

Model Construction and Simulation of Weighted Industrial Cluster Complex Network

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Abstract

In this paper, we construct a weighted industrial cluster complex network model according to preferential attachment and local world mechanism, in which the logistics amount of business contact between one enterprise and others is defined as edge weight. We simulate and analyze statistic characteristics of the industrial cluster model such as degree distribution, point strength, point strength-point strength correlation, and relationship with degree and point strength. The simulation results show that the degree and point strength distribution are accord with power law distribution, the point strength-point strength correlation is negative, and the relationship with degree and point strength is strongly linear.

Keywords: industrial cluster, weighted complex network, degree, point strength

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1. Introduction

The complex network theory is an important basis for a lot of network study in real life, with the gradual deepening of the complex network study, the weight difference of connection between nodes in the network is increasingly being recognized. In the literature [1] Barabasi and Albert mentioned that weighted complex networks is an important direction of the complex network research. In literature [2] S. Boccaletti, V. Latora, Y. Moreno, M.Chavez and D.-U.Hwang described the effects of weighted network theory for complex networks. Weighted network has become an important part of the field of complex networks. Many actual networks were researched as a weighted network, such as biological networks [3-4], social networks [5-6], economic networks [7-8], technology network[9], the transport network[10] and so on.

Enterprises in the industrial cluster network establish the appropriate connections according to business contacts. Logistics amount between enterprises can distinguish the strength of business contacts, it shows the co-operation between the enterprises, and can reflect the strength of dependency between the enterprise and other enterprises. In this paper we define the logistics amount between enterprises in the industrial cluster as the edge weight, build a weighted industrial cluster complex network model, and analyze statistics characteristics of the weighted industrial cluster complex network such as degree, point strength, relationship of degree and point strength by simulation.

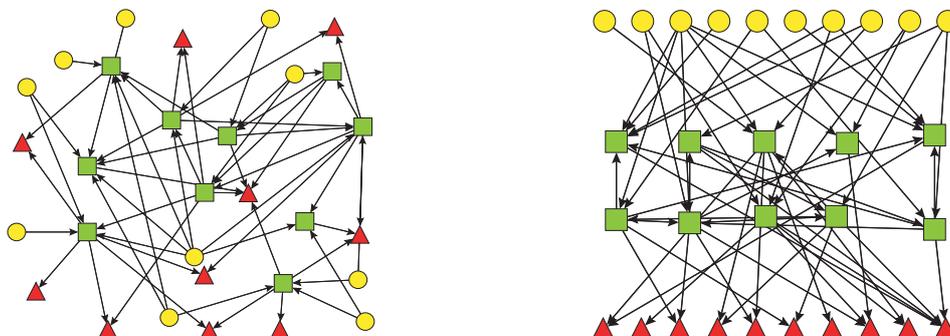


Figure 1. The Industrial Cluster Network

Figure 1 expresses industrial cluster network with 30 nodes. The rounds represent upstream enterprises, the squares represent midstream enterprises and the triangles represent downstream enterprises. There are 10 numbers respectively of the three kinds of enterprises in the figure. The left is hybrid and the right is layered based on node types.

2. Model Construction of Weighted Industrial Cluster Complex Network

2.1. Definition of weighted industrial cluster complex network

(1) Node definition

The node definition of weighted industrial cluster complex network is $v_i=(no, Class, Order)$, in which *no* standards for the node number, *Class* standards for the node class, in the industrial cluster all nodes are divided into upstream, middle and downstream enterprises. *Order* standards for the business order in the industrial cluster. The order of middle enterprise is higher than upstream enterprise, and lower than downstream enterprise. When a low order node is connected to a high order node, the direction should be from the low order node to high order node.

(2) Edge definition

The edge definition of weighted complex network is $e=[(v_i, v_j), w_{ij}]$, which represents the business contact of the enterprise v_i and v_j in the industrial cluster network. Weight w_{ij} represents the logistics amount between the enterprise v_i and v_j , and w_{ij} is weight of the edge from v_i to v_j . It is equal to w_{ji} which is weight of the edge from v_j to v_i .

(3) Net definition

The net definition of weighted industrial cluster complex network is $G=(V, E)$. V is the nodes set of industrial cluster enterpriss, and E is the edges set which present the business contract among the enterprise nodes of weighted industrial cluster. Weighted adjacency matrix W is used to represent the weighted network. w_{ij} presents logistics amount of the node i and node j . If there is no connection between the node i and node j , the weight $w_{ij}=0$.

