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Simulation of process innovation diffusion ratio based on WS small-world network model

Wanhong Li[1]*, Xia Cao [1] and Hailing He[2]
[1]School of Economics & Management, Harbin Engineering University, Heilongjiang, (P.R.CHINA)
[2]College of Civil and Architectural Engineering, Heilongjiang Institute of Technology, Heilongjiang, (P.R.CHINA)
E-mail : liwanhong@hrbeu.edu.cn; caoxia@hrbeu.edu.cn; hehailing@hit.edu.cn

ABSTRACT

Although research on technological diffusion has made many valuable contributions, the literatures still lack a theoretical method to simulate the characteristics of process innovation diffusion. Drawing from the diffusion probability, network scale, and network relationship strength, the paper studies how process innovation is diffused in the potential adopters based on the WS small-world network model. It can not only foster the broad application of process innovation but also help the innovators to get the process innovation benefits effectively. The simulation results indicate that the process innovation diffusion probability is proportional to diffusion ratio while inversely proportional to diffusion cycle firstly. Secondly, in a certain adoption period, the adopted ratio in different network scale will show volatility characteristics with the increasing of network scale. Thirdly, the relationship strength of the individuals in diffusion network has positive effects on adoption ratio, while negative effects on adoption speed and total adoption ratio.

KEYWORDS

Process innovation; Diffusion ratio; WS small-world network model.

INTRODUCTION

Process innovation diffusion is the follow-up sub- stage of a single innovation process. After enterprise makes a breakthrough progress in process innovation, the new process technology and new manufacturing methods will spread and be applied among the internal and external potential users. Therefore it is necessary to study the diffusion ratio in the potential adopters. It can not only foster the broad application of process innovations but also help the innovators to get the process innovation benefits effectively.

Since the 1960s, Fourt, et al. (1960), Mansfield (1961), Floyd (1962), Rogers (1962), Chow (1967) and Bass (1969) began to study innovation diffusion. After that time, the innovation diffusions' components, diffusion characteristics, diffusion models become important research topics in this field. Many theoretical models are put forward by researchers to interpret the innovation diffusion ratio, including, (1) Internal influence model, namely that innovation mainly diffused depended on external factors of social system rather than the dissemination between individuals. A typical model is Fourt-Woodlock model[1]. (2) External influence model, that is innovation mainly diffused through exchange and communication between individuals, so the innovation diffusion is similar to the disease process, such as Mansfield model and Gompertz model[2,3]. (3) Mixed influence model, that innovation diffusion is decided by both external factors of the social system and communication between internal individuals, such as the Bass model[4].

In recent years, researchers found that using complex network theory to analyze the innovation diffusion is more feasible and practical. Besides analyzing innovation diffusion speed and trend from the macroscopic aspect, this theory can also be applied to analysis the influence of individual interaction networks on innovation diffusion from the microscopic view. Therefore the small-world network model —WS model has been widely used in the economic management areas. For example Gibbons et al. (2004) put forward the new products forecasting methods and empirical testing which based on WS model. Combining the geographical distribution of the first few months' sale dates of new products, he predicted whether new products' sales can be success in the market[5]. Weiqiang Huang and Xintian Zhuang (2007) also researched the effects of network structure on the adoption of innovative and proliferation based on the WS small world network model[6].

These papers make an important contribution to analyze the innovation diffusion in inter-enterprise or intra-enterprises, but it is worth noting that researchers' studies largely focused on the "new product" rather than "new technology" diffusion. However, due to the difference between new technology and new products, process innovation diffusion is also different from product diffusion. Therefore, based on the research findings, the paper attempts to simulate the process innovation diffusion ratio using WS small-world network model, which would answer the question "What are the features of process innovation diffusion cycle and adoption rate?".

