CHEMICAL ENGINEERING TRANSACTIONS
VOL. 46, 2015
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet
Guest Editors: Peiyu Ren, Yancang Li, Huiping Song

ISBN 978-88-95608-37-2; **ISSN** 2283-9216
DOI: 10.3303/CET1546089

Research on Supply Chain Network Knowledge Dissemination Mode

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Supply chain network enables the enterprises to achieve the purpose of knowledge diffusion complementary. Based on the complex network theory, using the method of combining qualitative analysis and model deduction, we established a knowledge diffusion network model that view staff of supply chain as network node, discussed the mechanism of knowledge diffusion, analysed the main control parameters which impact on the speed of knowledge diffusion, and we found of knowledge diffusion laws of the supply chain network process. From the angle which take the enterprise as the supply chain network node, based on the complex network statistical theory, we studied the influence of cluster coefficient and the modulation to the network knowledge diffusion, and found that by changing the relationship between enterprises or introducing some other enterprises, it can accelerate the speed of knowledge diffusion.

1. Introduction

Knowledge is the main source of enterprise to obtain and maintain sustained competitive advantage. Knowledge diffusion is the social activity that with the help of specific media means, a part of social members in a specific social environment diffuse knowledge information to another part of the social members. By summarizing the relevant literatures, knowledge diffusion between individuals and the spread of viruses among the organisms has a strong similarity.

The purpose of network theory is to explain the complexity of the real world. The research on the relationship between network structure and behaviour is an important research direction of complex network theory. At present, many scholars have studied the knowledge diffusion in the network. Two knowledge diffusion models distinguished by the degree of involvement of the organizational members are proposed according to the perspectives of gene evolution and population dynamics by Huang and Jih-Jeng (2012). Kunal(2011) developed a dynamic general equilibrium model to understand how multinationals affect host countries through knowledge diffusion. Naumis et al. (2012) discussed a diffusive model for scientific communications based on scientometric study of 25 million papers and 600 million citations that encapsulates the epistemology of modern science. The diffusive model predicts and explains a surprisingly universal internal structure in the development of scientific research. Kreng et al. (2012) discussed knowledge diffusion model of the substitutive knowledge based on the activity-based costing (ABC) model and the diffusion model of single knowledge, presented to evaluate the changes of knowledge value and its corresponding enterprise benefits. Corinne et al. (2013) built upon the empirical results concerning localised knowledge spill overs in order to highlight some policy implications within the European regions. Noennig et al.(2014) studied the emergence and diffusion of knowledge in regards to environmental conditions and gave an outline for the description of Knowledge Ecosystems by integrating models for environmental dynamics based on resources and attractiveness, and models for knowledge dynamics based on the behaviours and processes of knowledge agents (innovators) and agencies. Yu et al. (2014) took main path analyses, namely local, global, and key-route, to depict the knowledge diffusion path and additionally implements the g-index and h-index to evaluate the most important journals and researchers in the data quality domain. Samir(2015) proposed interdependency, dynamism, variety (IDV) model attempts to detail actors' roles in intra- and inter firm knowledge diffusion during the fuzzy front-end of innovation (FFEI). Luo et al. (2015) proposed an agent-based model to study such co-evolutionary dynamics. Yang et al.(2015) present a knowledge diffusion model based on the local-world non-uniform hype network. Cowan et al. (2004) proposed a knowledge diffusion and knowledge growth model, studied the relationship between network structure and knowledge diffusion, network structure and knowledge growth. However, knowledge forgotten is a gradual process, and the degree of forgetting is greatly dependent on the number of people who have the knowledge. Knowledge forgetting and knowledge immune had rarely been considered in the existing researches on knowledge diffusion. In addition, the research on knowledge diffusion in the network is mainly concentrated on the field of numerical simulation, and only a few scholars begin to analyse the network structure and function of knowledge diffusion. Therefore, this paper attempts to establish a knowledge diffusion model, and to make the relevant mathematical analysis based on infectious disease dynamics theory, and give the conditions of continuous diffusion of knowledge in supply chain network.