2.2. Model Construction of Weighted Industrial Cluster Complex Network

The model construction of weighted industrial cluster complex network process is as follows:

(1) Start with a small number m_0 of nodes and small number e_0 of edges. The initial nodes are random allocated with node attribution, order, and edge weight. Point strength of these nodes is equal to the sum of the edge weight.

(2) Add a new node j at every time step t , set the node attribution include class and order, then set the edge number m and its local world [11] A_j according node attribution as follows:

- If the new node j is a upstream enterprise, then $m = 3$, the local world is all middle enterprises and lower order upstream enterprises;
- If the new node j is a middle enterprise, then $m = 5$, the local world is all upstream enterprises, all downstream enterprises, and other order middle enterprises;
- If the new node j is a downstream enterprise, then $m = 3$, the local world is all middle enterprises;

(3) In the local world of node j , using a preferential attachment with probability $\Pi_{local}(j \rightarrow i)$ defined by:

$$\Pi_{local}(j \rightarrow i) = s_i \left(\sum_{l \in A_j} s_l \right)^{-1}$$

Select m of nodes to connect with the new node j according to the connection probability. Randomly assign weight w_{ij} of edges between selected old node i and node j , and calculate the point strength of all nodes.

(4) Repeat 2), 3) until the number of node enterprises in the weighted network reaches to N .

3. Simulation of Weighted Industrial Cluster Complex Network

In the simulation of weighted industrial cluster complex network model, the initial industrial cluster network is set 10 of nodes, every new upstream, middle and downstream enterprise takes 3, 5, 3 edges which connect old nodes. The numbers of the three kinds of nodes which eventually join the industrial cluster network are set 480, 800 and 1280 respectively. Give the edge weight of the new node with a random integer range from 1 to 3, the old nodes connected to each edge get the edge weight, and the increase value of node point strength is the new edge weight.

3.1. Point Strength Distribution of Weighted Industrial Cluster Complex Network

In the weighted industrial cluster complex network model, point strength is defined by:

$$s_i = \sum_{j \in N_i} w_{ij}$$

N_i is the neighbors collection of the node i . The point strength takes consider with both the number of neighbors and weight between the node i and its neighbors, which is a comprehensive reflection of the node's local information.

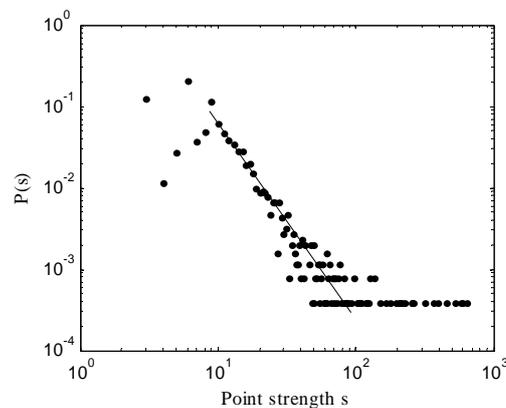


Figure 2. Point Strength Distribution

As show in Figure 2, enterprises node point strength distribution is accord with the power law distribution. Most point strength of the enterprise node is small, and a few enterprises point strength is very large.

In the evolution of industrial cluster network process, some enterprises develop rapidly, and their business contacts are fast increased. But most of the enterprises nodes have little business contacts with the restriction of business capacity, geographical and other reasons, then enterprises with large-scale business can attract more new nodes to establish business, and the newly established business contacts will lead to that the enterprises node with large amount business contacts grow more quickly, and these nodes will develop to be the core enterprises in the industrial cluster, thus point strength of enterprises show "the rich get richer" power-law behavior in the simulation model.

3.2. Degree Distribution of Weighted Industrial Cluster Complex Network

The degree distribution of weighted industrial cluster complex network is accord with the power law distribution. It is shown in Figure 3.