A RELATIONSHIP BETWEEN PROCESS INNOVATION DIFFUSION AND SMALL-WORLD NETWORKS

The WS small-world network model's origin

A cognitive of small world phenomenon originated from the famous experiments—*six degrees of separation* conducted by Stanley Milgram (1967), an American social psychologist[7]. Facts proved that many networks have small world properties in reality. This characteristic has also become a major legendary feature of complex networks[8]. While the in-depth study of small-world networks is derived from a paper published in *Science* by Watts and Strogatz (1998)[9]. In this paper, Watts and Strogatz put forward a single parameter of small-world network model (WS model), which can rationally reflect the statistical properties of network neither completely regular nor entirely random.

The building steps of WS model are as follows. Step I, start from the rule Figure. Considering a nearest neighbor coupling network which has N nodes and it forms a ring. In which each node is connected to the $K / 2$ nodes that are adjacent to its right and left. K is an even number. Step II, a randomized reconnect. Randomly re-connect each edge in network with probability p. One end side of the edge remained unchanged, while the other end side is a randomly selected node in the network. One of the provisions is that between any different two nodes can have one edge at most, and each node cannot have a side connected with itself. Step III, repeat step two until all the edges are traversed[10].

By adjusting the probability p value, the models can be obtained from rule network (Regular) ($p=0$) to random network (Random) ($p=1$) (Figure 1).

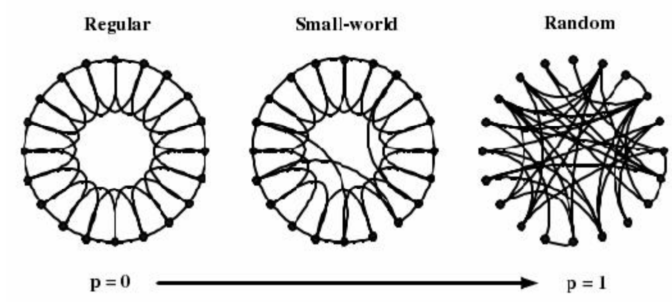

Figure 1 : Regular network, small-world network and random network

Process innovation diffusion in small-world network

As process innovation often diffuse in a social network, we can use the small-world network theory to analyze the process innovation diffusion. According to Rogers' Innovation Diffusion theory, process innovation diffusion adopters can be divided into innovators, early adopters, mid-adopters, late adopters and laggards based on their time into the S-curve of the innovation diffusion. Process innovation diffusion is carried out in the network which is constituted by these adopters as nodes (Figure 2).

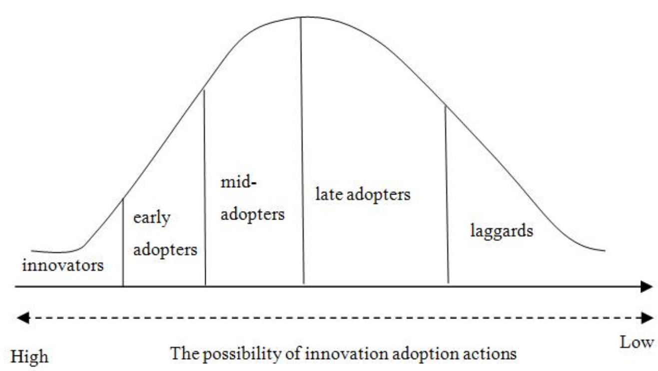

Figure 2 : Innovation adopters

These nodes have an interaction relationship with each other. If drawing the lines to represent the interaction relationship between these nodes, the network can be configured in different structures. In the process innovation diffusion network, homogeneous individuals will form some different factions, but there may be links between the heterogeneity individuals. Therefore innovation will diffuse not only in the homogeneous network, but also in heterogeneous network. Meanwhile, the communication between individuals can be as the clustering coefficient of process innovation network, the distance of diffusion network refers to the average numbers of other media-individuals when the network individuals communicate[11].

METHODOLOGY

Assumptions

First, the relationship between process innovation adopters will use the connection between the nodes in the network, and the connection is a two-way undirected connection.

Second, the connection strength has some differences between adopters of the network. The strength between homogenous individuals is stronger than heterogeneous individuals.

