Transmission Mechanism of Simmelian Ties on Knowledge Spiral——Conduction combination of High Performance Work Practice System and Knowledge Fermenting

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August 30, 2019

Abstract

The knowledge spiral is a dynamic process for knowledge creation and evolution. It makes use of external connection to circulate, integrate, and accumulate all kinds of knowledge resources. The simmelian ties is an effective way to form the external connection. This study constructs the theoretical framework of transmission mechanism of simmelian ties on knowledge spiral. The theoretical framework uses high performance work practice system and knowledge fermenting as conduction and dual media channel variables. It takes high-tech manufacturing enterprises as empirical analysis objects. The study carries out empirical research on the transmission mechanism and media paths of simmelian ties on knowledge spiral by *combinations of differential evolution algorithm method, extended DEMATEL method*, and *Bayesian estimation-SEM method*. **All of the above methodologies were approved by all human participants**. Empirical analysis results indicates that strong and weak simmelian ties have significantly positive effects on high performance work practice system respectively; high performance work practice system significantly promotes knowledge fermenting while knowledge fermenting further plays significantly positive roles in promoting the knowledge spiral. This study takes high performance work practice system and knowledge fermenting as the breakthrough points. It then extends the transmission paths of simmelian ties on knowledge spiral from the perspectives of theoretical and empirical standpoints, which provides theoretical references and practical guidances for promoting and catalyzing knowledge fermenting and knowledge spiral for high-tech manufacturing enterprises.

Transmission Mechanism of Simmelian Ties on Knowledge Spiral——Conduction combination of High Performance Work Practice System and Knowledge Fermenting

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Abstract: The knowledge spiral is a dynamic process for knowledge creation and evolution. It makes use of external connection to circulate, integrate, and accumulate all kinds of knowledge resources. The simmelian ties is an effective way to form the external connection. This study constructs the theoretical framework of transmission mechanism of simmelian ties on knowledge spiral. The theoretical framework uses high performance work practice system and knowledge fermenting as conduction and dual media channel variables. It takes high-tech manufacturing enterprises as empirical analysis objects. The study carries out empirical research on the transmission mechanism and media paths of simmelian ties on knowledge spiral by combinations of differential evolution algorithm method, extended DEMATEL method, and Bayesian

estimation-SEM method. Empirical analysis results indicates that strong and weak simmelian ties have significantly positive effects on high performance work practice system respectively; high performance work practice system significantly promotes knowledge fermenting while knowledge fermenting further plays significantly positive roles in promoting the knowledge spiral. This study takes high performance work practice system and knowledge fermenting as the breakthrough points. It then extends the transmission paths of simmelian ties on knowledge spiral from the perspectives of theoretical and empirical standpoints, which provides theoretical references and practical guidances for promoting and catalyzing knowledge fermenting and knowledge spiral for high-tech manufacturing enterprises.**Key words:** simmelian ties, high performance work practice system, knowledge fermenting, knowledge spiral

1.Introuction

Driven by the most powerful double-engine of mass entrepreneurship and innovation, enterprises, especially high-tech manufacturing enterprises' innovation activities are more and more active. With the communication and collision of ideas among knowledge workers, the enterprises' knowledge traverses the process of socialization, externalization, combination, and internalization. This process is called knowledge spiral. Under the process of knowledge spiral, the enterprises' knowledge constantly realize the innovation and breakthrough of knowledge ontology in order to deprive new knowledge that drives the technological process. Obviously, knowledge spiral is a natural barrier to promote enterprises' knowledge progress and healthy growth. An efficient knowledge spiral inevitably improves the efficiency of enterprises' knowledge and technology innovation. The core power of knowledge spiral stems from the knowledge interaction among knowledge workers. Knowledge spiral also depend on the consistency of organizational structure dimensions, relationship dimensions, and cognitive dimensions with various knowledge activities. This creates an appropriate internal and external environment, and fully mobilizes the subjective initiative of knowledge creation. This process is key to ensure the successful operation of knowledge spiral mechanism. The empirical results show that simmelian ties, high performance work practice system, and knowledge fermenting are the key conduction variables that promote the knowledge spiral, and they have excellent characteristics. Together, they discover the mechanism among simmelian ties, high performance work practice system, and knowledge fermenting while finding out the transmission mechanism of simmelian ties on high performance work practice system and knowledge fermenting as conduction**.** Two studies are important in solving the knowledge spiral dilemma and granting the rising trend of enterprises' knowledge spiral.

