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Research Article

Research of Enterprise Project Chain Risk Element Transmission Based on Complex Network Model

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Abstract: In order to research of enterprise project chain risk element transmission, constructed the enterprise project chain network model based on a complex network and analyzed the complex network characteristics. Take the mean-field theory to analyze the project chain risk element transmission and get the critical value of project chain transmission. The simulation results show that the project chain has the typical characteristics of a complex network. The distribution of it obeys the power law with lower average path length and higher clustering coefficient. It is a typical scale-free network. Based on randomly selecting risk nodes and the key risk nodes, simulate the relationship between transfer rate and the density of project chain risk nodes. It can provide reference for enterprise to make decision of project chain risk prevention. Finally, improve the whole project chain risk management efficiency and valuably.

Keywords: Complex networks, mean-field theory, project chain, risk element transmission, SIS model

INTRODUCTION

Enterprise informatization accelerates enterprise projects' assembly and leads to generation of project chain which is a general term about a group interconnected projects. Different types of enterprises have different degrees of complexity in project chains. For large enterprises, it has quite a lot items and each of them has a complex link. Because of the complicated contact among the projects, project chain has become a complex nonlinear system. As for the dynamic characteristics of risk, risk element transmission between projects has become one of the main contents in current project risk management. It will bring serious effect to project chain goal if not strengthen management on risk element transmission in project chains. So, researching risk management transmission in project chains is significant and has a practical value.

Complex network theory provides a new analytical way to study a complex system, especially the research on the dynamic behavior of complex network. The transmission dynamics and complex network have been applied in social, biology, information technology and other fields (Albert and Barabasi, 2002; Boccaletti *et al*., 2006; Newman, 2003; Strogatz, 2001; Keeling and Eames, 2005). In the research of complex network spread, different scholars made their researches from different fields. Based on the data of auto parts enterprises, it constructed a directed weighted competitive relationship complex network model and simulated its competitive diffusion effect (Yao *et al*., 2011). Ni *et al*. (2011) studied the impacts of the different types of network dissemination about infectious diseases on society using Mean-field theory and extensive numerical simulation. They divided the nodes in network into positive and negative according to the different reflects on infectious diseases. Then, they modeled the spread behavior of infectious diseases based on the social impact theory. Nekovee *et al*. (2007) built a stochastic model on general random rumor spreading and used the mean-field equations describing the complex social network in a dynamic model. Vicent (2006) studied the congestion problems on complex network information transmission and proposed a new strategy to improve efficiency of path selection. This strategy not only considered the node congestion, but minimized the cost of application which was in contrast with the traditional way. The result showed that dispersed more homogeneous nodes can reduce the average network load and crashed nodes. Yoo *et al*. (2011) studied the problem of epidemic spreading on this kind of dynamic network, specifically the one in which the rewiring dynamics of edges are carried out to preserve the degree of each node (called fitness rewiring). They also considered the adaptive rewiring of edges, which encourages disconnections from and discourages connections to infected nodes and eventually leads to the isolation of the infected from the

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susceptible with only a small number of links between them. Chang-Chun and Chen (2012) researched the rumour spread from the view of complex network and established a new model of rumour spreading using Mean-field theory. And then, presented and proved four propositions which had an important management meaning. Ji and Guo (2011) studied the dissemination knowledge of complex network in virtual community organization. After comparing the dissemination knowledge of complex network in virtual community organization with the real one, they got the factors affected the dissemination knowledge in virtual community organization. Dai and Chu (2011) analyzed the feasibility and significance of combining the industry chain, complex network and risk communication theory together. Then, they proposed the model about the spread of industry chain risk to investigate the rule and the path of spread of risk in an industry chain network. The above based on dissemination of complex network provide a reference method to research the risk element transmission in projects.

