Abstract—Supply chain, as an effective strategy in intense business competition, has been accepted by scores of enterprises, but how to evaluate its performance properly is still an issue. Based on complex adaptive system (CAS) & emergence, this paper investigates the complex adaptive features and emergency dynamism of supply chain system and innovatively proposes a new method to assess the performance of supply chain.

Keywords—Complex Adaptive System (CAS); Emergence; Supply Chain System; Performance Evaluation

I. INTRODUCTION

John Henry Holland [1] defined Complex Adaptive System (CAS) as “a dynamic network of many agents (which may represent cells, species, individuals, firms, nations) acting in parallel, constantly acting and reacting to what the other agents are doing”. Gell-Mann [2] considered CAS as an open system which can recognize regularities in its dynamic process and has the ability to learn. The term “emergent” was coined by the pioneer psychologist Lewes [3], who wrote, “Every resultant is either a sum or a difference of the co-operant forces; their sum, when their directions are the same - their difference, when their directions are contrary”. Goldstein [4] defined emergence as: “the arising of novel and coherent structures, patterns and properties during the process of self-organization in complex systems”. Goldstein’s definition can be further elaborated to describe the qualities of this definition in more detail by Peter [5]. “The common characteristics are: (1) radical novelty (features not previously observed in systems); (2) coherence or correlation (meaning integrated wholes that maintain themselves over some period of time); (3) A global or macro “level” (i.e. there is some property of “wholeness”); (4) it is the product of a dynamical process (it evolves); and (5) it is “ostensive” - it can be perceived. For good measure, Goldstein throws in supervenience - downward causation.”

“A supply chain is a system of organizations, people, technology, activities, information and resources involved in moving a product or service from supplier to customer (from Wikipedia).” Because of the complex structure of supply chain system, it is difficult to evaluate the performance. Lummus el al. [6] believed performance of supply chain should be evaluated in 4 aspects – supply, process management, delivery and demand management. Beamon [7] pointed out evaluation indexes of a supply chain performance system can be classified in two groups – qualitative ones and quantitative ones. Roger [8] considered supply chain system should be evaluated through the following aspects: tangibles, reliability, responsiveness, competence, courtesy, credibility, security, access, communication and understanding of consumers. In general, because most researchers treat supply chain as a simple system, few evaluation systems could assess performance without bias. In fact, supply chain should be considered as a complex adaptive system (CAS), in which it is not only material flow, but also information flow that makes the system more dynamic and unpredictable, this is called the emergency of supply chain system. The purpose of this paper is to construct a quantitative model for performance evaluation of supply chain based on CAS & emergence.
D. Non-linearity

Non-linearity means when the system inputs vary in specified order of magnitude, the output, however, doesn’t show corresponding linear relation. Variables in a supply chain system are influenced by many complex factors, so the system behavior has characteristics of non-linearity.

III. THE EMERGENCE OF SUPPLY CHAIN SYSTEM

A. Emergence on Individual Level

Agent companies in a supply chain system can be considered as complex systems as well, and it will also show emergence, which is represented as performance of single companies. This kind of emergence depends on continuous individual learning. It is not simply a transfer of knowledge, techniques and experience generating in team communication, but brand-new concept cognition caused by this transfer.

B. Emergence of Supply Chain System

The emergence of supply chain system is represented as the increase of performance and self-organizational capability. It is a kind of coherence effect. Supply Chain performance is the most direct manifestation of emergence. It can not be gained simply by summing of individuals performance. It is the “collective outcome” which includes three aspects: target accomplishment, satisfaction of agent companies and capability of collaboration.

C. The Influencing Factors of Emergence

- Differentiation

There always exist differentiations between agents. It refers to the difference between node companies which is shown as the variation of knowledge, techniques, experience, etc, and directly influences the learning process in communication between node companies.

- Inner Communicational Learning

Communication can enable companies to better understand the common goal, strengthen the cohesions and trust of the entire supply chain. Only through continuously communication, can a supply chain form a better inner interaction and feedback mechanism and become a real complex adaptation system.

- Common Goal

Supply chain is a task-oriented system. Via cooperation, it can achieve certain goals, but the goals do not need to be a specific one. In the supply system, goal together with corporate value, number of the companies and integrative environmental factors is simplified into a stable quantity. However, it does not mean common goal is unimportant. Actually, one of the significant features of a complex system is that it is hard to predict the future development according to present structure and behavior.

- Environment

Environment provides supply chain with resources required in an emergence (such as new techniques, ideal location) and constraints. Also, it is a useful method to evaluate performance and functional value emerging from the system.

IV. A QUANTITATIVE MODEL FOR PERFORMANCE EVALUATION OF SUPPLY CHAIN SYSTEM

A. A Logic Model of Supply Chain System

Based on the above analyses, the supply chain system is a complex adaptive system, whose emergence is represented as the increase of performance and self-organizational capability. According to the complex adaptive features of supply chain system and the characteristics of emergence, we can establish such a logic model (fig 1).

\[
\text{Figure 1 Logical Model of Supply Chain System}
\]

In this logic model, supply chain performance is decided by Knowledge (K), Technique (Te) and Experience (E) of agent companies. This process is caused by nonlinear interaction in certain time, ‘t’ (t∈(0,t’), assume that t’ is the length of the supply chain life circle ). The influencing factors includes number of the companies (N), structure, frequency as well as methods of learning (L), corporate value (V), integrative environmental factors (I), and the goal of the entire system (G), etc.