2. Knowledge diffusion model of supply chain network with employees as nodes

2.1 Knowledge diffusion basic model structure

A large number of empirical studies have found that most of the real life networks have small world characteristics, such as high concentration, short path, namely, small world network or scale free network. The relationship between network structure and behaviour are important research directions of complex network theory, such as infectious disease model, rumour spreading model and so on. The main body of knowledge communication in the supply chain network is people, and the relationship between human is a kind of friend or colleague. The supply chain network, which is composed of these relations, is very similar to the form of the NW small world network. So this paper employs the construction of the NW small world model to consider the diffusion behaviour of knowledge. Building a NW small world network with N nodes, each node represents an individual, the enterprise employees in the supply chain network can only affect the nodes which connected with them (Newman and Watts, 1999). Its construction method is as follows:

Considering a nearest neighbour coupled network containing N nodes, which is surrounded by a ring, where each node is connected to each nod $k/2$ adjacent to it, and k is an even number. Plus an edge with probability p between a pair of nodes selected randomly. Among them, there is at least one edge between any two different nodes, and each node cannot be connected to its own.

The model reflects the characteristics of social relations network, most people are friends with their colleagues in the same unit work or live together with the neighbours. On the other hand, there are some people who live far away, or even in a foreign country, which is a remote connection to the NW world model.

2.2 Model hypothesis and building

In order to facilitate the model, the key factors are considered in this paper, and the reasonable hypothesizes are made.

Hypothesis 1: The number of people in supply chain network is a constant N, without considering individuals in and out; the day is the unit of time.

Hypothesis 2: There are only two types of individuals in the network. One is the person with certain knowledge, we called knowledge owner. Another class is called knowledge blank who does not own the knowledge. $i(t)$ and $s(t)$ are expressed the proportion of the two groups in the total number of N at t moment, it is obvious that $i(t) + s(t) = 1$.

Hypothesis 3: Since knowledge diffuse require the individuals to be in a certain way to contact. Suppose each knowledge owner can communicate with k people in unit of time. The k represents the average degree of network nodes in the network, and it is a constant.

Hypothesis 4: In the supply chain network, the employees are defined as nodes, and the relationship among the individuals is defined as the edge between nodes, and any two nodes are connected means the possibility of communication between them.

According to the rules of NW small world network structure, this paper formulates knowledge diffusion rules: suppose when node a (a knowledge owner) meets node b in the bordered randomization process, if node b is the knowledge blank, b can become knowledge owner with probability λ. Then each knowledge owner can changes $\lambda ks(t)$ knowledge blank into knowledge owner in unit time. Since the total knowledge owner is $Ni(t)$,so there are $Ni(t)\lambda ks(t)$ knowledge blank become knowledge owner in unit time, namely $Ndi(t)/dt = Ni(t)\lambda ks(t)$.

Suppose the ratio of the initial time (t=0) knowledge is i_0, then we can get:

$$\begin{cases} di(t)/dt = i(t)\lambda ks(t) \\ i(0) = i_0 \end{cases} \quad (1)$$

Because $i(t) + s(t) = 1$, then the solution $i(t)$ is:

$$i(t) = \frac{1}{1+(\frac{1}{i_0}-1)e^{-k\lambda t}} \quad (2)$$

From Eq.(2), we can know that , when $t \to \infty$, $i(t) = 1$, which means that, if knowledge diffuse in the supply chain network, all people will become the knowledge owner eventually.

From the second order derivative of $i(t)$ with t, we can obtain that, when $i = 1/2$, $di(t)/dt$ reached maximum, it denotes the rate of increase of knowledge owner is the largest. $i = 1/2$ substitute into Eq.(2), then we can get the time $t_m = ln(i_0 - 1)/(k\lambda)$. Namely at the time t_m, the knowledge owner is increasing rapidly, and it is a time to reach the peak of knowledge diffusion, as shown in figure 1. This is the moment that the organization should pay attention.

Because t_m is inversely proportional to k and λ. λ relates to the staff's ability to accept knowledge. So in order to shorten the period of the spread of the supply chain network knowledge, the managers should develop the personal qualities and communication skills. At the same time, the larger of the average degree k of network, the faster the diffuse speed, that is, for the employees, the more communication, the shorter the diffusion cycle. This requires the organization always organize collective activity to establish a platform for the extensive exchange between employees, expand the average degree of network.

From Eq.(2), we can know that, when $t \to \infty$, $i(t) = 1$, all employees will have the knowledge. In fact, this is not the truth, due to difference in the ability of each employee in the supply chain network, such as understanding ability, memory ability, communication ability are not the same, then some employees may become knowledge blank again after some time, they should learn the knowledge again. Based on the above reasons, we need to improve the model.

2.3 Model improvement

Hypothesis 5: Since differences in the quality of individuals, some employees may have forgotten the knowledge and become knowledge blank, they need to learn again.