The existing studies about project risk transmission are basic about a limited number of scale projects studied from micro aspects. It lacks risk transmission on complex project chains. Yuan-ming and Dao-Zhi (2008) studied the risk of transmission in construction projects and analyzed the transfer mechanism of construction project quality risk. Then, they put forward a two-stage risk transmission model about controllable quality. Xiao *et al*. (2009), thought that in the supply chain, the risk of product quality had a progressive transmission and expanding effect and built the quality risk transfer model under the environment of supply chain. Xiao-ju and Yue (2004) presented a risk transfer algorithm for the relationship between construction period and risk in large-scale integration projects. The algorithm can calculate the total risk of duration in large-scale integration projects. Yong-Zheng *et al*. (2007), provided a risk transmission model composed of risk network and risk-propagation algorithm. The model is used to assess the security risk in network information system and to prove that the assessment method of risk propagation has more advantages. Fu *et al*. (2012), built a structure matrix probability model to assess the change of risk dissemination from requirements to software architecture and used it to assess the time and cost in software development.

Generally speaking, previous researches on project risk element transmission are studied from a partial angle instead of regarding the project chain as a whole. The transmission dynamics and complex network provide powerful instruments in studying the project chain risk transmission from the angle of a system. So, the study attempt to build a model about the project chain complex network from the angle of a complex network. Combine project risk element transmission's microscopic interaction mechanism with macroscopic property using Mean-field method to quantitatively study the project risk element transmission rule. Simulate the process of project chain risk element transmission with the rule of selecting at random and the degree of importance and analyze the transfer mechanism.

THE COMPLEX NETWORK MODEL OF PROJECT CHAIN

The project chain is an organic connection of projects aimed to achieve the same goal including duration chain, capital chain, cost chain, recourse supply chain, comprehensive evaluation chain, mixed chain and so forth. These chains are intertwined making the projects linked together. The diversity and complexity of the linkage lead project chain to be a complex system. Amount of researches confirm that complexity is the root of causing the project chain risk and poor overall performance. Through researching the impact of project chain element and their interaction relationship as well as the factor dynamic change on project performance, which can reduce the complexity degree and the risk of project chain and improve project performance, is a new area of research on complex project management at this stage. Therefore, according to the feature of project chain complex network, the below build a complex network model about project chain to study the project chain risk element transmission.

Behavioural features of project chain complex network:

- **Small-world and scale-free effects in project chain:** Small-world and scale-free effects are the basic characters of a complex network. In project chain, each element (the nodes in project chain network) has a direct or an indirect effect. From the perspective of the author, there are many kinds of interaction relationship between any two elements. But the mediating variables are not many among them. That is to say, the distance between any two elements is generally very short in the project chain. So, it fits for the Small-world effect. Additionally, the degree of interaction among elements composed the project chain is greatly different. Some of the elements and other majority of them have a correlation, such as the progress of the project chain, the level of technology, the support of senior management, external environment and so forth. However, some of the elements almost have no relation with others. This kind of elements satisfies the feature of scale-free network.
- **Complex network behavioral feature of the project chain:** Based on the implication of the complex network feature and the project chain complexity, there are lots of project chains have the complex network behavioral feature. According to the feature, we can view the elements composed the project chain as the nodes in the complex project

network and the relationship between them as the edge of the project chain network. This kind of project chain network has some features as follows,

- The project chain network consists of many elements or modules (nodes) which can affect each other and interact. The interactive relationship among elements can reflect the function and structure of the project chain. The change on any element can lead the unbalance among the nodes and influence the function and structure of the project chain.
- Some of the nodes or the local networks (or sub-network) consisted of some nodes have different functions and positions in the whole structure of the project chain network. The breakage of some critical nodes can make the whole network lose balance, or even damage it.
- The modules or elements have the function of self-discipline, adaptive and self-regulation. They don't need to rely entirely on the regulatory of the external environment.
- The project chain is a typical weighted network. The relationship and the strength of interaction are different among nodes in the project chain. Besides, in many cases, this kind of difference plays a vital role in the whole network.

As the project chain network have the complex network behavioral features, such as dynamic, non-linear evolution etc. we can use the theories and methods of the complex network to analyze the project chain's structure and feature and seize the operation rule about the project chain network. In this way, we can improve the overall performance of the project chain.

