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Evolution Modeling of Degree Preference Supply Chain Network

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Abstract: Complex networks theory grows rapidly since 1998 and has attracted various researchers in the world. The research on supply chain's evolution has great theoretical and practical importance in a global logistics supply chain and to a simple enterprise in the supply chain. In this study, based on the knowledge of complex networks and Multi-agent simulation, supply chain networks of enterprises, as well as statistical analysis, were established and researched. On different optimal conditions for the establishment of cooperative networks of different companies, the statistical nature of the obtained co-operation between enterprises was analyzed. When the degree preference was considered, an interesting supply chain network was got with bimodal distribution in degree, uniform distribution in clustering coefficient and hierarchy topological structure. The present model extends previous approaches to the development of supply chain management.

Key words: Evolution modeling, complex networks, supply chain, degree preference

INTRODUCTION

With the rise of global manufacturing and to adapt rapidly changing of customers' needs supply chain management becomes a new management model, has become a research hotspot of the world in recent years.

More and more enterprises and intermediate links are involved in the modern production process, from raw materials procurement, production, distribution, transportation of products to sell. With the deepening of globalization, the structure of supply chain is more and more complex, which forms a network of suppliers, manufacturers, distributors (or distribution center), retailers users and other entities (Lee and Billington, 1993).

In general, the supply chain expresses as a complex network, specifically the chain, tree, two-way tree, star-shaped structure and compound structure morphology in the actual supply network. Supply chain management is not only related to the organizations upstream and downstream, but also related to the suppliers' suppliers, customers' clients; actually it is not management of just a simple chain, but a intertwined network.

In the competition, cooperation, dynamic market environment, a company can belong to different supply chains, competition among enterprises hasactually transformed into competition between different supply chains. In such a competitive situation, the operating environment becomes more complex. Companies are required to re-examine their mode of operation from a new viewpoint. The companies in the supply chain have to allocate optimal resources and make production strategies from a viewpoint of whole supply network.

In the context of economic globalization, information technology and a large number of uncertain factors, most supply chains as network systems, are lack of ability of resist uncertainty, some of them even cannot withstand risks. Strengthen research of supply chains' structure character, simulation the mechanism of choosing different partners to companies and analysis the evolution mechanism of supply networks, has great significance for improving the operational performance and robustness of the supply chain.

A group of physicists led by Helbing is in the use of complex network theory of supply chain network at abroad.

Helbing *et al.* (2006) finds that the bullwhip effect in supply chain management, that is, information amplifying effect, relate with the nature of the supply chain network topology. Good supply chain structure can weaken the bullwhip effect, while increasing stability and resistance to aggressive.

Douglas (Powel *et al.*, 2005) finds in the commercial relations of the U.S. biopharmaceutical industry, the network of commercial relations of the U.S. biopharmaceutical industry formed with homogeneous nodes as representation of industry, have hub such as Merck, pfizer, Myers, which had more business partners compared with other biopharmaceutical companies., have a large number of links in the network; also finds in the evolution of the supply chain, network size constantly

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increases, cooperation between enterprises, the edge of the network, grows even more rapidly.

Kuhnert *et al*. (2006) finds that the city's material supply network obeys a scale-free distribution, that is there are a small number of core nodes, playing an important material scheduling and distribution role in the network.

Yan *et al*. (2010) construct a real supply chain network of China MengNiu Dairy Inc., then they analysis the topological structure of the complex network. Furthermore, they evaluate and measure the importance of every node in this supply chain in a virtual cascading process, then identify the most important nodes in this supply chain network.

This research studies the evolution mechanism of supply chain network. The results try to explain what is the key role or the important feather for a company in partner selection. This study use the multi-agent method to simulate a real supply chain's growing process especially in a degree preference selection rules contrast with random selection. Furthermore, this study gives a complex network statistical analysis and explains the deference between the two rules.