Then the knowledge diffusion rule is: when node a (a knowledge owner) meets node b in the bordered randomization process, if node b is the knowledge blank, b can become knowledge owner with probability λ. If node b is the knowledge owner, b can become knowledge blank with probability μ. Then the knowledge owner reduce $N\mu i(t)$ per unit time, Eq.(1) revised to:

$$\begin{cases} di(t)/dt = i(t)\lambda k s(t) - \mu i(t) \\ i(0) = i_0 \end{cases} \tag{3}$$

The solution of the equation is:

$$i(t) = \begin{cases} [\frac{\lambda k}{\lambda k - \mu} + \left(\frac{1}{i_0} - \frac{\lambda}{\lambda - \mu}\right) e^{-(\lambda-\mu)kt}]^{-1}, \lambda \neq \mu \\ (\frac{1}{i_0} + \lambda k t)^{-1} \qquad , \lambda = \mu \end{cases} \tag{4}$$

Let $di/dt = 0$, then we can obtain: $i = \begin{cases} 0 & , \lambda < \lambda_c \\ \frac{\lambda - \mu/k}{\lambda} & , \lambda \geq \lambda_c \end{cases}$, which $\lambda_c = \frac{\mu}{k}$ is diffusion critical value.

The result shows that there is a limited positive critical value λ_c in the supply chain network. If the diffuse rate λ is greater than the critical value λ_c, the knowledge owner can spread the knowledge and the total number of knowledge owner in the network is stable in a certain equilibrium state. At this point, the network is active phase; if the diffuse rate is lower than the critical value, the knowledge is exponential decay, and cannot be diffuse in a large range, then the network is absorption phase.

Let $\gamma = \lambda k$, $\delta = \gamma/\mu$, then γ denotes the average effective diffuse number of employee per unit time for each knowledge owner. $1/\mu$ means average diffusion period of knowledge, and δ implies the average effective diffusion number of each knowledge owner in a period of knowledge diffusion. When $t \to \infty$, according to Eq.(4),we can get $i(\infty) = \begin{cases} 1 - 1/\delta, \delta > 1 \\ 0 \quad , \delta \leq 1 \end{cases}$. $\delta = 1$ is a threshold value, when $\delta < 1$, $\gamma < \mu$, the effective average number per unit time of each knowledge diffusion is less than the number of forgotten, $i(t)$ getting smaller and smaller and tends to 0 eventually. When $\delta > 1$, $i(\infty) = 1 - 1/\delta$ is a constant, which depends on δ, and increases with the increase of δ.

According to Eq.(3), let $d[i(t)\lambda k s(t) - \mu i(t)]/dt = 0$, then we can know that when $i = (1 - 1/\delta)/2$, di/dt reach the maximum value, at this time $t_m = ln(\frac{1}{i_0}(1 - \frac{1}{\delta}) - 1)/(k\lambda - \mu)$. Compared to the without considering forgetting case, $ln(\frac{1}{i_0}(1 - \frac{1}{\delta}) - 1)/(k\lambda - \mu < ln(i_0 - 1)/(k\lambda))$, peak diffusion time delayed, and the ratio of final knowledge owner is also small($1 - 1/\delta < 1$).

Sometimes knowledge is useless to some employees, for example, computer knowledge may be without any help for the employees who work in the packaging, and they may choose to forget or not to diffuse the knowledge. Moreover, in the case of a person who is in the process of communication, if he encounters a people who is also knowledge owner, he maybe will not diffuse the knowledge. These two kinds of people are

collectively called to the knowledge immune. Based on the above reason, we need to improve the model again.
Hypothesis 6: All of the staff are very motivated, and responsible for their work, because knowledge maybe is useless to them, then they would choose to forget the knowledge and would not to diffuse the knowledge. And knowledge owner may always encounter knowledge owner, they may also would not to diffuse the knowledge. In this paper, the employees who have the knowledge but do not diffuse the knowledge or forgotten the knowledge because of useless are called knowledge immune.
Then the knowledge diffusion rule is: when node a (a knowledge owner) meets node b in the bordered randomization process, if node b is the knowledge blank, b can become knowledge owner with probability λ. If node b is the knowledge owner or knowledge immune, b can become knowledge immune with probability μ.
μ is related to the knowledge applicability of the general staff in the network. The more suitable of knowledge, the more people can use this knowledge, and the μ is smaller.
According to the hypothesizes, the employees can divided into knowledge owner and knowledge blank, knowledge immune, the proportion of the three types of people are recorded as $i(t), s(t)$ and $r(t)$. $i(t)+s(t)+r(t)=1$. For the knowledge immune, we have $Ndr(t)/dt=\mu Ni$. At the initial time $t=0$, suppose the proportion are i_0, s_0 and r_0 respectively. Then we can obtain equation of the model.