B. A Quantitative Model for Performance Evaluation of Supply Chain System

According to fig1, supply chain performance Sc (t) can be defined as

\[
Sc(t) = f(k, te, e, N, L, V, I, G, t)
\]

\[f\] is a nonlinear function, and it is continuous on \(t \in (0, t']\). k, te and e separately represent the K, Te and E varying with time.

\[
Sc(t) = P_{co}(t) + P_{sc}(t)
\]

\(P_{co}\) represents the sum of performance of single companies and it is influenced by K, Te, E, V and I. \(P_{sc}\) represents the overall performance and relates to G, L, N and I.

\[
P_{co}(t) = \phi(k, te, e, v, i; t)
\]

\[
P_{sc}(t) = \phi(g, l, n, i; t)
\]
Therefore, knowledge ($K$) is influenced by Value ($V$), Technique ($Te$), Experience ($E$), Goal ($G$), Number of companies ($N$), and Learning Capability ($L$). They interact with each other and change with the time ($t$).

In order to simplify the equation, $V$, $N$, $G$ can be considered as relatively stable parameters in team life circle ($t'$). Environment ($I$) is also crucial. It involves too many factors, but if we only consider physical factors, $I$ is also stable in $t'$. Therefore, their interaction effect can be replaced by a unified constant, '$\omega_0$'. The equation then transformed into

$$k(t) = \int_0^t f(\omega, e, l; \tau) d\tau + \omega_0^\tau$$  \hspace{1cm} (5)

Equally,

$$te(t) = \int_0^t f(k, e, l; \tau) d\tau + \omega_0^\tau$$  \hspace{1cm} (6)

$$e(t) = \int_0^t f(k, te, l; \tau) d\tau + \omega_0^\tau$$  \hspace{1cm} (7)

According to (5) ~ (7), we assumed such an interaction process: when the variables change, $K$, $Te$ and $E$ can change immediately requiring no reaction time.

However, in reality, the equations (5) ~ (7) can be accepted, but while dealing with learning capability ($L$), it can not be assumed in the same way, because a company needs a period of time to learn and understand the $K$, $Te$ and $E$ during communication (assume that the structure, frequency and method can be measured, and the impact factors are $\alpha, \beta, \gamma$ respectively). This directly leads to the time delay ($At$) of learning process ($L$). Noticeably, with the increase of communication between agent companies, the $L$ will grow up, while the $At$ will decrease. So we assume the execution time of the $L-KTeE$ circle is a constant, $\lambda 0$. $At$ decreases in exponential form $a^{-t}$ ($\lambda0 > 0, a > 1$). Actually, the $L-KSE$ circle is quite special: $L$ does not change until time $\eta$ has passed.

$$\eta \alpha^n = \lambda_0$$

$$L(t) = \int_0^{\eta^{-\lambda_0}} f(k, te, e, \alpha, \beta, \gamma; \tau) d\tau + \omega_0^\tau$$

Namely,

$$L(t) = \int_0^{\eta^{-\lambda_0}} f(k, te, e, \alpha, \beta, \gamma; \tau) d\tau + \omega_0^\tau$$  \hspace{1cm} (8)

In balanced environment, if $K$, $S$ and $E$ are continuous functions, $L$ will change continuously. But even only one environment factor changes, $L$ will become discontinued. This will lead to a brand-new $L-KSE$ circle. Time lag makes supply chain system constantly adapt itself. This discontinued learning process ($L$) causes the supply chain structure evolving inconsteuctively which enables the system to develop in a transient way.

$t$ is the life circle of supply chain, $\tau \in [0, \lambda t], t \in [0, \lambda t]$. (1)~(4) can be altered into:

$$Sc(t) = p_\infty + p_\infty = f(k, te, e, l; t) + \omega_0^\tau$$  \hspace{1cm} (9)

$$p_\infty = \phi(k, te, e; t) + \omega_0^\tau$$  \hspace{1cm} (10)

$$p_\infty = \phi(t; l) + \omega_0^\tau$$  \hspace{1cm} (11)

Quations set (5) ~ (11) is a quantitative model of Complex Adaptive Supply Chain System. It is obviously that this system is full of feedbacks and circles, and change of certain factors will lead to different performance outputs.

In this model, $K$, $Te$ and $E$ are important variables, and $V$ is relatively stable in $t$. Therefore, the selection of agent companies in supply chain becomes extremely important.

V. CONCLUSIONS

Supply chain should be considered as a complex adaptive system (CAS), emergence exists in the supply chain system. The emergence is a kind of hierarchical evolving process which guarantees the irreducible evolution of supply chain system. According to the quantitative model for performance evaluation of supply chain, the analysis on supply chain behavior and functions by using features of CAS and emergence enables people to better understand the time-varying evolution process. It enables us to understand the problems and phenomena in supply chain performance evaluation procedures. Last but not least, it provides organizers and managers with brand-new operation methods on supply chain system.

REFERENCES