The project chain complex network model: The project chain is a complex nonlinear system and the traditional method to solve a simple system is no longer fit for it. The complex network provides a new way to study the project chain risk. Projects in the project chain are the nodes of complex network and the relationship among them is the edge. Constructing the project chain complex network model applies the basis to reveal the project chain operation.

- **Network construction:** In the initial network, the number of nodes is m0 and the edge is e_0. They link together as a specific way.

Increasing: Every time we just put one new node into the network and the node's connection is m .

The preferential mechanism in a local world: We choose randomly M nodes from the existing nodes ($M \geq m$) as the local world for the new one. So, the priority choice probability of new node introduce is shown as following.

$$\prod_{Local}(k_i) = \prod'(i \in LW)\frac{k_i}{\sum_j {}_{Local}k_j} = \frac{M}{m_0+t}\frac{k_i}{\sum_j {}_{Local}k_j} \quad (1)$$

- **The characteristic parameters of project chain network:**
- **The degree distribution of project chain:** The degree is a simple but important concept of the separate node attributes. The degree of node i is k_i defined as the node number connecting with it. That is to say, if the degree of a node is bigger, the node is more important in a sense. We can use a distribution function $P(k)$ to describe the node degree distribution in a network. The function $P(k)$ expresses that the probability of a node randomly choosing is k . For a project chain, the bigger the degree is, the more important position it has in a project chain and the greater the intensity of the risk management. The degree distribution can reflect the distribution of the importance degree of each project node.
- **The average path length:** d_{ij} is the distance between the node i and the node j. The distance is defined as the number of edges of the shortest path. The average path length L is the mean distance between any two nodes:

$$L = \frac{1}{\frac{1}{2}N(N+1)}\sum_{i\geq j} d_{ij} \quad (2)$$

The average path length of the project chain network represents the average shortest distance between any two projects in the network. It can be used to measure the efficiency of information exchange within the entire network. The shorter the average path length is, the closer degree contact of the entire network will be. At the same time, the transmission speed of risk element is faster and has more effects on the goal of project chain.

- **The clustering coefficient:** Generally speaking, assume that there are k_i edges connecting the node i with the other nodes. So there are k_i nodes and we call them the neighbor of the node i. Absolutely, there are no more than $k_i(k_i-1)/2$ edges among the k_i nodes. The ratio of the actual edges E_i and the possible number of edges $k_i(k_i-1)/2$ is the clustering coefficient of the node i C_i:

$$C_i = \frac{2E_i}{k_i(k_i-1)} \quad (3)$$

The clustering coefficient of project chain network reflects the tightness of contact between projects from the front. The bigger clustering coefficient is, the closer contact among nodes will be. And it reflects the possible occurring degree of risk element transmission on the project chain network from the side.

In summary, the three features of complex network reflect the complex network characteristic of project chain to some extent. They also provide the theoretical basis to analyze the project chain risk element transmission from the view of the complex network.

THE PROJECT CHAIN RISK ELEMENT TRANSMISSION BASED ON THE COMPLEX NETWORK

The phenomena of risk element transmission generally exist in the project chain network. When some nodes in the project chain break through the risk threshold, it will bring the risk and transfer the effects brought by the risk to the adjacent project via the process of risk element transmission which can lead to the corresponding change in the adjacent project. If this kind of change is out of control, it will transfer the risk effects to the other adjacent project and finally affect the goal of the project chain. The study is aimed at providing a risk control scheme to low the risk of project chain and improve the enterprise benefits through analyzing the project chain network risk element transmission.

The project chain network risk element transmission:

- **The risk element and risk threshold:** The risk element is some uncertain factors that can affect the actual results in a certain circumstance and a particular period of time. For a specific project, the risk elements are not the same but the transfer mechanism is familiar. The risk elements that affect the project chain can be divided into two aspects. One is the natural risk element and the other is the artificial risk element. The artificial risk element can be avoided by improving the management. However, the natural risk element cannot be avoided and we can just predict the probability of occurring.

Any node in the project chain has the ability to resist the risk but limited. When the risk intensity exceeds the bearing ability of the node, the node will become the risk node and affect the adjacent one. The risk element transmission happens.