MATERIALS ANS METHODS

Complex networks theories: A lot of complex systems in the real world can be described by networks. A network consists of many points (nodes) and connections (edges), while nodes stand for the individuals, agents or sub-systems in the real systems and edges are used to represent the linkages between individuals or the relationship between sub-systems.

Historically, the study of networks has been mainly the domain of a branch of discrete mathematics known as graph theory. Complex network model is simple, therefore it has universal goodness and it has a wide range of applications in many fields. In fact, any system can be abstracted into a complex network in some appropriate manner; including supply chain system.

Complex network is the key to portray and study structure and behavior of complex systems. The last decade has witnessed a new movement in networks research, these networks have irregular structure, large- scale in nodes and dynamical reaction between nodes with links. The theoretical and applied research associated with complex networks has been infiltrated into many disciplines such as physics, biology, computer science, management, sociology and economics.

Complex networks have not yet precise and rigorous definition; it is called as complex network because of its complexity, which is mainly manifested in the following areas.

First, the complex structure: The huge number of nodes and a variety of different structure characteristics; Second, the network evolution: The performance of the nodes or connections producing and disappear; Third, the diversity of connections: Connection weights between nodes are different and there may exist directional; Fourth, the complexity of the dynamics; Fifth, the diversity of nodes: Nodes of complex networks can represent anything; Sixth, the multiple complexity integration: Multiple above complexity interactions lead to more unpredictable results.

The study of complex networks mainly focuses on the characteristics of network structure at the beginning, including the calculation of static statistics, seeking community structure and the discovery of modular or motifs.

The basic static statistics of complex network includes the degree distribution, average clustering coefficient, average shortest distance length, the between ss of nodes or edges and the degree correlation. Below a brief introductory about physical significance and calculation methods of all kinds of static statistics will be given in undirected and unweighted complex networks.

Suppose that there is a network,G, with nodes labeled 1…N. The measures below can all computed from the adjacency matrix of this network. The adjacency matrix of G is an N×N matrix with entries defined by:

$$A_{ij} = \begin{cases} 1 & \text{There is an arc from node i to node j} \\ 0 & \text{othrewise} \end{cases} \tag{1}$$

Two nodes joined by a link are referred to as adjacent or neighboring. A is always a symmetric binary matrix for an undirected unweighted network.

Each node i in the complex network connects with others through links, the neighbors' number is called node's degree, usually symbolic representation as k_i:

$$k_i = \sum_j A_{ij} \tag{2}$$

Frequency statistics on sequence of all nodes' degree values gives the degree distribution of the network P (k), which represents the probability of a randomly select node with degree of k. The degree distribution in ER random network (Erdos-Renyi Model) is Poisson distribution:

$$P(k) \sim e^{-<k>} \frac{<k>^k}{k!} \tag{3}$$

While a power law distribution $P(k) \sim k^{-\alpha}$ in a scale free network (4).

Clustering coefficient of node i is definition as ratio between actual links number e_i among its neighbors to the possible biggest number of edges ki (ki-1)/2:

$$C_i = \frac{2e_i}{k_i(k_i-1)} = \frac{\sum_{j,m} a_{ij} a_{jm} a_{mj}}{k_i(k_i-1)} \tag{5}$$

that is, ratio of neighbors of node i being close neighbors between each other. Therefore clustering coefficient is of the range [0, 1], usually symbolic representation as C_i. The bigger of the clustering coefficient C_i reflects the more tightness between close neighbors of node i. To complex networks, because of huge number of nodes, it is often not to study the detail of the clustering coefficient of each node, but the average clustering coefficient $\langle C \rangle$ of the entire network from a statistical point of view, that is, average of the clustering coefficient of all nodes.

The average clustering coefficient $\langle C \rangle$ describes the possibility of the formation of groups or communities in the network. The larger of $\langle C \rangle$, more coherent groups or communities are formed from the perspective of probability. It's not difficult to calculate average clustering coefficient in random network, i.e., $\langle C \rangle_{rand} = p$.