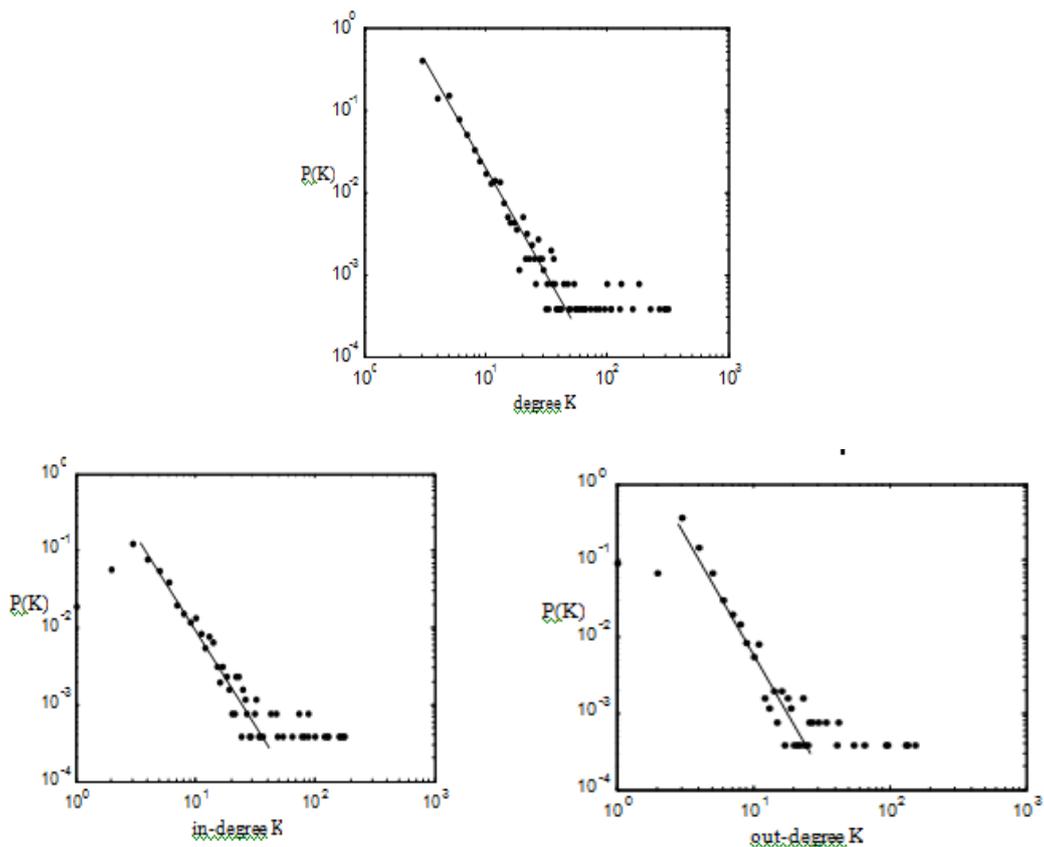


Figure 3. Degree Distribution

In the weighted industrial cluster complex network model, a new enterprise node choose to establish business contacts according to point strength of the original enterprise node, therefore, the higher point strength enterprise nodes can get more business contacts of the newly added enterprise nodes, and these point strength is increased with adding new business contacts, while a large number of lower point strength enterprise nodes can only get less new business contacts, so the power law phenomenon of "the rich get richer" is appeared.

3.3. Point Strength-point Strength Correlation

Point strength-point strength correlation reflects an enterprise node choice to the others according to the scale of business contact. Large-scale business contacts mean the large point strength of enterprise node. If the enterprise node with large point strength is inclined to connect to the enterprise node with small point strength, the correlation is negative. If the enterprise node with large point strength is inclined to connect to the enterprise node with large point strength, the correlation is positive. The measure index of point strength-point strength correlation is the average point strength of all neighbor enterprise nodes for enterprise node i , which is defined by:

$$s_{m,j} = (s_i)^{-1} \sum_{j \in v(j)} s_j$$

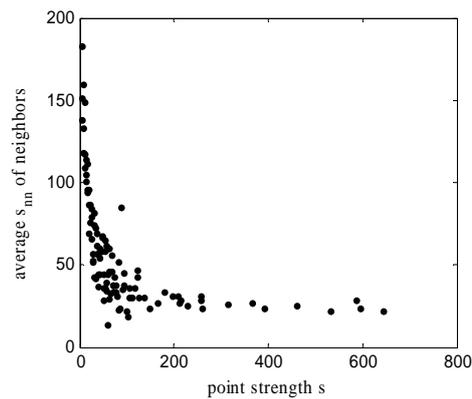


Figure 4. Point Strength-point Strength Correlation

Figure 4 shows point strength-point strength correlation in weighted industrial cluster complex network. When the point strength of a node is small, the average point strength of its neighbor nodes is large, with the increasing of point strength, the average point strength of its neighbor nodes decrease rapidly, but the continuing increasing of the point strength can lead to the neighbor average point strength stabilize at a fixed values.

3.4. Relationship of Point Strength and Degree

Figure 5 shows the relationship of point strength and degree in weighted industrial cluster complex network, which (a) is in the linear and (b) is in the double logarithmic coordinate system.