The project chain risk element transmission: There are two parts forming the risk of any node. One is system risk which is caused by the internal activity in a project chain. The other is brought by risk transmission effect through the connection of project chain. Based on the describe above, the risk intensity of the node k at the time t is follow:

$$R_t(k) = \alpha R_t^1(k) + (1-\alpha) R_t^2(k) - \theta(k) \tag{4}$$

$$R_t^2(k) = \sum_{i \in L(k)} R(i) \tag{5}$$

$$R_t^1(k) = f_k(r_1, r_2, \ldots, r_n) \tag{6}$$

$R_t^1(k)$ = The system risk intensity of the node k at the time t
$R_t^2(k)$ = The transfer risk intensity of the node k at the time t
$\theta(k)$ = The risk threshold of the node k
α = The internal risk coefficient
f_k = The endogenous risk comprehensive function
r_i = The risk element i that affects the project
$L(k)$ = The set of adjacent nodes of the node k

The analysis of the mean-field theory: Considering the non-uniformity of the project chain network, we assume that $p_k(t)$ is the risk transfer probability of the project node, the degree of which is k. Based on the existing references about Mean-field theory (Wang *et al*., 2006; Ni *et al*., 2008; Pastor-Satorras and Vespignani, 2001), the mean-field function of the project chain network risk element transmission is:

$$\frac{d\rho_k(t)}{dt} = \lambda k(1-\rho_k)\theta(\rho_k) - \rho_k \tag{7}$$

λ is the average risk transmission probability of the project chain node at the time t. $\theta(\rho_k)$ is the connection probability of a node that degree is k and a risk node. $\theta(\rho_k)$ is expressed as follows:

$$\theta(\rho_k) = \frac{1}{<k>} \sum_k kP(k)\rho_k \tag{8}$$

Assuming that $dp_k(t)/dt$ can approach zero in a long time, we can obtain that:

$$\rho_k = \frac{k\lambda\theta(\rho_k)}{1 + k\lambda\theta(\rho_k)} \tag{9}$$

When we integrate Eq. (8) and (9), we can know that:

$$\theta(\rho_k) = \frac{1}{<k>} \sum_k kP(k) \frac{k\lambda\theta(\rho_k)}{1 + k\lambda\theta(\rho_k)} \tag{10}$$

If the $\theta(p_k)$ needs non-zero solution, it should meet the condition as follows:

$$\frac{d\theta(\rho_k)}{d\theta} = \frac{d}{d\theta}\left(\frac{1}{<k>} \sum_k kP(k) \frac{k\lambda\theta(\rho_k)}{1 + k\lambda\theta(\rho_k)}\right)\Bigg|_{\theta=0} \geq 1 \tag{11}$$

Table 1: The complex network characteristic of the project chain network

The initial node m_0	Edge	Average degree	Clustering coefficient	Average path length
10	5	15.878	0.052	2.669
10	8	15.884	0.055	2.661
8	5	9.950	0.043	2.965
8	3	5.978	0.037	3.463

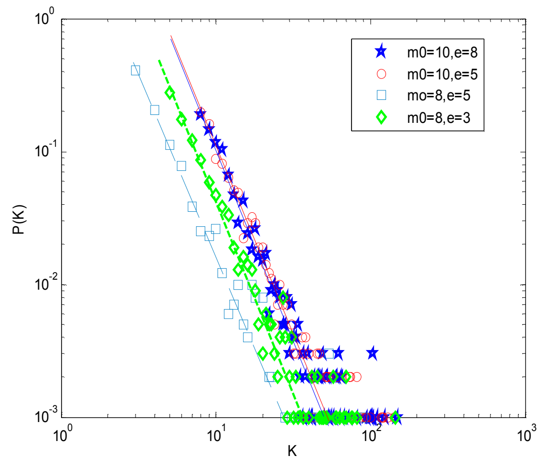

Fig. 1: The degree distribution of the project chain network P (k) (N = 1000)

That is to say:

$$\sum_k \frac{kP(k)\lambda k}{<k>} = \frac{<k^2>}{<k>}\lambda \geq 1 \quad (12)$$

By doing this, we can get the risk transmission threshold of the project chain network λ_c:

$$\lambda_c = \frac{<k>}{<k^2>} \quad (13)$$

For the project chain network, when the scale of network N is infinities, the threshold tends to zero. For the limited project chain network, if the risk transferring rate among projects is bigger than λ_c, the risk will transfer among the projects. On the contrary, the risk element transmission just occurs in local network and has no effect on the entire goal of the project chain.