Through looking at all different literatures, the research on cross-boundary ties of organization and organizational knowledge performance generally go through two stages. In the first stage, related literatures focus on the relationship between the ties' characteristics (strong or weak) and ties' space structure with results (organizational knowledge performance including the extent of knowledge sharing and the efficiency of knowledge transferring)(Dekker, 2006). For instance, Kogut and Zander(1992) pointed that the core knowledge of organizations were comprehensively tacit and widely embedded into the practitioner communities, teams, and other social structures. Jason(2010) pointed that weak ties which only served as mediators were useful for the exploration and derivation of knowledge, and strong ties which served as connectors were useful for the discovery and application of knowledge. The literature in the second stage focuses on the characteristics (simmelian ties or not) of ties that have effects on results(Zhangwei, 2016). Sorenson (2006) and other scholars pointed that non-simmelian ties were likely to directly absorb and integrate knowledge and information with middle or low heterogeneity. Simmelian ties are more likely to directly improve the overall knowledge innovation performances of enterprises by the desire of sharing knowledge and similar knowledge base among knowledge workers.

Following the research logic, this study not only integrates the features and characters of simmelian ties into the same research framework, but also tries to clarify the specific mechanism of the cause and reason of knowledge performance. It takes high performance work practice system and knowledge fermenting as the breakthrough points, and constructs theoretical framework of transmission mechanism of simmelian ties on knowledge spiral. The theoretical framework sets high performance work practice system and knowledge fermenting as conduction and dual media channel variables, which takes high-tech manufacturing enterprises

as empirical analysis objects. The study carries out empirical research on the transmission mechanism and media paths of simmelian ties on knowledge spiral by combinations of differential evolution algorithm method, extended DEMATEL method, and Bayesian estimation-SEM method, which provides theoretical references and practical guidances for promoting and catalyzing the knowledge fermenting and knowledge spiral situation of high-tech manufacturing enterprises.

2.Literature review and theoretical hypothesis

2.1 Simmelian ties and high performance work practice system

Simmelian ties are concrete extensions of Georg Simmel's sociological theory in modern organization network theory. Simmel believed that the tie between two individuals cannot constitute social analysis unit, and the complete social analysis unit must include three or more individuals. When participants present interactive ties and associate with the third parties,the ties are simmelian ties(Krackhardt, 1998).The differences among simmelian ties and isolated two individuals ties are that the former can significantly inhibit individual interests, weaken individual bargaining power, promote cooperation, solve conflicts, and so on(Krackhardt, Martin, 2002). Simmelian ties can be divided into strong or weak according to their characteristics. Typical simmelian ties are shown in Figure 1.

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Figure 1 Simmelian ties

High performance work practice system (for short HPWS) is a type of human resource management system that creates sustainable competitiveness for enterprises. Cappelli and Neumark (2001) defined it as the sum of a series of activities and policies that ensure human resource management can serve as the enterprises' development strategy in their own operations[8]. Scholars have clarified the compositions of high performance work practice system from different perspectives. For instance, Huselid (1995) divided high performance work practice system into the ability of employees, information resource sharing among enterprises' departments, employee skills training, and employee job rotation. Guthrie (2001) pointed out the main dimensions of high performance work practice system, which were composed of cross-departmental communication, job rotation among employees, and internal employee promotion. Arthur (1994) suggested that the high performance work practice system was composed of employee communication and involvement. This study follows the classification of Qin jian (2012), who indicated that the high performance work practice system mainly consist of three dimensions: cross-departmental communication, job rotation, and employee training.