Third, we ignore that the different propagation path will bring different effects on innovation diffusion process, that is to say the probability of process innovation diffusion is constant.

The model's principles

WS small-world network model of process innovation diffusion ration is as follows,

$$G=(V,E) \tag{1}$$

Where G is the process innovation diffusion network, V is the node sets of process innovation adopters, and E is the edge sets between adopters. Other parameters also should be informed[12].

N : The nodes of process innovation diffusion network. That is, the total number of all providers, adopters and potential adopters of process innovation.

k : The degree of process innovation node. A node degree means the number of edges associated with this node. The greater a node degree is, the larger it brings influence in the network.

$<L>$: Process Innovation average diffusion time. In general, the two non-adjacent nodes i, j of complex network can be connected by m edges, $(i,k_1)\,(k_1,k_2)\,;\cdots\cdots,(k_{m-1},j)$, and the set of edges are called the paths between i and j . Under normal circumstances, we are only interested in the shortest path of all. Therefore, this shortest path length is defined as the "shortest path length", as d_{ij} . Average shortest path length of $<L>$ is defined as the average shortest path between any two points, in which N is the nodes of network, then

$$<L>=\frac{1}{\frac{1}{2}N(N-1)}\sum d_{ij}=\frac{2N}{K}f(pNK/2) \tag{2}$$

In the WS small-world network model of process innovation diffusion, $<L>$ is the average diffusion time form provider to adopters in the network. This parameter reflects the process innovation diffusion speed. The larger $<L>$ means more intermediate links and lower diffusion ratio.

C : The clustering coefficient of process innovation. Watts and Strogatz believe that the node i of degree k connects with other k nodes of the network. If k nodes are fully inter-connected with each other, there should have $k(k-1)/2$ line connecting. If the fact that among these nodes only E_i line connecting, the clustering coefficient of the node i is

$$C_i=\frac{2E_i}{k(k-1)} \tag{3}$$

Then averaged the cluster coefficient of all the nodes, we can get the entire network clustering coefficient. That is

$$C=\frac{1}{N}\sum_{i=1}^{N}C_i \tag{4}$$

In WS small-world network model of process innovation diffusion ratio, the parameter reflects the tightness of the network between process innovation adopters. The higher clustering coefficient means the closer relationship between enterprises process innovation.

The description

In the N nodes of process innovation diffusion network, at any time t , we will select an individual i (a single entity in the initial situation of the network) at certain probability p as an innovation adopter or not an adopter.

Before deciding whether adopt process innovation, the individual i has an initial evaluation value a_i^0 on process innovation. According to the central-limit theorem, the initial evaluation of the value obeys the random distribution $a_i^0 = rand[0,1]$ $(i = 1, 2, \cdots, N)$. Meanwhile, the individual has an adoption threshold value b_i ,and $b_i = rand[0,1]$, $(i = 1, 2, \cdots, N)$. In adoption period t, when the initial evaluation value of the individual is greater than the adoption threshold ($a_i^0 > b_i$), he will adopt the process innovation, in which adoption status is $s_i^0 = 1$. Or not adopt, which is $s_i^0 = 0$.

Individual i affects the decision of its neighbors with the probability λ_{ij}. λ_{ij} shows the relationship strength between the process innovation adopters, that is, the strength of relationship between i and j (we assume that $\lambda_{ij} = \lambda_{ji}$,that each relationship strength is equal between these two individuals). λ_{ij} =1, indicates that is the most tightly connection relationship between them, and the fastest diffusion ratio. λ_{ij} =0, indicates no connection between them, that is, without innovation diffusion. Generally, the relationship strength between the homogenous individuals is greater than the heterogeneity. Therefore, evaluation information of λ_{ij} for i in adoption cycle t will update to