THE SIMULATION AND ANALYSIS OF EXPERIMENT

The simulation and analysis of the complex net-work feature: We build the network based on the method of constructing project chain network mentioned above. The number of total nodes N is 1000; the beginning number of nodes m0 is 10; the edge brought by the new coming node m is 6. We analyze the degree distribution of project chain, the average path length and the clustering coefficient and get the simulation results as Fig. 1 and Table 1.

From the Fig. 1 we can see that the different initial nodes and the new coming node with the edges lead to the different degree distribution, but the trend is nearly the same. The curve fitting indicates that the degree distribution function of project chain network using the method of the local word evolution model can be nearly described by the power-law function with the index 3.

The Table 1 indicates that the project chain network has a relatively small average path length. Compared with the higher clustering coefficient, it has the feature of small-world and scale-free. The average path length has a direct relationship with the initial node and the edge. When the APL is 2.669, it presents that any two projects can link together via two or three projects in the project chain. This means the relationship among the projects is closely. When a node has a risk, it's easy to transfer to another project node and finally influence the entail goal or benefit of the project chain. The average degree is used to reflect the connection degree value between any project and the adjacent ones. It's the basic condition of project chain risk element transmission. The average degree is bigger, the connection is closer and the possibility of risk element transmission is larger. In summary, the project chain network has the feature of complex network. As a result, studying the project chain risk element transmission from the view of the complex network has a significant meaning in theory and actual.

The simulation and analysis of the risk element transmission: An important aspect of studying the behavior of project chain network risk element transmission is that what the different effects of the different status of the node in the project chain have on the behavior of risk element transmission. This study analyses the project chain network risk element from the view of the complex network. We use two methods (the random selection and the priority selection) to simulate the risk element transmission under a solid project chain network construction. The random selection means choosing randomly 5% of the nodes as the initial nodes; the priority selection means choosing 5% of the nodes possessing the biggest degree and the others in a susceptible state. We get the risk element transmission curve by doing 50 times simulation on each infection rate λ and getting the average value.

Simulate a network circumstance. The total number of the network nodes N is 100; the edge brought by the new coming node is 5; the number of initial nodes is 10; the average degree <k> is 9.52; the clustering coefficient C is 0.196; the APL is 2.2265.

According to the state transition rule defined above, the study operates the risk element transmission

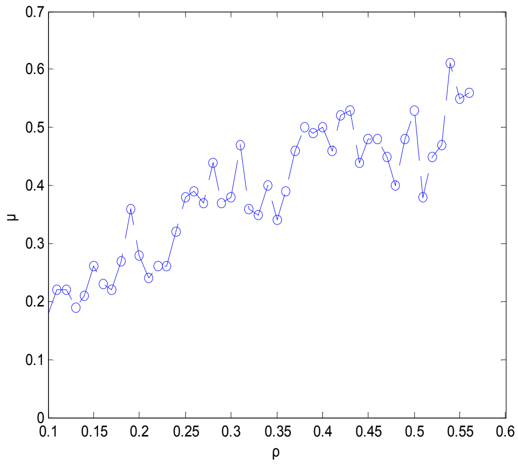

Fig. 2: The relationship between the risk density and transmission rate

simulation on the SIS model of project chain complex network. The risk element transmission rate is λ = ρ/ø. ρ is the transmission rate and φ is the healing rate. Ignoring the effect on the risk element transmission, we define ø is 0.5.