As complex social network relationships, simmelian ties effect high performance work practice system from cross-departmental communication, job rotation, and employee training. Firstly, unlike isolated two individuals ties, the simmelian ties introduces the third social units which extremely weaken an individual's bargaining power. This ensures the benefits of participants in cross-departmental communication are balanced. In others words, simmelian ties make the behavior of participants in cross-departmental communication more rational (Zhangwei, 2016). They are able to express oneself objectively and calmly within a reasonable frame and then improve the situation of participants who are in conflict. The third party also makes participants who hold different opinions move towards seeking a common ground while resolving differences and reconciliation could be possible(Krackhardt, 1999). Secondly, according to Sheng ya's and Li wei's (2012) research achievements, strong simmelian ties mean that the organizations have active social interaction behaviors. Strong simmelian ties standarize the behavior and social-economic characteristics among knowledge workers. Strong simmelian ties are useful for enterprises to carry out reasonable knowledge division and modularization operation under the existing resource circumstances and the established organization framework. Strong simmelian ties adopt local and gradual way to implement job division and job rotation in order to achieve optimal allocation of knowledge workers. At the same time, weak simmelian ties enrich

the social network with new knowledge and a great many of non-redundant knowledge resources, which also help break down the barriers of knowledge transferring among individuals and departments, and improve information exchange in internal enterprise by job rotation. Thirdly, employee training is aimed at updating existing knowledge and improving the professional quality and skills of employees in order to promote the optimization of enterprises' overall knowledge structure, and achieve the established goals of enterprises. The structure of simmelian ties can enhance knowledge communication and interaction in the process of employee training , which also promote the formation of the consistency of context among knowledge workers. Similar knowledge bases further improve the ability of knowledge workers to absorb knowledge(Zhangwei, Renhao, 2012).

Furthermore, Miao Ren-tao (2013) and other scholars pointed out that the implementation effects of high performance work practice system were restricted by organizational situation. To be more specific, the high performance work practice system becomes more effective and approporiate only when the knowledge workers positively evaluate the fairness of the organization. In networks of simmelian ties, knowledge workers of enterprises become familiar with each other and gradually build up basic trust and abide behavior criterion. The relatively closed and stable tie method makes knowledge workers want to observe and recognize complementary value. This helps to clear up and resolve misunderstanding, and forms positive exchange relationships among knowledge workers and enterprises (Tortoriello, Krackhart, 2010). According to the above mentioned analysis, this study makes hypothesis 1 as follows.

Hypothesis 1: Strong and weak simmelian ties have significantly positive effects on high performance work practice system respectively.

2.2 High performance work practice system and knowledge fermenting

Barthelmé (1998) was the first scholar who proposed the possibility of combination between Bionics theory and knowledge evolution phenomenon. Later, Chinese scholar He Jin-sheng (2005) put forward the theory of knowledge fermenting by analogizing the theory of biological fermentation. Knowledge fermenting is the core element of knowledge innovation and evolution of enterprises, the theory successfully explains the internal mechanism of knowledge spiral. The theory of knowledge fermenting indicates that under the basis of existing knowledge, new knowledge should be able to traverse through the process of communication, interaction, and sharing in order to create the innovation and proliferation of knowledge (Barthelmé, 1998). High performance work practice system is composed of a series of collaborative and complex human resource management practices, the impact of high performance work practice system on knowledge fermenting permeates all aspects of human resource management of enterprises. Zhang Hui-yan (2015) and other scholars pointed out that learning-oriented high performance work practice system carries out training,and it encourages other ways to establish knowledge base and sharing mechanism. The system encourages knowledge workers to continuouslyually reflect and learn about the enterprises. At the same time, the system also provides sustainable learning space for knowledge workers. For example, the enterprises that recruit employees based on high performance work practice system, enterprises will highly focus a lot on the basic knowledge structure and potential learning ability of job seekers. This type of recruitment is useful for knowledge workers to quickly integrate into the organization and quickly acquire the new knowledge and skills that are required by enterprises. The recruitment based on high performance work practice system can improve the accumulation and comprehension of the basic carrier (knowledge ontology) of knowledge fermenting. For employee training, high performance work practice system not only improves the employee's technical ability to some extent, but also enhances the social value and self-identity of employees. High performance work practice system greatly stimulates the initiative of employees to learn and acquire new knowledge, which also stimulates the activity of knowledge enzyme that plays an important catalytic role in knowledge fermenting.

