The Entropy Model of Fractal Supply Chain Network System Based on Fuzzy AHP

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***Abstract*—The entropies of structure, information and the effectiveness entropy between knowledge and organization structure are main entropy sources of supply chain network. Entropy model of fractal supply chain network organization structure is established. Moreover, the basic principle and process of fuzzy AHP are introduced. Fractal knowledge management network outside independently organization structure is set up based on fuzzy AHP. Knowledge and organization structure have the whole similarity, and its entropy model is established. Finally, the entropies of structure, information and the effectiveness entropy are summed to research. And the model shows that fractal structure has prominent effect of dropping entropy.**

***Index Terms*—fractal supply chain network, entropy, fuzzy AHP, fractal knowledge management network**

I. INTRODUCTION

Physical locations included in a Supply Chain Network can be manufacturing plants, storage warehouses, carrier cross docks, major distribution centers, ports, intermeddle terminals whether owned by your company, your suppliers, your transport carrier, a third-party logistics provider, a retail store or your end customer.

In recent years, information flow, logistics and funds flow in supply chain network (SCN) are regarded as major factors influencing SCN operation, but in fact, they are considered just surface phenomenon.

The most core elements of SCN are information, human resource and organization structure in this paper. Because organization structure is the vector of existence and development for the information flow and human resource, and staff are both the "nodes" in structure and the vector of information flow. So, the influence of staff and other factors outside SCN can be transformed into the effects of organizational structure and information.

Moreover, structure and information are pro indiviso[1]. That is, no independent information from the system, nor independent structure from information.

So the entropies of structure, information and the effectiveness entropy between knowledge and organization structure are main entropy sources of SCN in this paper. Firstly, establish entropy model of fractal supply chain network organization structure. Secondly, the fractal trait of the knowledge in SCN is indicated, and fractal knowledge management network (FKMN) outside independently organization structure is set up. Moreover, knowledge and organization structure to have the whole similarity and its entropy model is established. Furthermore, effectiveness entropy model between knowledge and organization structure is builded, and the model shows that fractal structure has prominent effect of dropping entropy by comparing with literature[3]. Finally, the entropies of structure, information and the effectiveness entropy are summed to research synthetically and analyzed comprehensively.

II. LITERATURE REVIEW

With globalization of the economy and consumer personalization, product life cycles continue to be shorten. Market competition has surpassed individual enterprises, and increases the supply chain competition. Supply chain is a network and chain structure system connecting suppliers, manufacturers, distributors, retailers and users. Supply chain system and the market which is the supply chain's environment are opening, complex and nonlinear dynamic system, and they constantly exchange the information flow, logistics and funds flow so that they are interdependent and mutually constraints.

Therefore, in order to adapt to the market, the supply chain must be perpetual in the dynamic structure away from balancing. The senior management of supply chain must continually adjust its operational objectives and organizational structure to better adapt to the changes in the market environment, and to shorten the gap with the market reaction.

To this end, the works [5], [7], [8], have respectively studied the supply chain from different angles with fractal principle.

The work [5] has constructed the studied the fractal supply chain with the functions of self-similar, self-organization, self-optimizing functions based on fractal theory, and studied the similarity evaluation model of fractal supply chain. The work[7] has emphasized the flexibility and stability of fractal supply chain in the process of remodeling. And dynamic adaptation and coordination model of fractal supply chain was constructed by agent mechanism in work [8].

Based on this study, the authors were inspired by biological macromolecules fractal network architecture,

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and the dynamic conformation of biological macro molecular network is defined as the ideal state of fractal supply chain, and the SAW model of biological macro molecular is adopted as the fractal computing model of fractal supply chain network system in ideal state.