In addition to the average clustering coefficient, another important indicators of the clustering coefficient is C(k), i.e., the relationship between the average clustering coefficient $\langle C \rangle$ and degree of k. The power law function $C(k) \sim k^{-1}$ indicates that the network may have a hierarchical structure (Ravasz and Barabasi, 2003; Ravasz *et al*., 2002).

The degree correlation $k_m(k)$ (Newman, 2002) refers to the relationship of degree value of the two vertexes of one edge. The degrees of the vertices at both ends of each edge can be listed, the larger degree on the left, the smaller degree the right side, so that both sides of degree value format a sequence of degree, one definition of the degree correlation is the correlation coefficient of these two sequences. Of course, the specific operation to calculate the degree correlation can also be designed as other programs. The purpose of calculating degree correlation is to study the connected trend between nodes in a complex network. Positively correlation indicates that the nodes with more links in the network tend to connect with nodes with also more neighbors, this feature is known as assortativity; on other hand, negative correlation indicates that nodes with more links tend to connect with nodes with few links, which called disassortativity.

Degree correlation expresses a kind of individual preferences of choosing neighbor in the system, which will have a certain impact to ultimately form the network topology and dynamic properties in system evolution. To Scale-free network, if the value of degree correlation is negative, then the dynamics on the network is stable, the contrary, it is unstable (Jeong *et al*., 2000).

The large number of empirical studies (Bu *et al*., 2003; Barabasi and Oltvai, 2004) show that social networks are generally positive, natural networks, e.g., biological networks, are generally negatively correlated. Both social networks and natural networks can be scale free or small world, but only in this dimension the two have some obvious differences. Therefore, there is no doubt that this will become of a breakthrough in one of the social networks and biological networks different evolution mechanism.

Complex supply chain networks evolution algorithm: The degree preference complex supply chain network is simulated in this way:

- **Rule 1:** Network A (control group), randomly generate partnership, that is and generate edge if the probability p> 0.5
- **Rule 2:** Network E (preference network), Taking into account in actual customers choose business cooperation with more inclined. From network A as an initial network, if the degree of the node i and j are both greater than the mean degree of the whole network, an edge is established between the two nodes

If the degree of the node i and j are both less than the average degree, connection can't be created. If only one of the degrees of the node i and j is greater than the mean degrees, the edge will be built randomly.
Rule 2 describes one preference for the collaborators choose during practice supply chain network evolution.

RESULT AND DISCUSSION

Degree and degree distribution: The properties measured about the number of nodes' neighbour's are: total number of vertices or nodes (No. of nodes); the minimum number of degree; the maximum number of degree; mean degree; the standard (Std.) deviation of degree. Although, the mean degree of these two networks is almost same, the Std. deviation of preference network is significantly higher than the control one.

As can be seen from Table 1, network A (control network) and network E (preference network) have no significant difference in average degree but preference network has broader distribution with bigger standard deviation. That is, the degree preference rules promote a non-homogeneous network, the preference

Table 1: Descriptive statistics of degree of control networks and preference networks

Network	No. of nodes	Minimum degree	Maximum degree	Mean degree	Std. deviation
A	225	92	137	112.9	7.62
E	225	46	180	111.43	56.11