- **Experiment 1:** the transmission threshold of the project chain network The Fig. 1 shows the degree distribution of the network nodes. And the nodes in the network meet the power-law distribution. The Mean-field theory has indicated that the spread threshold of the scale-free network met the power-law distribution is $\lambda_c = <k>/<k^2>$. According to the project chain in this study, the spread threshold λ_c is 0.105.

  Considering the random incidents in the process of risk element transmission, we do 100 times simulation on each transmission rate when $\lambda_c \in [0.1, 0.5]$ and count the number of the risk element not transferring in the project chain. The result is shown in Fig. 2.

  We can see from the Fig. 2, when the transmission rate is bigger than 0.105, the entire risk of project chain network will increase compared with the increasing of the transmission rate. In this case, it is the same with that analyzed with Mean-field theory.

- **Experiment 2:** Based on SIS model, analysis the influence of risk transfer speed and infected projects number by different transmissibility under two difference risk nodes selected methods.

Assume that the healing rate of each risk node is a determined value which means the prepared recourses to deal with the risk is determined. We set φ = 0.5 and it indicates that we prepare half of the producing recourses as the threshold to resist the occurrence of the risk. We

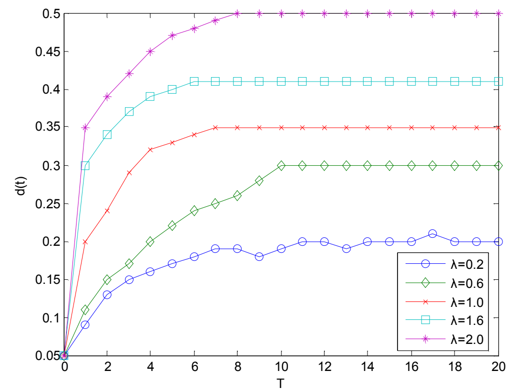

Fig. 3: The change of risk node density under the priority selection way

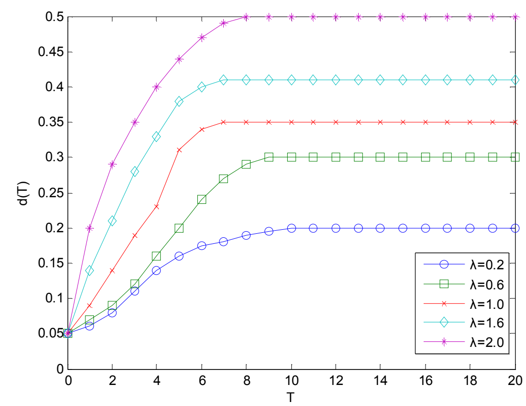

Fig. 4: The change of risk node density under the random selection way

simulate when λ is 0.2,0.6,1.0,1.6 and 2.0. The results are shown as Fig. 3 and 4.

From the Fig. 3 and 4, we can get that when the λ is bigger, the speed of virus transmission is faster and the ratio of nodes being infected is higher when it is stable. Comparing the two Figures, when the transmission is the same, the speed of risk element transmission is faster under the priority selection way than that under the random selection way. When it is stable, the ratio of risk nodes in the network is the same with that of the selecting initial nodes. This indicates that in the SIS model, the ratio of nodes occurring risk in the project chain network has something to do with the value of the threshold λ and has nothing to do with the initial nodes. The selecting of initial nodes just affects the transmission speed of risk element.

CONCLUSION

Studying the project chain risk element transmission from the view of complex network gives a new thinking on the project risk management. The projects connect with each other via the businesses in the enterprise and make the project chain network become a complex system. The complex network has provided a new way to study the complex system. Especially when the transmission dynamics appears, the application of complex network spread to many kinds of fields. As a complex system, the study on risk element transmission of the project chain has a significant meaning in theory and actual. On the base of analyzing the complexity of project chain, this study has constructed the project chain complex network model and analyzed the complex network feature. Then we use the SIS model analyzing the transferring rule of the risk element. We can see from the simulation that the project chain has Small-world and Scale-free features of the complex network. The APL and the degree distribution obey the power-law distribution. The complex network feature of the project chain network has supplied a new method to study the project chain risk element transmission. That is to say, we can use the spreading theory of complex network to study the project chain risk element transmission. On the base of studying the transferring function of risk element transmission among the project chain network nodes, the study uses the classic SIS model discussing the risk element transmission on the project chain complex network model. The result shows that the selection way of choosing the initial nodes has an important effect on project chain risk element transmission. If there is a risk appearing on some important projects, the risk will spread quickly to the entire project chain network via the risk element transmission and make the whole project chain at risk. On the contrary, if the risk appears on the unimportant projects, the risk will spread slowly and can adjust later to avoid the effect on the entire project chain. This analysis provides theoretical support for the project chain risk management. It has a certain practical value.