A. Entropy

Entropy originated from Thermodynamics. Principle of entropy increase revealed all irreversible processes in system to the spontaneous direction is entropy increasing. And, in statistical physics, entropy is metric to the movement of the disorder degree (Boatman) and confusion (Gibbs). Just shown by Eq.(1),

$S = K \ln W$ (K is Boltzmann coefficient, W is system microstate number) (1)

N. Wiener and C.E. Shannon founded information theory, and Shannon called the signal uncertainty of information sources in the communication process as information entropy, and the elimination of a number of uncertainties as information. Generally,

$H = -C\sum P_i \ln P_i$ (H is Shannon entropy; C is undetermined constant; P_i is the probability of random occurrence of elements in set) (2)

B. Fractal

Benoit B.Mandelbrot (1975) determined "fractal": A fractal is a shape made of part similar to the whole in some way. And fractal dimension is the dimension number of fractal, and it metrics the ability of system filled space (compact) or crannies (osteoporosis), and characterizes the system disorder.

Generally, fractal dimension is calculated by:

$D_f = -\ln N(\varepsilon)/\ln \varepsilon$ (ε is measuring-scale, $N(\varepsilon)$ is number of parts under ε) (3)

C. Generalized entropy and generalized dimension

Generalized dimension is expressed by Eq.(4).

$$D_\alpha = -\lim_{\varepsilon \to 0} \frac{S_\alpha(\varepsilon)}{\lg \varepsilon} \quad (4)$$

Where $S_\alpha(\varepsilon)$ is Generalized Entropy, and it is α order Renyi information entropy.

When the limit symbol is removed, Eq.(4) is to be:

$$D_\alpha = -\frac{S_\alpha(\varepsilon)}{\lg \varepsilon} + O(\varepsilon^2) \quad (5)$$

Namely $S_\alpha(\varepsilon) \approx \lg \varepsilon^{-D_\alpha}$ (6)

$$D_\alpha \approx -S_\alpha(\varepsilon)/\lg \varepsilon \quad (7)$$

Eq.(6),(7)shows that the relation between fractal dimension and entropy was demonstrated theoretically, in which the fractal dimension is a measure of the entropy and a state function[2].

If fractal dimension has the minimum measurement scale $\delta_{\min}$, then $\delta_{\min} = \delta_c$.

Generally, $\varepsilon_c = |\delta_c| < 1$. While, $\varepsilon \to 0 \Leftrightarrow \varepsilon \to \varepsilon_c$. Let $a = 1/\lg \varepsilon_c < 0$. Then,

$$S_\alpha(\varepsilon_c) = -D_\alpha / a \quad (8)$$

$$D_\alpha = -aS_\alpha(\varepsilon_c) \quad (9)$$

Generalized Entropy have the characteristics of nonambiguity, additivity, extremum.

III. Entropy Model of Organization Structure

According to the similarity of fractal theory with lean principle, and based on core competence to integrate SCN business process (BP).

The FSCN structure shown by Figure 1: the FSCN system consists of modules: Input, Operation and Output, and is just similar to three large functions of SCN: supply, manufacture and sale. And Input concludes Interface and Transformation sub-modules. Then, the task will be transferred to Operation including Decision, Organization and Implementation sub-module. After this, it is monitored in Monitoring and Output sub-module in Output finally. Meanwhile, each sub-module is coupled by several lower-level nested sub-module until the simplest BP(task group) as the basic fractal unit of FSCN, so that a number of nested layers couple a huge FSCN. And FSCN has been continuously evolution and development with the formation of fractal growth mechanism.

With fractal theory, structure fractal dimension of FSCN. Apply Eq. (3) and Fig.1:

ε =1/3 (Input, Operation and Output module).

$N(\varepsilon)$ =7 (Interface, Transformation, Decision, Organization, Implementation, Monitoring and Output sub-module)

$$D_g = -\ln 7/\ln(1/3) = 1.77 \quad (10)$$

By Eq.(8),(10), the entropy of organization structure is:

$$S_g = -D_g / a_g \quad (11)$$

Where, $a_g = 1/\ln \varepsilon_g$, ε_g is the measuring scale organization structure of FSCN.