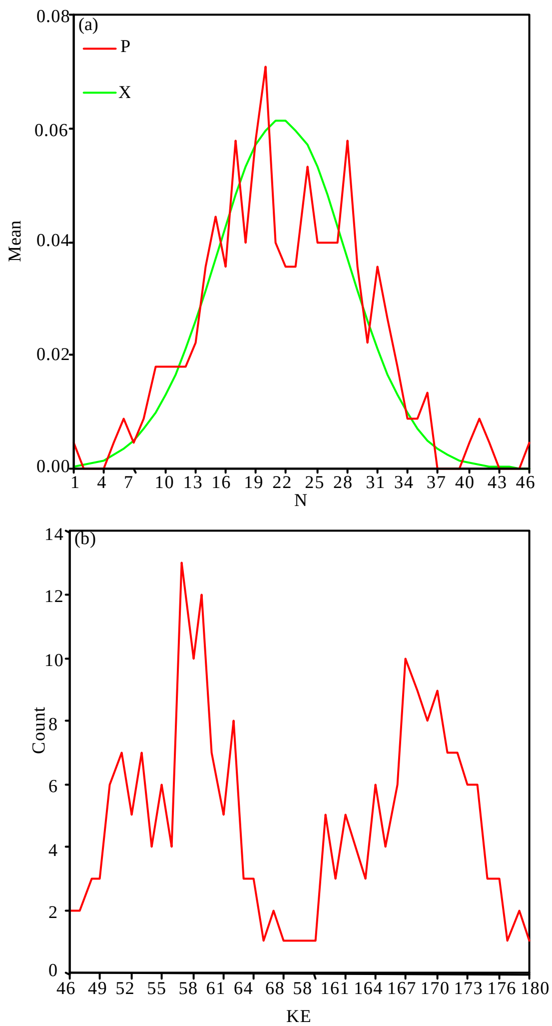

Fig. 1: Degree frequency distributions p (k) of control networks and preference networks, (a) Network A (control group), (b) Network E (preference network)

make some nodes get more neighbors than the other. Some detail information of degree distribution is more apparent in the distribution diagram (Fig. 1). The horizontal axis for each panel is node degree K and the vertical axis is the probability distribution (frequency count) of degrees, i.e., the fraction of nodes that have degree equal to degree K of this degree group. The networks shown are: (a) The network A, network of control group, the green curve in (a) is normality fitting, (b) The network E, network of simulated supply chain under degree preference in collaboration choosing. Network (a) appears to have normal degree distribution, as indicated by approximately normal fitting; while network (b) present bimodal status or possibly two combined normal degree distribution.

P (K) is defined as the fraction of nodes in the network that have degree K. i.e., p (K) is the probability that a node chosen uniformly at random has degree K. A plot of p (K) for a given network can be formed by making a histogram of the degrees of nodes. This histogram is the degree distribution for the networks. In Fig. 1, in network A, each edge is present with equal probability and hence the degree distribution is binomial or Gauss. The network E is very unlike the random graph in the degree distribution. The degree of distribution of preference network has two centers, no longer as bell-shaped distribution, changes in the network structure is precisely caused by preferences. Some nodes in network E have significantly more neighbors than others, which mean in network E the nodes are no longer equal to each other as network A, some are bubs with more links and are more important to the whole supply chain than others because of more collaborate resources. This found is consistent with some empirical report Douglas, (Powel *et al*., 2005), But the degree distribution doesn't appear power-law like Kuhnert *et al*. (2006).

The table stands for the two curves' correlations in Fig. 1a, the curve presents 46 data. The pearson correlation coefficient of the degree frequency of the network A and Gauss fit is 0.912, the p-value of this hypothesis testing question is approximately zero, that is, the hypothesis, the curve of degree distribution of network E is nothing about Gauss distribution, is rejected.

Conclusion can be gotten from Table 2 that the Gauss fit on the degree distribution p (K) is very good, with 91.2% of relevance.

Degree correlation: The degree correlation coefficient k_m (k) is measured, the hypothesis that k_m (k) is zero is tested, the t statistics value is calculated and the 95% confidence interval with df 224 is listed. The t statistics values are both beyond the 95% confidence interval, that is under the confident level of 5%, the k_m (k) of these two network is significantly nonzero.

The pearson correlation coefficient of the degrees at either ends of an edge is calculated respectively in network A and in network E in Table 3. The positive number indicates an assortatively mixes network and

Table 2: Pearson correlation and fit test on the degree probability distribution p (K) of Network A in SPSS

Pearson correlation Sig. (2-tailed)	Real degree distribution of network E	Guass fit degree distribution
Real degree distribution	1.000	0.912
of network E	0.0	0.000
Guass fit degree	0.912	1.000
distribution	0.000	0.0

Table 3: Degree correlations and t test of control networks and preference networks