$$a_i^t = \lambda_{ij} \sum_{j=1}^{(n-1)^{t-1}} a_j^{t-1} / n^t \tag{5}$$

Finally we can get the probability of process innovation diffusing in the whole network. In each adoption cycle *T*, when the individual's value of states adoption is accumulated, we can get the cumulative number of adopters. Thus the whole adoption proportion is

$$R(t) = \sum_{i}^{N} s_i^t \tag{6}$$

SIMULATION

We simulate the process innovation diffusion ratio, with employing MATLAB7.0 version and compiling C + + language. To ensure the reliability of the simulation results, we randomly generate 10 different networks and average their results under the condition of fixed parameters. Based on the results, we analysis the diffusion characteristics in small-world network model, and explain the simulation results from the relationship between process innovation diffusion ratio and the diffusion probability, the network scale, and the network relationship strength.

Diffusion probability and process innovation diffusion ratio

Let $N = 1000$, $K = 20$, $T = 10$, $p = [0.01, 0.1, 0.3, 0.5, 0.9]$, we can get a relationship diagram of process innovation adoption cycle and adoption proportional under the different diffusion probability in a fixed network scale (Figure 3).

In Figure 3, the probability diffusion and diffusion proportion have a positive correlation with each other. With the increasing of diffusion probability, the diffusion proportion in a certain diffusion cycle will increase until the adoption ratio reaches steady situation. When the diffusion probability is 0.9, that is to say, in the diffusion cycle neighbors who directly connect to process innovation adopters almost adopt the process innovation. Therefore, in a very short period of time the process innovation will be adopted by the majority of adopters in the network, and the adopted proportion of process innovation can up to the maximum in a very short time. This case is similar to random networks.

In addition, the diffusion probability and diffusion cycle is inversely proportional. The higher of the diffusion probability is, the shorter diffusion period of process innovation is.

Network scale and process innovation diffusion ratio

Let $K = 20$, $T = 10$, $p = 0.5$, $N = [100, 300, 500, 1000]$. We can get a relationship diagram of process innovation adoption period and the adoption of proportion under a fixed diffusion probability and different network size (Figure 4).

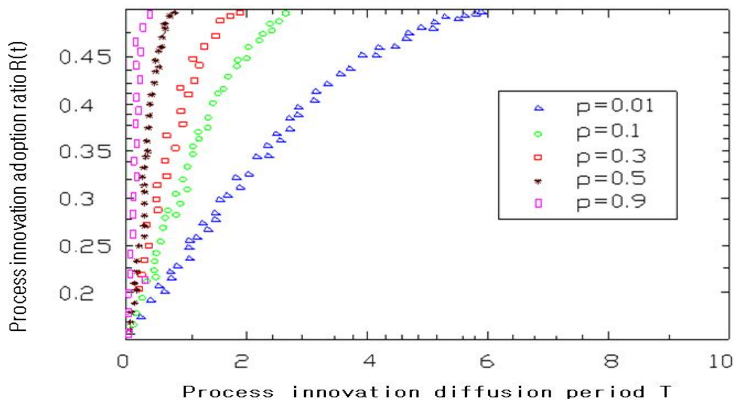

Figure 3 : Process innovation diffusion ratio under different diffusion probability