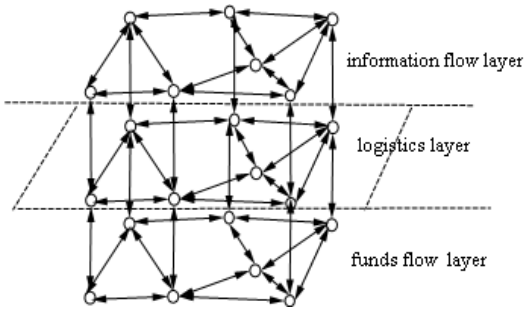

Fig.1 Fractal Module of SCN Organization Structure of fractal supply chain

IV. FUZZY AHP

AHP（The Analytic Hierarchy Process）was presented by American operational research expert T.L.Satty in 1977. AHP is a decision-making method combining with quantitative and qualitative analysis. The AHP provides a comprehensive and rational framework for structuring a decision problem, for representing and quantifying its elements, for relating those elements to overall goals, and for evaluating alternative solutions. It is used around the world in a wide variety of decision situations, in fields such as government, business, industry, healthcare, and education. In AHP, the complex problem is divided into several factors, and the factors are separated into hierarchical and ordinal structure by control relationship.

Fuzzy AHP is a new AHP, it is combined by AHP and triangular fuzzy number. The definition of fuzzy AHP are shown as definition 1[4]:

If M=(l,m,u)、M1=(l_1,m1,u1)and M2=(l_2,m2,u2) are all triangular fuzzy numbers, then:

M1⊕M2=(l_1,m1,u1)⊕(l_2,m2,u2)=(l_1+l_2,m1+m2,u1+u2) (1-1)

M1⊗M2=(l_1,m1,u1)⊗(l_2,m2,u2)=($l_1 l_2$, m1m2, u1u2) (1-2)

∀(λ)∈R，λM=λ(l,m,u)=(λl,λm,λu) (1-3)

$$\frac{1}{M}=\left(\frac{1}{u},\frac{1}{m},\frac{1}{l}\right) \quad (1\text{-}4)$$

Let M1≥M2 :V(M1≥M2)，then，the necessary and sufficient condition of V(M1≥M2)=1 is m1≥m2, if m1≤m2: V(M1≥M2)= $\frac{l_2-u_1}{(m_1-u_1)-(m_2-l_2)}$ = $\frac{u_1-l_2}{(u_1-l_2)+(m_2-m_1)}$（if l_2≤u1）;

V(M1≥M2)=0（if l_2≥u1） (1-5)

Let the value of M is larger than k triangular fuzzy numbers: Mi(i=1,2,3…,k) be V(M≥M1,M2,…,Mk), then:

V(M≥M1,M2,…,Mk)=minV(M≥Mi)(i=1,2,3…,k)(1-6)

Let M_{Ei}^{j} (j=1,2,…,m) is the values of the jth approch to m goals,the value of the“General weight”is:

$$s_i=\sum_{j=1}^{m} M_{Ei}^{j}\bullet w_i^j \otimes\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{Ei}^{j} w_i^j\right]^{-1}$$ i=1, 2,…,nw is the weight value,

$$\forall(\lambda),\sum_{j=1}^{m} w_i^j=1. \quad (1\text{-}7)$$

The value of the approach: X_i is prior to the other approaches is：d(x_i)=minV($s_i \geq s_j$)j=1,2,…,n；while j≠i, and provided:

V($s_i \geq s_i$)=1 (1-8)

V. KNOWLEDGE ENTROPY MODEL

In the process of FSCN integration, there is the bidirectional circulation integration process of tacit-explicit- tacit or explicit- tacit- explicit knowledge. There are acquisition, transfer, transformation, application and innovation of knowledge in these processes, which is main source of knowledge entropy.

A. Knowledge acquisition entropy model

Knowledge acquisition is a method of learning, first proposed by Aristotle in his seminal work "Organ on". Aristotle proposed that the mind at birth is a blank slate, or tabular raze. As a blank slate it contains no knowledge of the objective, empirical universe, or of itself. As a method, it is opposed to the concept of "a priori" knowledge, and to "intuition" when conceived as religious revelation. The acquisition of empirical knowledge, which begins the process of filling the tabular raze, is thus by means of the experience of sensation and perception. Sensation and perception are described elsewhere in Wikipedia as parts of "psychology, and not anatomy or physiology," they belong to cognitive science. Perception is the retention of a group of sensations transmitted through the sensory system, which gives the knowing subject the ability to be aware, not only of the singularity of stimuli presented by sensation itself, but of an entity, a thing, an existent. Retention of percepts allows the human mind to abstract information from the percepts. The abstraction is considered the extensional definition of the percept.