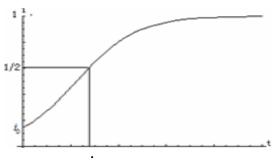
$$\begin{cases} di(t)/dt = i(t)\lambda k s(t) - \mu i(t) \\ ds(t)/dt = -i(t)\lambda k s(t) \\ i(0)=i_0, s(0)=s_0 \end{cases} \tag{5}$$

In this paper, the properties of the solution are discussed in the phase trajectory $s\sim i$. The domain of the phase trajectory $(s,i)\in D$, and $D=\{(s,i)|s\geq 0, i\geq 0, s+i\leq 1\}$. Eliminate the dt in the Eq.(5) can obtain $\begin{cases} di/ds = 1/\delta s - 1 \\ i|_{s=s_0} = i_0 \end{cases}$, then we can get:

$$i(t) = s_0 + i_0 - s(t) + \frac{1}{\delta}\ln(\frac{s}{s_0}) \tag{6}$$

In the domain D, the curve of Eq.(6) is the phase trajectory, just as shown in figure 2, the arrows indicate the change of $s(t)$ and $i\ (t)$ with time t.
The following we analysis the extreme values of $i(t), s(t)$ and $r(t)$ when $t\to\infty$, labeled as i_∞, s_∞ and r_∞ respectively.
(1) According to Eq.(5) we can know that $ds(t)/dt\leq 0$, and $s(t)\geq 0$, $s(t)$ exist the lower bound, so s_∞ exist. Since $dr(t)/dt=\mu i\geq 0$ and $r(t)\leq 1$, so r_∞ exist. Because $i(t)+s(t)+r(t)=1$, so r_∞ exist.
Suppose there exists a constant $\varepsilon>0$, make $i_\infty=\varepsilon$, we can know that $dr(t)/dt>\mu\varepsilon/2$ for a sufficiently large t, which will lead to $r_\infty=\infty$. This is in contradiction with r_∞ exist. In summary, i_∞ exist and i_∞ can not be greater than 0, so $i_\infty=0$.
(2) Since the final knowledge ratio is s_∞ and $i_\infty=0$, so according to Eq.(6), s_∞ is the single equation of $s_0+i_0-s_\infty+\frac{1}{\delta}ln(s_\infty/s_0)=0$ in the interval $(0,1/\delta)$, just as shown in the figure 2.
(3) According to Eq.(6), we can know that if $s_0>1/\delta$, then $i(t)$ increase with t, and reach the maximum value $i_m = s_0+i_0+\frac{1}{\delta}(1+\ln(s_0\delta))$, after that, $i(t)$ decreases monotonically to s_∞. It can be seen that $1/\delta$ is a threshold, when $s_0>1/\delta$, the knowledge will diffuse. That is, in the premise of s_0 fixed, to make knowledge diffusion, only to improve the δ. We note that $\delta=\lambda k/\mu$, so the stronger knowledge accept ability, the more extensive communication, and knowledge is more suitable ,then the bigger δ.
By the above three points, we can see that the supply chain network of knowledge diffusion process can be simple generalized as follows: under the premise $s_0>1/\delta$, the system has only a small amount of knowledge owner, the other are knowledge blank, the number of knowledge immune is 0 at first. As the knowledge owner begin to diffuse knowledge, the number of knowledge blank rapid decrease, and the number of knowledge owner increased sharply. After the number of knowledge owner reached a peak, it begin to decline. At last, the number of knowledge owner is 0, many employees become knowledge immune and a few employees become knowledge blank.
We can see that in this model δ is an important parameter. At the end of the diffusion $i_\infty=0$, then $\delta=\frac{ln\, s_0-ln s_\infty}{s_0-s_\infty+i_0}$ according to Eq.(6). Because the initial value of the i_0 is usually very small, $i_0\to 0$, so we can get $\delta\approx\frac{ln\, s_0-ln s_\infty}{s_0-s_\infty}$, s_0 and s_∞ can be estimated by historical data, then δ can by calculated.
Let $x=s_0-s_\infty$, x denotes the proportion of knowledge receive, then $x+\frac{1}{\delta}\ln(1-\frac{x}{s_0})\approx 0$. The first two terms of the Taylor expansion of the logarithmic function is $x(1-\frac{1}{s_0\delta}-\frac{x}{2{s_0}^2\delta})\approx 0$. Let $\sigma=s_0-1/\delta$, then σ means

the part of the proportion of knowledge blank exceeds the threshold $\frac{1}{\delta}$. When $\sigma \ll \frac{1}{\delta}$, $x \approx 2\sigma$. This result shows that the proportion of the number of people being diffused is about 2 times of σ.