As an important dimension of high performance work practice system, cross-departmental communication and j ob rotation play an important role in the process of knowledge fermenting. Two kinds of human resource management systems can greatly promote communication among knowledge workers and enhance the trust and identity among internal knowledge workers. Two kinds of human resource management systems also promote the circulation, extension, and sharing of knowledge. Two kinds of human resource mana-

gement systems benefit to construct overall knowledge network and relation network. Cross-departmental communication and job rotation also play a role in catalyzing and promoting knowledge growth. Under the organizational strategy and vision determined by the knowledge sourdough (social knowledge demand)**,**cross-departmental communication, and j ob rotation are helpful to update new knowledge capital and knowledge type. Then cross-departmental communication and j ob rotation can promote the growth and diffusion of knowledge. To sum up, high performance work practice system creates appropriate internal environment for knowledge fermenting, high performance work practice system also provides essential elements for knowledge fermenting and then pushes the process of knowledge fermenting. Based on the above analysis, this study makes hypothesis 2 as follows.

Hypothesis 2: High performance work practice system can significantly promote knowledge fermenting.

2.3 Knowledge fermenting and knowledge spiral

Japanese scholars Ikujiro Nonaka and Hirotaka Takeuchi (1996) combined with the idea of "power" in physics with the theory of knowledge management in order to construct the theory of knowledge spiral. The knowledge spiral represents the dynamic chain of knowledge creation. In other words, the internal and external knowledge workers of the organization by exchanging and learning knowledge from each other in order to bring about the transformation and sharing of explicit knowledge, and then realize the dynamic creation and spiral process of knowledge circulation, integration, transfer and accumulation. Thus, the dynamic creation and spiral process of knowledge can be realized through circulation, integration, transferring and accumulation (NonakaI, 1994). The theory shows that the knowledge creation refers to dynamic and progressive activities. Through the sustainable interaction of tacit knowledge and explicit knowledge, knowledge creation traverses the four knowledge transfer modes. Firstly, knowledge creation traverses the process of socialization (from tacit knowledge to tacit knowledge, in other words, sharing the intensional knowledge). Secondly, knowledge creation traverses the process of externalization (from tacit knowledge to tacit knowledge, in other words, intensional knowledge is transformed into formal knowledge). Thirdly, knowledge creation traverses the process of combination (from explicit knowledge to explicit knowledge, in others words, integrating and perfecting new and old formal knowledge). Fourthly, knowledge creation traverses the process of internalization (from explicit knowledge to tacit knowledge, in other words, formal knowledge is transformed into intensional knowledge). The transfer process for short is SECI. Finally, knowledge creation promotes the diffusion, embeddedness, and accumulation of knowledge(Wangyan etc., 2007,Niupanqiang etc., 2010).

Just as biological fermentation process, the knowledge fermenting model is composed of knowledge sourdough, knowledge ontology, knowledge enzyme, knowledge fermenting environment, knowledge bar (Hejinsheng etc., 2005)and so on. Obviously, the efficiency of SECI of knowledge spiral is determined by the appropriate degree of knowledge fermenting. The socialization stage of knowledge spiral is the process of accumulation and integration of tacit knowledge integrate with experiences. The socialization stage of knowledge spiral emphasizes on the common experience and perception of both sides who interact knowledge. Under the initiation and induction of the knowledge strain, such knowledge interaction will achieve strategically guidence and plan(Wangyue, 2005). Wang hui (2012) and other scholars found out that knowledge sourdough could fully mobilize the subjective initiative of enterprises to engage in knowledge innovation. Knowledge sourdough creates a good external environment for individuals and enterprises. Knowledge sourdough also helps enterprises to identify, search, and absorb valuable key knowledge in order to ensure the sustainable and healthy operation of the knowledge spiral. The externalization of knowledge spiral is the process of encoding, realizing, and standardizing of tacit knowledge. Nahapiet (1998) pointed out that enterprises must deal with the relationship with other enterprises in the stage of the externalization of knowledge spiral correctly. This is to improve the frequency of resource exchange and the quality of information knowledge acquisition, and to promote the transferring and exchanging efficiency of tacit knowledge. Cheng (2013) and others scholars thought that under the stage of externalization of the knowledge spiral, knowledge enzyme is useful for knowledge workers in the stage of externalization to unreservedly share and communicate valuable experience, secret, and knowledge. Under the combined stage of SECI, individuals' piecemeal knowledge is further integrated and systematically processed, and then the systematic explicit knowledge needed by