It includes two ways for knowledge entropy acquisition, on the one hand, it is from the inner of FSCN, on the other hand, it is from the outer of FSCN. So, knowledge acquisition entropy is defined as:

$$S_1(j)=-P_1(j)\ln P_1(j) \quad (12)$$

B. Knowledge transfer entropy model

Argote & Ingram[8] define knowledge transfer as "the process through which one unit (e.g., group, department, or division) is affected by the experience of another. They further point out the transfer of organizational knowledge (i.e., routine or best practices) can be observed through changes in the knowledge or performance of recipient units. The transfer of organizational knowledge, such as best practices, can be quite difficult to achieve. Knowledge transfer in the fields of organizational development and organizational learning is the practical problem of transferring knowledge from one part of the organization to another (or all other) part(s) of the organization. Like Knowledge Management, Knowledge transfer seeks to organize, create, capture or distribute

knowledge and ensure its availability for future users. It is considered to be more than just a communication problem. If it were merely that, then a memorandum, an e-mail or a meeting would accomplish the knowledge transfer. Knowledge transfer is more complex because knowledge resides in organizational members, tools, tasks, and their sub networks[8] and much knowledge in organizations is tacit or hard to articulate[9].

With the move of advanced economies from a resource-based to a knowledge-based production [9], many national governments have increasingly recognized knowledge and innovation as significant driving forces of economic growth, social development, and job creation. In this context the promotion of knowledge transfer has increasingly become a subject of public and economic policy.

There is knowledge entropy transfer in the bidirectional circulation integration process of tacit-explicit- tacit or explicit- tacit- explicit knowledge. So, knowledge transfer entropy is defined as:

$$S_2(j) = -P_2(j)\ln P_2(j) \qquad (13)$$

C. Application of knowledge entropy model

The purpose of knowledge integration is application of knowledge. Applications of knowledge usually happen in organizational studies, A variety of methods are used in organizational studies.

Employees apply knowledge in work to realize knowledge transfer from tacit to explicit, and to accumulate personal unique skills. In the process of application of knowledge, it is emphasized that coordination between member knowledge level including coordination of stock, absorptive capacity and utilization ability of knowledge. These are to guarantee development and optimization of knowledge in every link of final product. So, application of knowledge entropy is defined as:

$$S_3(j) = -P_3(j)\ln P_3(j) \qquad (14)$$

D. Knowledge innovation entropy model

Knowledge innovation is the core of knowledge integration. Knowledge innovation is a new way of doing something. It may refer to incremental and emergent or radical and revolutionary changes in thinking, products, processes, or organizations.

Knowledge innovation is an important topic in the study of FSCN of economics, business, design, technology, sociology, and engineering. Colloquially, the knowledge innovation is often synonymous with the output of the process. However, people tend to focus on the process of knowledge innovation, from the origination of an idea to its transformation into something useful, to its implementation; and on the FSCN system within which the process of innovation unfolds. Since knowledge innovation is also considered a major driver of the economy, especially when it leads to increasing productivity, the factors that lead to innovation are also considered to be critical to policy makers. In particular, knowledge innovation stress using public policy to spur innovation and growth.

Those who are directly responsible for application of the innovation are often called pioneers in their field, whether they are individuals or organizations.

Knowledge innovation is necessary for the existence and development of SCN to not only increase value, but also to create new value. Knowledge innovation is the basic way to create new value and feasible strategy to produce and maintain competitive advantage of SCN. So, knowledge innovation entropy is defined as:

$$S_4(j) = -P_4(j)\ln P_4(j) \qquad (15)$$

E. Knowledge transformation entropy model

Knowledge transformation is realized through explicit knowledge. Tacit knowledge (as opposed to formal or explicit knowledge) is knowledge that is difficult to be transferred to another person by means of writing down or verbalizing it. For example, stating to someone that Tooting is in London is a piece of explicit knowledge that can be written down, transmitted, and understood by a recipient. However the ability to use algebra, speak a language, or design and use complex equipment requires all sorts of knowledge that is not always known explicitly, even by expert practitioners, and which cannot be explicitly transferred to users.