			95% Confidence interval of the difference	
	k_m (k)	t statistics	Lower	Upper
A	-0.913	-19.167	-24.1782	-19.6701
E	-0.985	-12.732	-207.4619	-151.8476

Table 4: Descriptive statistics of clustering coefficient C of control networks and preference networks

Network	No. of nodes	Minimum C	Maximum C	Mean C	Std. deviation
A	225	0.4891	0.5182	0.504307	5.66941E-03
E	225	0.6139	1.0000	0.831802	0.171435

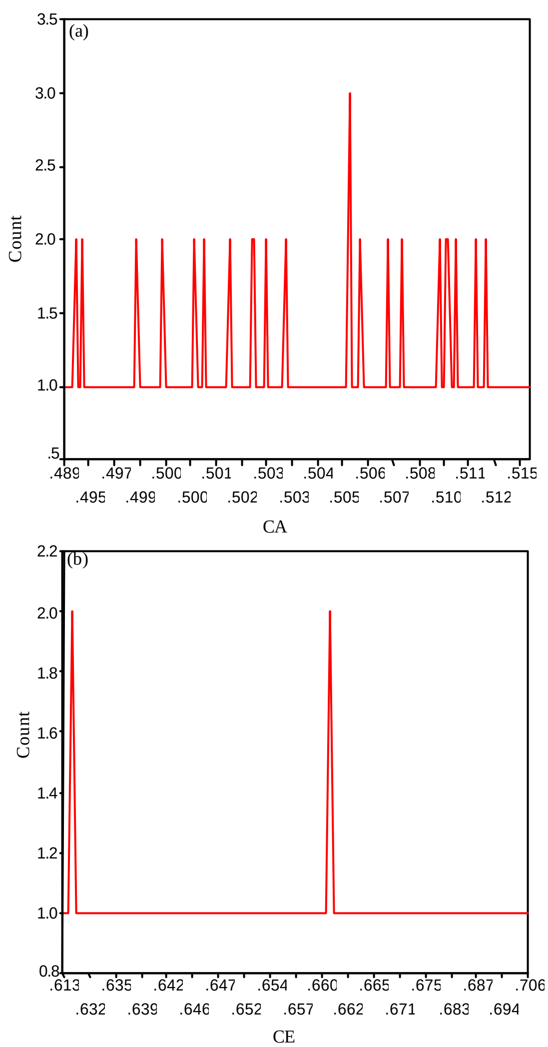

Fig. 2: Distribution of clustering coefficient for the two different networks, (a) Network A, (b) Network E

negative for disassortative one. Negative one in Table 3 means that the high-degree vertices in a network prefer to attach to low-degree ones. A significant correlation between degree value connected nodes has been found, which means the preference supply chain is disassortativity. But there is no significant difference in this feature between the preference network and the control network. This feature always appears in some information networks, technological networks and biological networks.

Clustering coefficient: The properties measured are: total number of vertices or nodes (No. of nodes); the minimum clustering coefficient (C); the maximum clustering coefficient; mean clustering coefficient; the standard (Std.) deviation of clustering coefficient. The mean clustering coefficient and the Std. deviation of preference network is significantly higher than the control one.

As can be seen from Table 4, there is big difference between the average clustering coefficient of the network A, network E, both are approximately uniformly distribution, but network E has a bigger average clustering coefficient and a wider distribution. Network E has more density of triangles and density of longer loops, which may help the supply chain to improve the efficiency of information transmission. And the preference can get group of fully connected (also can be seen from Fig. 2).

The horizontal axis for each panel is node clustering coefficient C and the vertical axis is the probability distribution (frequency count) of clustering coefficient, i.e., the fraction of nodes that have clustering coefficient equal to clustering coefficient C of this clustering coefficient group. The networks shown are: (a) The network A, network of control group; (b) The network E, network of simulated supply chain under degree preference in collaboration choosing. Network (a) has disperse frequency, indicated the homogeneous structure; while network (b) present more concentrated clustering coefficient or bigger clustering coefficient distribution.