the enterprises is formed(Xiongdeyong,Hejinsheng, 2004). The knowledge bar provides an appropriate place for the combination and reconstruction of knowledge. In knowledge bar, the individual knowledge has been excavated and expanded, and the depth and breadth of the whole knowledge base of the enterprises have been extended. The knowledge bar contributes to the reconstruction process of knowledge system during the knowledge spiral connection stage, and the popularization process of tacit knowledge during the socialization stage (Lin,Su,Chien, 2006). Under the stage of internalization of the knowledge spiral, enterprises' knowledge can transform from explicit systematic knowledge to tacit operational knowledge.The process is the sublimation of knowledge. Meanwhile, in the stage of internalization, the knowledge management function of enterprise's managers produces catalytic synergistic effect known as knowledge enzyme. Knowledge eneyme plays an important role in exploring effective knowledge management models under different environmental coditions. It stimulates the enthusiasm and creativity of knowledge workers from the aspect of the system design and mechanism(Liuhongwei etc., 2003). Knowledge enzyme enhances mutual recognition and common vision among enterprises and provides a "cohesive" mechanism for knowledge integration in enterprises (Inkpen,Tssang, 2005). Knowledge enzyme also breaks the original knowledge barrier of the enterprises, and then dredges the original media of knowledge communication. Finally, knowledge enzyme makes explicit knowledge diffuse into knowledge workers of the enterprises in order to become a part of tacit knowledge of knowledge workers. Therefore, this study makes hypothesis 3 as follows:

Hypothesis 3: Knowledge fermenting plays a significantly positive role in promoting knowledge spiral.

To sum up, the theoretical framework of this study is obtained, which is shown in figure **2**

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Figure 2 The transmission mechanism of simmelian ties on knowledge spiral

Research design and empirical analysis

3.1 Data collection

In this study, we send questionnaires to the teams of 160 high-tech manufacturing enterprises in the eastern and central parts of China. We use the snowball sampling method and nomination interpretation method, then each team is asked to report 3-6 partners who have relationships with them. Each team member is asked to answer the questionnaires according to their own situations. Each team appoints a team leader to answer the questionnaires, and then forms the matching questionnaire of team leader with team members. Finally, 132 questionnaire of teams are collected. The effective recovery rate of sample is 82.5%. The result of statistical analysis shows that there are 520 members in tota, they are divided into 132 groups, 50 groups consist of 3 members, and 40 groups consist of 4 members, plus 42 groups consist of 5 members. Most of the team members are technical elities or engaged in research and development work. The demographic characteristics of the team and team members are shown in Table1.

Table1 The demographic characteristics of the team and team members

Demographic variables	Characteristic quantity and proportion
Team age (measured by team life)	90 teams are between 5 years and 10 years, accounting for68.18%; 42 teams are more than 10 years, accounting for 31.82%.
Enterprise scale	The number of large enterprise is 52 ,accounting for 39.39%; the number of medium enterprise is 80,accounting for 60.61%.

Demographic variables	Characteristic quantity and proportion
Gender	The number of male members is 300, accounting for57.69%; the number of female members is 220, accounting for42.31%.
The position of a team member	The number of senior managers is 80, accounting for 15.38%; the number of middle managers is 170, accounting for32.69%; the number of ordinary employees is 270, accounting for 51.93%.

3.2 Reliability and validity test of scale

According to the related research results of Marco (2010) and Krackhardt (2002), the measuring process system, and method of simmelian ties, we can ensure the scale of simmelian ties. The simmelian ties mainly include the strong simmelian ties and the weak simmelian ties. This study refers to and synthesizes the results of related literatures(Cappelli,Neumark, 2001 Inkpen,Tsang, 2005), and combines the theme, context, and causal relational among variables to ensure the high-performance work practice system, knowledge fermenting, knowledge spiral scale, and related indicators system.