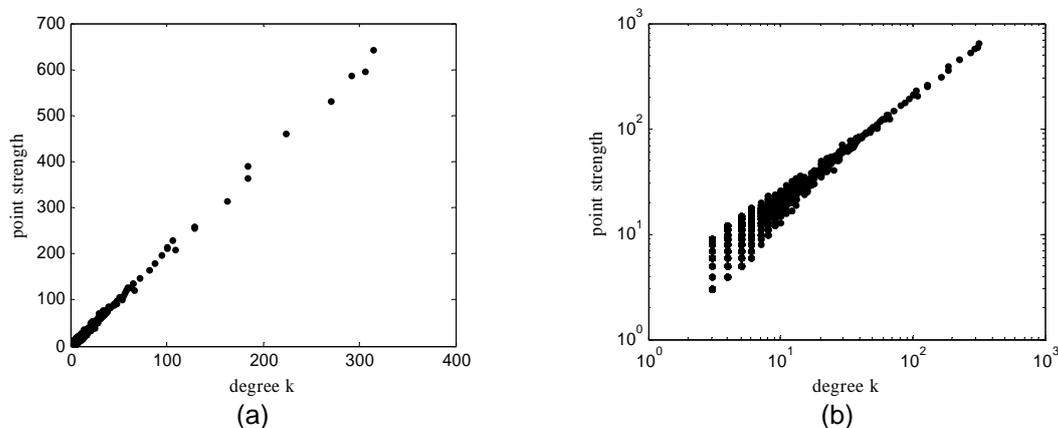


Figure 5. Relationship of Point Strength and Degree

There is a strong linear relationship between node point strength and its degree, and greater degree can lead to greater point strength. This means that the enterprise node with large business contacts generally have greater logistics amount, for example, the upstream enterprise with more business contacts generally have strong ability to supply, and downstream enterprise with more connection generally have strong purchasing capacity.

In double logarithmic coordinates, in the case of smaller node degree, some enterprise nodes have same degree but different node point strength. This means that in the weighted industrial cluster network, the node point strength with similar business contacts may be different. In the evolution of industrial cluster network, each node which joined into the industrial cluster network has different point strength and each edge has different logistics amount. When

the point strength of enterprise nodes is smaller, the logistics amount of each business contact is the major factor in affecting the whole node point strength. When the point strength of enterprise nodes is larger, the logistics amount factor of each business contact become minor, and the number of business contacts become the major factor in affecting the whole node point strength. So, in the industrial cluster network the enterprise nodes with smaller business contacts may have similar business contacts number while have different point strength.

3.5. Rich-club Property

The rich-club property is characterized by the rich-club connectivity and the node-node edge distribution, which measure the interconnection between rich nodes. Nodes in the network are sorted by degrees of node enterprises. The rich-club property $\phi(r/N)$ is defined as the ratio of the total actual number of edges to the maximum possible number of edges among the members with maximal degrees. The maximum possible number of links between nodes is $n(n-1)/2$. In the weighted industrial cluster complex network, the point strength is used instead the degree of node enterprises. The rich-club property of weighted industrial cluster complex network is defined as the ratio of the the total actual number of edges to the maximum possible number of edges among the members with maximal point strength.

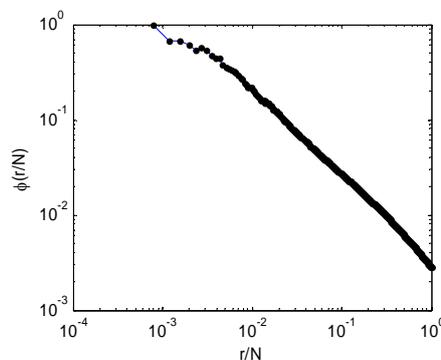


Figure 6. Rich-club Property with Point Strength

Figure 6 shows the rich-club property with point strength of weighted industrial cluster complex network. At the start of the rich-club curve, the decline speed is slower than the end of the curve. This phenomenon shows that rich-club is existed in the weighted industrial cluster complex network.

4. Conclusion

In this paper we construct a weighted industrial cluster complex network model to research the evolution of the industrial cluster network. The weight is set as logistics amount of the enterprise connection. With growth of the network, every edge weight remains unchanged, and the enterprise node point strength increases. Simulation show that the degree and point strength distribution are accord with power law, point strength-point strength correlation is negative, and relationship with degree and point strength is strongly linear. In real world, edge weight in industrial cluster may change as the network grows, so, how to establish the more realistic model of industrial cluster network according to different network evolution mechanism, is the future research direction of industrial cluster network.

Acknowledgements

This paper is supported by the Youth Foundation for Social Science Development and Research of Hebei Province of China under Grant No. 201204124 and the Fundamental Research Funds for the Central Universities under Grant No. 13MS113.

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