Relation between clustering coefficients and degrees: The pearson correlation coefficient between clustering coefficients and degrees for each node is measured, the hypothesis that a node's C is nothing to do with its degree is tested, the t statistics value is calculated and the 95% confidence interval with df 224 is listed. The t statistics values are both beyond the 95% confidence interval, that is under the confident level of 5%, but the pearrson correlation is nearly -1, indicated that the nodes with less neighbors will get more close neighborhood in network E.

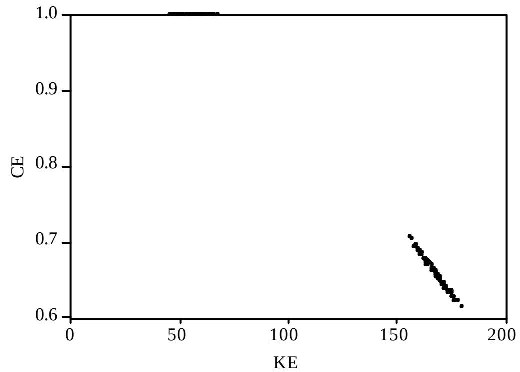

Fig. 3: Relationship of degree K and clustering coefficient C in the network E

Table 5: Pearson correlation and its t test between clustering coefficients C and degree K of control networks and preference networks

	Pearson correlation	t-statistics	95% Confidence interval of the difference Lower	Upper
A	0.006	221.297	111.3926	113.3943
E	-0.998	27.479	103.2060	117.9927

Table 6: Regression test of degree and clustering coefficient in network E

Dependent Variable: KE
Method: Least squares

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	383.0876	1.207975	317.1320	0.0000
CE	-326.5871	1.422470	-229.5915	0.0000
R-squared	0.995787	Mean dependent var		111.4311
Adjusted R-squared	0.995768	S.D. dependent var		56.10605
S.E. of regression	3.649734	Akaikeinfo criterion		5.436035
Sum squared resid	2970.484	Schwarz criterion		5.466400
Log likelihood	-609.5539	F-statistic		52712.26
Durbin-Watson stat	2.064837	Prob (F-statistic)		0.000000

As can be seen from the Table 5, the clustering coefficient of the nodes in the network A is irrelevant with their degree; while relatively large negative correlation in the network E.

The horizontal axis is clustering coefficient C and the vertical axis is degree K for the same node. Except the above little nodes with clustering coefficient C value of 1, the relationship between clustering coefficient C and degree K forms straight line for most nodes.

Figure 3 shows straight tail which indicates preference network has a hierarchical structure (Jeong *et al*., 2001; Huang *et al*., 2004). From the Table 6 the function of degree K and clustering coefficient C can be estimated as follow:

$$K = 383.0876-326.5871\times C.$$

CONCLUSION

In recent years a large number of empirical studies have shown that, the complex network abstracted from the real complex systems is not completely random, but has a certain structural organization and rules.

It was discovered that many complex networks abstracted from the actual system have some common structural features, so to establish a unified mechanism of the network evolution model for these systems becomes a research focus in complex networks.

Using complex network theory, Macroscopic properties of the overall supply chain network can be straight revealed, the dynamic process and the macroscopic behavior can be easier studied, the stability of the supply chain network and the ability to resist risks can also be evaluated. The results from complex networks view give a good reference for the management of such complex systems. Complex network theory of supply chain management brings a fresh perspective and inspiration and application of complex network theory of supply chain management has a very important practical significance and theoretical significance.

Although, the study of the supply chain has been extensive literature published, but study of supply chain system from the point of view of the system and research feature as a whole is missing.

The evolution of complex networks is the description of freshmen demise and the evolution of the networks' nodes and connections over time, but also refers to the process and mechanisms of the formation of network structure, update and change. The structure of complex network in a large extent determines its function, game, cooperation, synchronization, search and essential nature of dynamic processes on complex networks, the dynamic behavior showed significant differences because of different topological structure. Study the mechanisms and models of evolution of the complex network to reproduce real network topological properties have very important significance.

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