Firstly, Cronbach's alpha coefficient and total correlation coefficient (CITC) are verified, at the same time, exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) are performed by factor analysis and structural equation model (SEM). The results are shown in Table 2. The Table 2 of various indicators show that the scales have good reliability and validity, both EFA and CFA pass the test.

Table2 Reliability and validity test

		Reliability Analysis	exploratory Factor Analysis(**EFA**)	exploratory Factor Analysis(**EFA**)	Confirmatory Factor Analysis(**CFA**)	Confirmatory Factor Analysis(**CFA**)	Confirmatory Factor Analysis(**CFA**)
Scale variables	Corresponding evaluation index	Cronbach's alpha coefficient(>0.6 passinspection.)	KMO(>0.6 passed in spection.)	Cumulative explaination variance variation ratio of common factor(>60%passinspection.)	Factor loading(>0.5pass in spection)	composite reliability CR(>0.6passin spection)	Average variance extraction AVE(>0.5pass
Simmelian ties	——	0.743	0.574	86.381	0.917	0.9534	0.8364
Knowledge fermentating	X_5-X_{12}	0.904	0.840	72.880	0.900 0.911 0.930 0.894 0.694 0.749 0.904 0.735 0.762 0.768 0.850	0.9329	0.6365

		Reliability Analysis	exploratory Factor Analysis(**EFA**)	exploratory Factor Analysis(**EFA**)	Confirmatory Factor Analysis(**CFA**)	Confirmatory Factor Analysis(**CFA**)	Confirmatory Factor Analysis(**CFA**)
High performance work practice system	X_{13}-X_{20}	0.905	0.885	60.322	0.724	0.9238	0.6033
					0.789		
					0.851		
					0.750		
					0.785		
					0.697		
					0.840		
					0.765		
Knowledge spiral	X_{21}-X_{32}	0.921	0.811	66.791	0.642	0.9412	0.5729
					0.773		
					0.722		
					0.870		
					0.758		
					0.718		
					0.810		
					0.826		
					0.720		
					0.720		
					0.790		
					0.705		

3.3 Hypothesis Test and empirical analysis results

(1) Based on the interval number expansion DEMATEL method, this study firstly deals with the complexity, fuzzy and uncertain factors in the range of interval numbers, and according to the numerical size of the center degree and the reason degree of each variable to determine the ordering result of the influence degree of the independent variables (influence factor) on the target variable (dependent variable) in order to determine the direction and degree of action of each variable (influence factor) on the dependent variable. The relationship among the four variables of simmelian ties, high performance work practice system, knowledge fermenting and knowledge spiralin the theoretical framework is transferred from the perspective of centrality and causality. This study determines the direction and degree of interaction among independent variables (influence factors) and dependent variables, and distinguishes the key cause variables and result variables. The study determines the causal relationships between simmelian ties and high performance work practice system, the causal relationships between high performance work practice system and knowledge fermenting, and the causal relationships between knowledge fermenting and knowledge spiral, then the four variables in the theoretical framework of the mechanism of action are determined. The centrality variable, the cause variable, and the result variable belong to the four variables.

The interval number DEMATEL method follows the following steps (Jinweijian,Huhanhui, 2011; Gaopeiran,Luxinyuan, 2014;Jiangqian etc., 2016):

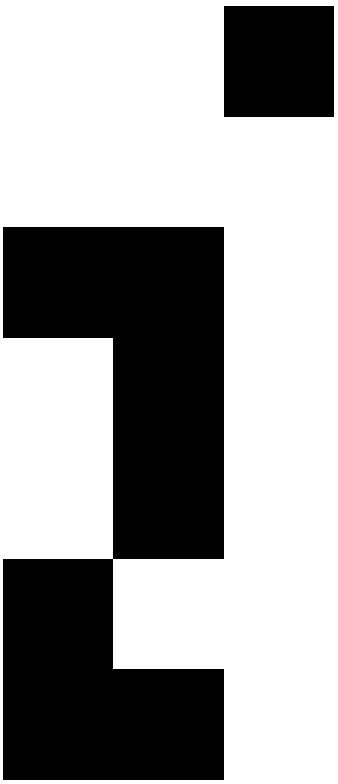
Step one, constructing interval number matrix.