Compare with the literature[3], the process of calculation of FSCN of effectiveness entropy and quality entropy, shows that knowledge propagation in the fractal structure of SCN has obvious advantage of dropping entropy than in the traditional organizational structure in literature[3], and entropy of calculation is relatively simpler.

F. Effectiveness entropy

We entitle “effectiveness” of system is the transmission circulation extent of knowledge in nodes of FSCN system, and entitle “effectiveness entropy” is the measurement of the effectiveness, which reflects the uncertainty of knowledge circulation in system.

Since the establishment of organization structure of FSCN and FKMN independently outside organization, the circulation of knowledge is not point by point, but “One Click Is Enough” to share, that is, to share the majority except a handful of top-secret knowledge. Such as “orders” as long as arrival FSCN, all the nodes can share this data. So, let a knowledge element j circulates in FSCN shown as Fig.1.

The total effectiveness entropy of system is defined as:

$$S_T(j) = -P_T(j)\ln P_T(j) \qquad (16)$$

G. Quality entropy

We entitle “quality” of system is the measurement of the accuracy of knowledge circulation and ‘quality entropy’ describe the uncertainty of the system quality. In this paper, it exists that the feedback of local knowledge nodes in the system. So, the total quality entropy of system is defined as:

$$S_Q(j) = -2 \cdot \sum P_Q(j) \ln P_Q(j) \quad (16)$$

So, effectiveness entropy between organization structure and knowledge is:

$$S_{TQ} = S_T(j) + S_Q(j) \quad (17)$$

VI. TOTAL ENTROPY MODEL OF FSCN SYSTEM

By Eq.(11),(14),(15),(16),(17), the total entropy of FSCN is :

$$S = S_g + S_k + S_c + S_{TQ} + S_1 + S_2 + S_3 + S_4 + S_e \quad (18)$$

$$S = -D_g / a_g + K \ln \sum_{i=1}^{N} w_i + \sum P_c(l) \ln P_c(l) + (-\sum P_T(j) \ln P_T(j)) + (-\sum_{i=1}^{4} P_i(j) \ln P_i(j)) + (-2 \cdot \sum P_Q(j) \ln P_Q(j)) + S_e$$

Namely,

$$\Delta S = \Delta S_g + \Delta S_k + \Delta S_c + \Delta S_T + \sum_{i=1}^{4} \Delta S_i + \Delta S_Q + \Delta S_e \quad (19)$$

In Eq.(18),(19), the entropies are positive entropy, expect that S_c and S_e are negative entropies. So, it is not difficult to derive: only $\frac{\Delta S_c + \Delta S_e}{S_c + S_e} \geq \frac{\Delta S}{S}$, FSCN can maintain the order status of dissipative structure. However, entropy increase does not mean randomness increase, such as Baynard Pattern is an example of entropy and order increase simultaneously [7]. So, manager of FSCN can't blindly pursue dropping entropy, when entropy is lower, the structure stability is higher. But, market is illusive, if system is more stable, its strain ability is poorer. And maintaining a certain entropy increase makes that FSCN have higher flexibility, adaptability, reconstruction, coordination and can response immediately for external change, so as to improve continuously competence and whole benefit of FSCN.

VII. CONCLUSION

(1) According to the principle, constructing the model with information flow layer, logistics layer and funds layer of fractal supply chain in the ideal state, and adopting fuzzy AHP model to compute the fractal dimension is significant to analysis of running features of fractal supply chain network system. It has guiding significance to improve the operational efficiency of the supply chain.

(2) Due to fractal Characteristics of information and knowledge, FKMN is established the established independently outside the organization structure, which makes knowledge circulating and sharing in organization structure more quickly.

(3) Knowledge circulation in the fractal structure of SCN has obvious advantage of dropping entropy than in the traditional organizational structure of the literature[3], and entropy of calculation is relatively simple.

(4) Manager of FSCN can't blindly pursue dropping entropy, and maintaining a certain entropy increase makes that FSCN have higher flexibility, adaptability, reconstruction, coordination and improve continuously competence and whole benefit of FSCN.

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