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REFERENCES

Albert, R. and A.L. Barabasi, 2002. Statistical mechanics of complex networks. Rev. Modern Phys., 74(1): 47-97.

Boccaletti, S., V. Latora, Y. Moreno, M. Chavez and D.U. Hwang, 2006. Complex networks: Structure and dynamics. Phys. Rep., 424(4-5): 175-308.

Chang-Chun, W. and C. Chen, 2012. Rumor propagation model based on complex network. Syst. Eng. Theory Pract., 32(1): 0203-0210.

Dai, M. and Y. Chu, 2011. Review of Risk Spread in Industrial Chain Based on Complex Networks Theory, 9: 014-019.

Fu, Y., M. Li and F. Chen, 2012. Impact propagation and risk assessment of requirement changes for software development projects based on design structure matrix. Int. J. Project Manag., 30: 363-373.

Ji, X. and F. Guo, 2011. Research on complex network of knowledge transfer in cyber community [J]. Technol. Econ., 30(20): 031-035.

Keeling, M.J. and K.T.D. Eames, 2005. Networks and epidemic models. J. Roy. Soc. Interface., 2(4): 295-307.

Nekovee, M., Y. Moreno, G. Bianconi and M. Marsili, 2007. Theory of rumour spreading in complex social networks [J]. Physica A, 374: 457-470.

Newman, M.E.J., 2003. The structure and function of complex networks. SIAM Rev., 45(2): 167-256.

Ni, S., W. Weng and H. Zhang, 2011. Modeling the effects of social impact on epidemic spreading in complex networks [J]. Physica A, 390: 4528-4534.

Ni, S.J., W.G. Weng, S.F. Shen and W.C. Fan, 2008. Epidemic outbreaks in growing scale-free networks with local structure. Physica A, 387(21): 5295-5302.

Pastor-Satorras, R. and A. Vespignani, 2001. Epidemic dynamics and endemic states in complex networks. Phys. Rev. E, 6306(6): 066117.

Strogatz, S.H., 2001. Exploring complex networks. Nature, 410(6825): 268-276.

Vicent, C., 2006. Dissemination of information in complex networks with congestion [J]. Physica A, 366: 571-577.

Wang, X., X. Li and G. Chen, 2006. Complex Network Theory and its Application. Tsinghua University Press, Beijing.

Xiao, Y., W. Chang and R. Zhang, 2009. Based on the quality supply chain quality risk transfer model. Project Manag. Technol., 7(8): 013-017.

Xiao-Ju, L. and W. Yue, 2004. Evaluation and control of the lead-time risk of the system integration project with risk transfer algorithm. Oper. Res. Manag. Sci., 13(1): 038-043.

Yao, C., J. Yang and D. Zhang, 2011. Rivalry spread effect based on industrial complex network. Chinese J. Manage., 8(2): 0254-0265.

Yong-Zheng, Z., F. Bin-Xing, C. Yue and Y. Xiao-Chun, 2007. Risk Propagation Model for Assessing Network Information Systems. J. Softw., 18(1): 137-145.

Yoo, J., J.S. Lee and B. Kahng, 2011. Disease spreading on fitness-rewired complex networks [J]. Physica A, 390: 4571-4576.

Yuan-Ming, W. and Z. Dao-Zhi, 2008. The transmission model of controlled quality risks in construction projects. J. Bus. Econ., 200(6): 0015-0020.