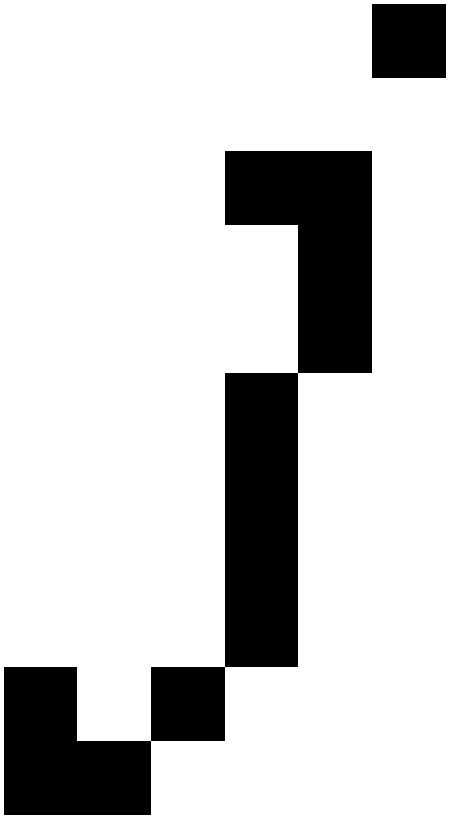
$$\{S_1, S_2, \cdots, S_N\}$$

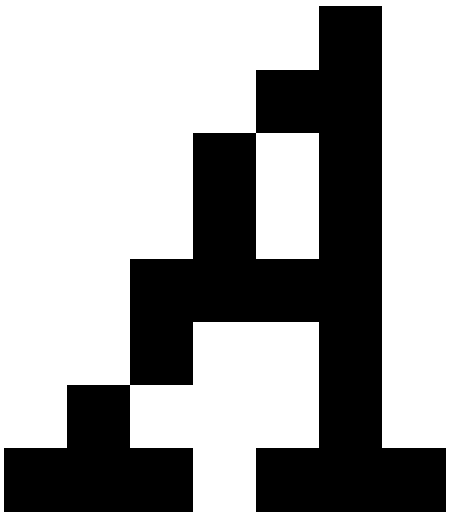
$$a_{ij} = \left[\bar{a}_{ij}, a_{ij}^{+}\right]$$

$$\in [0,0] - [1,1]$$

$$\bar{a}_{ij} \leq a_{ij}^{+}$$







The system index system is ,interval number()represents the direct influence of theinfluence factor on the influence factor. The interval number directly influences matrix, it can be expressed as:

$$A=\begin{pmatrix} 0 & a_{12} & \cdots & a_{1n} \\ a_{21} & 0 & \vdots & a_{2n} \\ \vdots & \cdots & 0 & \vdots \\ a_{n1} & a_{n2} & \cdots & 0 \end{pmatrix}=\begin{pmatrix} [0,0] & \left[a_{12}^{-},a_{12}^{+}\right] & \cdots & \left[a_{1n}^{-},a_{1n}^{+}\right] \\ \left[a_{21}^{-},a_{21}^{+}\right] & [0,0] & \vdots & \left[a_{2n}^{-},a_{2n}^{+}\right] \\ \vdots & \cdots & [0,0] & \vdots \\ \left[a_{n1}^{-},a_{n1}^{+}\right] & \left[a_{n2}^{-},a_{n2}^{+}\right] & \cdots & [0,0] \end{pmatrix}$$

(1)

Step two, constructing the interval number synthesis direct influence matrix.