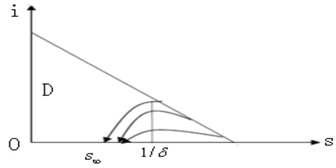


Figure 1. $i(t)$ changes with t Figure 2: the change of $s(t)$ and $i\ (t)$ with time t

3. Knowledge diffusion model of supply chain network with enterprises as nodes

We use small world network describe the characteristics of the supply chain network, then the nodes are the enterprises, scientific research institutes, government departments and other agencies, the connection is the interaction between the various nodes. In this way, we can describe and analyse the characteristics of supply chain network by the characteristics of the small world network, such as clustering coefficient C and rewiring probability P.

Suppose a small world network connectivity graph is G. The clustering coefficient is C in the small world network model, which reflects the average degree of the nodes. In this paper, the number of G_i connected edges is m, the maximum number of connections is M. For node i, the local clustering coefficient C_i is defined as shown in Eq.(7).

$$C_i = \frac{m}{M} = \frac{m}{k_i(k_i-1)/2} \quad (7)$$

Where G_i is the neighbor local graph of node i, k_i is the neighbors number of node i. G_i has at most $k_i(k_i - 1)/2$ edges. When G_i fully connected, C_i means the ratio of the number of edges actual existence and the number of edges allowed to exist.Then the network clustering coefficient C can be calculated by Eq.(8):

$$C(G) = \sum_{i\in G} C_i / N \quad (8)$$

$C(G)$ represents the average value of C_i for all nodes in graph G.

According to the Eq.(7) and Eq.(8), we can see that, when the number of connections between an enterprise and other enterprises increases, namely m increases, the maximum number of the enterprise connections unchanged, at this time the supply chain network clustering coefficient increases. High clustering coefficient can improve the efficiency of supply chain network, reduce the transaction costs of enterprises. Therefore, it can improve the knowledge diffuse efficiency of the supply chain network by adjusting the clustering coefficient.

The clustering degree of nodes in the supply chain network describes the centralized trend among nodes, which can be used to distinguish the network connection of each node, the greater the difference, the higher the connection proportion of some nodes, and they occupy the central position in the knowledge diffuse network. C_i reflects the cooperation degree between enterprises of supply chain network, it is used to distinguish the network connection of each enterprise, the greater the clustering coefficient, the higher the connection proportion of the enterprise, that is, the enterprise occupy the central position in the supply chain network.

In the supply chain network, the clustering coefficient can be increased by bond breaking rewiring. In the network, a small amount of edge bond breaking rewiring with probability P or directly join a small shortcut to maintain the basic structure of the network unchanged, the network will have the characteristic of high clustering coefficient. Namely, by changing the relationship between enterprises or the introduction of other enterprises, it can accelerate the speed of knowledge diffusion.

Speeding up the knowledge diffusion among the supply chain network, in addition to changing the relationship between the enterprise and the introduction of other enterprises, we can also control the key knowledge diffusion enterprises of supply chain network. To find out the key knowledge diffusion enterprises, it must be module division on the supply chain knowledge network. Because the CP algorithm can find the overlapping points of each module in the knowledge network (Palla et al., 2005), the overlap points are the key enterprises in the supply chain network. Key enterprises are "chain nuclear" of the supply chain network, they play key roles in the stability and development for building supply chain symbiosis. By the CP algorithm, find the key enterprises, exert feedback control of key enterprises in the network, so as to be capable stability large scale complex dynamic network, obtain high control efficiency of knowledge diffusion.

4. Conclusion

Supply chain network enables the enterprises to achieve the purpose of knowledge diffusion complementary. Knowledge is the core competitiveness for the supply chain network, knowledge diffusion seems particularly important. Understanding and using knowledge is the ultimate goal of knowledge diffusion. Based on the complex network theory, management theory, system engineering theory, using the method of combining qualitative analysis and model deduction, we regard the employees and the enterprise as the network nodes respectively, analysed the characteristics of knowledge diffusion in the supply chain network, and researched the knowledge diffusion law. We established a knowledge diffusion network model that view staff of supply chain as network node, discussed the mechanism of knowledge diffusion, analysed the main control parameters which impact on the speed of knowledge diffusion. From the angle which take the enterprise as the supply chain network node, based on the complex network statistical theory, studied the cluster coefficient and the modulation to the network knowledge diffusion influence.

Acknowledgments

This work is supported by the science and technology foundation of Guizhou province (Guizhou J word [2013]2085), Guizhou Natural Science Foundation Project ((2014) 264).

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