

The steady-state solution of Eq. (6) is:

$$f = \zeta e^{-V} \quad (11)$$

where ξ is normalized constant, the generalized thermodynamic potential function V is expressed as:

$$V = 2B / Q \quad (12)$$

The above Eq. (6) to (12) is the solution process of alliance steady-state solution. In the analysis of alliance relations in complex manufacturing collaborative logistics network, alliance dynamic change is regarded as the over damped motion of a particle in a force field; potential function of force field is shown as Eq. (13):

$$\dot{u} = -\frac{\partial V}{\partial u} \quad (13)$$

λ_u Symbol different will lead to potential function appear completely different states. If $\lambda_u < 0$, the solution of alliance steady-sate is u = 0, if $\lambda_u < 0$, the alliance in complex manufacturing collaborative logistics network is non-equilibrium, a new stable solution will appear by the transition.

System self-organization analysis: Complex manufacturing collaborative logistics network is a complex self-organizing open system, under the constrains of contract rules in network, the whole network develops according to the role defined by public relations and thus forms the orderly structure. Basis on the self-organization theory and thermodynamics point of view (Peter, 2003), system vitality and sustainability critically depends on the ability of self-organization within system nonlinear coherent effect. Meanwhile, system doesn't always tend to be stable and balance its growth, evolvement, evolution is a dynamic process of super-cycle and this dynamic process depends on dissipation matter and energy of outside to maintain. It can be said that the orderly operation of complex manufacturing collaborative logistics network primarily relies on its system's symmetry breaking. The analysis of system self-organization is mainly considered from chaos and complexity two aspects.

System chaos analysis: Entropy is irreversible state parameter to reflect the spontaneous process from the second law of thermodynamics and describes the disorder degree measure of a large number of microscopic particles (Rutner *et al*., 2003). In isolation or adiabatic conditions, the direction of system spontaneous process is always the direction of increasing entropy, it is "entropy increase principle", the greater the entropy, the system is more chaotic, more disorderly. Logistics as the business activities adherence subject of complex manufacturing collaborative logistics network, whether flow smoothly is directly deciding the whole operation result of network, it affects the normal operation. Therefore, it can link the weather orderly operation with entropy increase. Kolmogorov entropy and correlation dimension are introduced to measure the chaos degree and complexity degree of system running state and indirectly reflects the orderly situation.

Kolmogorov entropy (K entropy) in the dynamics is used to describe the number of system-orbit splitting progressive growth rate and mainly characterize the system of mixed degree. Its mathematical description, such as Eq. (14):

$$K = -\lim_{\tau \to 0} \lim_{\varepsilon \to 0} \lim_{d \to \infty} \frac{1}{d\tau} \sum_{i_1 \cdots i_d} P(i_1, \cdots, i_d) \log_2 P(i_1, \cdots, i_d) \quad (14)$$

where,

τ : Time interval measure

ε : System state measure (such as the length of phase space)

$P(i_1, \dots, i_d)$: The probability of $j\tau$ time system in the volume element (the length of volume element is ε^f, the number of freedom is f)

For complex manufacturing collaborative logistics network, the meaning of k entropy is that: one can effectively measure its operating status of the mixed degree; the other hand, also given its future operating status of the projection period, that is $k \sim 1/T$ (T the projection period). If k = 0, it indicates the network operation status is fully ordered regular exercise and the forecast period of its future state $1/K \to \infty$ is the measurement system. If $K = \infty$, it indicates the operation status is completely random Brownian motion and the forecast period of its future state $1/K \to 0$ is completely unpredictable system. The greater of k entropy value shows that the higher chaos of the network operation state and the shorter of the forecast period.

System complexity analysis: The correlation dimension D is also called the Grassberger-Procaccia correlation dimension, is the important characteristic parameter that reflects the fractal structure of the nonlinear dynamic system and can quantitatively describe the complex degree of the system internal structure and its mathematical description is shown as Eq. (15):

$$D(m) = \lim_{r \to 0} \frac{\ln C_m(r)}{\ln(r)} \tag{15}$$

where,

m : The embedding is dimension of the phase space

r : Defined as the volume element radius of the m dimension phase space, is the given critical distance

$C_m(r)$: Correlation integral and is the probability that the distance between two points is smaller than r in phase space, its expression is shown as Eq. (16):

$$C_m(r) = \frac{1}{M(M-1)} \sum_{i \neq j} \theta(r - \| X_i - X_j \|) \tag{16}$$

$x_1, x_2, \ldots, x_N$ is the one-dimensional sequence which transforms to $X_i = \{x_i, x_{i+1}, \ldots, x_{i+(m-1)}\}$, i = 1, 2,…, N-m+1 in the m phase space, M = N - $(m-1)$ is the total number of the phase space and the θ is Heavy side step function and is the measurement of the spatial correlation:

$$\theta(x) = \begin{cases} 1 & x \geq 0 \\ 0 & x < 0 \end{cases} \tag{17}$$

For the complicated manufacturing collaborative logistics network, the significance of the correlation coefficient D is that: it can reflect the complexity of the system and avoid that the overly complex system leads to the difficulties in communicating and the synergistic benefits dispersion. As a rapid response agile manufacturing system, the simple is one of the important construction principles of the complex manufacture collaborative logistics network, which suggests that the nested hierarchy should not be many and the correlation dimension should not be very big. So the reasonable control of system fractal dimension is the key to achieve the orderly operation of self-organization.

In summary, whether the self-organization mechanism of the complicated manufacturing collaborative logistics network could orderly operate, the key depends on the low entropy of k and the reasonable correlation dimension. That is to say, making $k \to 0$ and controlling the value D is the essential condition to protect the orderly operation of self-organization.

CONCLUSION

The research content is in the newest research front of this domain and is the systematic continual research for the first time at home and abroad on the measure analysis for order degree of the collaborative logistics network faced on shipbuilding. Thus, the research about order degree also has the important theoretical significance and the realistic directive significance. Based on the outline of complex manufacturing and the collaborative logistics network, the study makes use of the thought of the system and the dynamic evolution, then carries the theory research on the system evolution, the operation mechanism and the measure of the order degree of complex manufacturing collaborative logistics network.

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