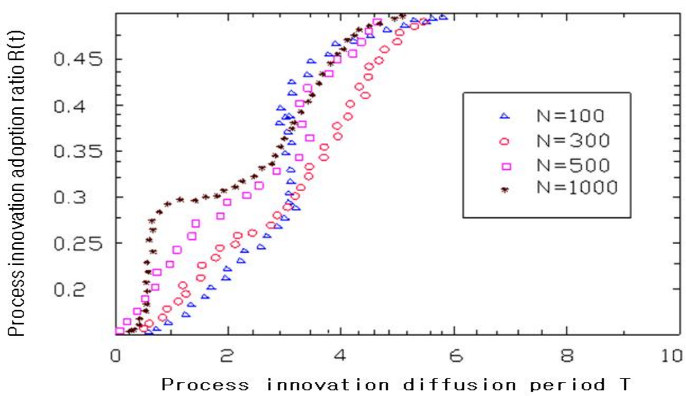

Figure 4 : Process innovation diffusion ratio under different network scale

In Figure 4, process innovation often diffuse among potential adopters with different scales. On the one hand, when the adoption period is fixed, the adoption proportion of different scale networks will fluctuate along with the growth of scale until the end of diffusion. Thus, the sizes of network and the diffusion ratio are unrelated to the adoption proportion. On the other hand, in the entire diffusion period, network scale has little effect on the proportion of process innovation diffusion. When Network scale is from 100 to 1000 units and the diffusion probability is 0.5, process innovation will need about four and a half periods to diffuse to the whole network. This feature is similar to small-world model, that is, as the number of nodes increasing, the process innovation diffusion cycle substantially constant.

Network relationship strength and process innovation diffusion ratio

Let $N = 1000$, $K = 20$, $T = 10$, $p = 0.5$, $\lambda_{ij} = [0.2, 0.4, 0.6, 0.8]$, we can get the relationship diagram of process innovation adoption cycle and the adoption proportional under in a fixed scale networks and different strength (Figure 5).

The relationship strength between the individuals of process innovation network has a positive impact on the ratio of process innovation adoption. In a network with strong relationship, potential adopters of process innovation are affected largely by neighbors, and the adoption will reach a higher proportion in a short period.

But the relationship strength is inversely proportional to the adoption speed and the overall adoption proportion. That is, the network with strong relationship is close to the homogeneous network, while homogeneity can only promote the new technology diffusion ratio in the level[13]. The network with weak relationship is close to the heterogeneous networks, while process innovation diffusion in heterogeneous network is more permeable. Thus the adoption proportion of heterogeneous networks will be relatively higher than the homogeneous networks. Therefore, in the network with strong relationship, the proportion of early adopters of process innovation will increase, but the late adopters' proportion will grow slowly. In the network with weak relationship, the proportion of early adopters will increase slowly, while the late adopters will steadily improve.

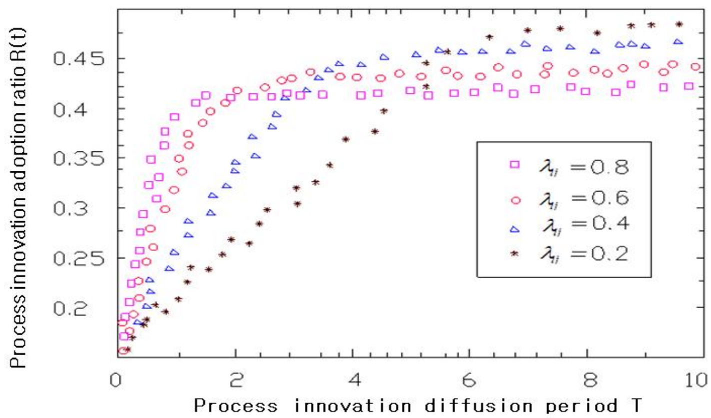

Figure 5 : Process innovation diffusion ratio under different network relationship strength

CONCLUSION

The results indicate that the diffusion probability, network size and network relationship strength will affect the enterprise process innovation diffusion ratio and ultimate adoption ratio. The process innovation diffusion probability is proportional to diffusion ratio while inversely proportional to diffusion cycle. In a certain adoption period, the adopted ratio of process innovation in different network scale will show volatility characteristics with network scale increasing. Otherwise, the network scale has little effect on the diffusion ratio in a whole period. The relationship strength of the individuals in diffusion network has positive effects on adoption ratio, while negative effects on adoption speed and the total adoption ratio.

However, compared with product innovation, process innovation diffusion has some characteristics such as the passive resistance of innovative provider, enterprise as main innovation adopter. Therefore, what is the difference between the diffusion ratio of process innovation and product innovation? Whether the initial providers' attitude to innovation diffusion of process innovation will decide the innovation diffusion ratio? These questions should be answered in the following research.

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