First, the matrix A is a standardized process, and the normalized interval number is directly affected by the following matrix:

$$X=(x_{ij})_{n\times n}=(x_{ij}^{-},x_{ij}^{+})_{n\times n}$$

$$X^{-} = (x_{ij}^{-})_{n \times n}$$

$$X^{+} = (x_{ij}^{+})_{n \times n}$$

, ,.

$$X = AA$$

(2)

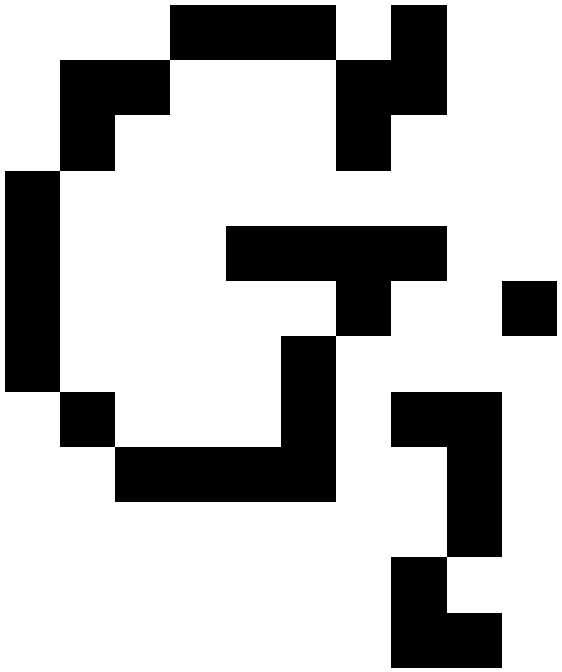
$$\lambda = 1 / \max_{1 \le i \le n} \left(\sum_{j=1}^{n} a_{ij}^{+} \right)$$

(3)

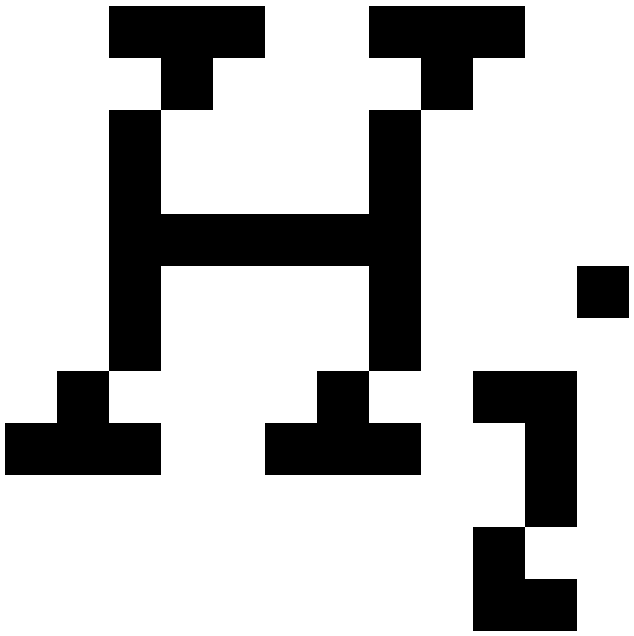
Then form standardized interval number directly affects matrix.

$$
\begin{aligned}
T &= \lim_{k\to\infty}(X + X^2 + \cdots + X^k) \\
&= \left[\lim_{k\to\infty}((X^-) + (X^-)^2 + \cdots + (X^-)^k), \lim_{k\to\infty}((X^+) + (X^+)^2 + \cdots + (X^+)^k)\right] \\
&= \left[X^-(1-X^-)^{-1}, X^+(1-X^+)^{-1}\right]
\end{aligned}
$$

(4)



$$i = 1,2,3,\cdots,n$$



$$i = 1,2,3,\cdots,n$$

Step three, estimate the central degree()among the influence factors and dependent variable, the causal degree()among the influence factors and the influence factors.

$$i = 1, 2, 3, \cdots, n$$

$$i = 1, 2, 3, \cdots, n$$

The sum of every row of matrix :.

$$i = 1, 2, 3, \cdots, n$$

The sum of every column of matrix :

$$i = 1, 2, 3, \cdots, n$$

.

$$i = 1, 2, 3, \cdots, n$$

$$i = 1, 2, 3, \cdots, n$$

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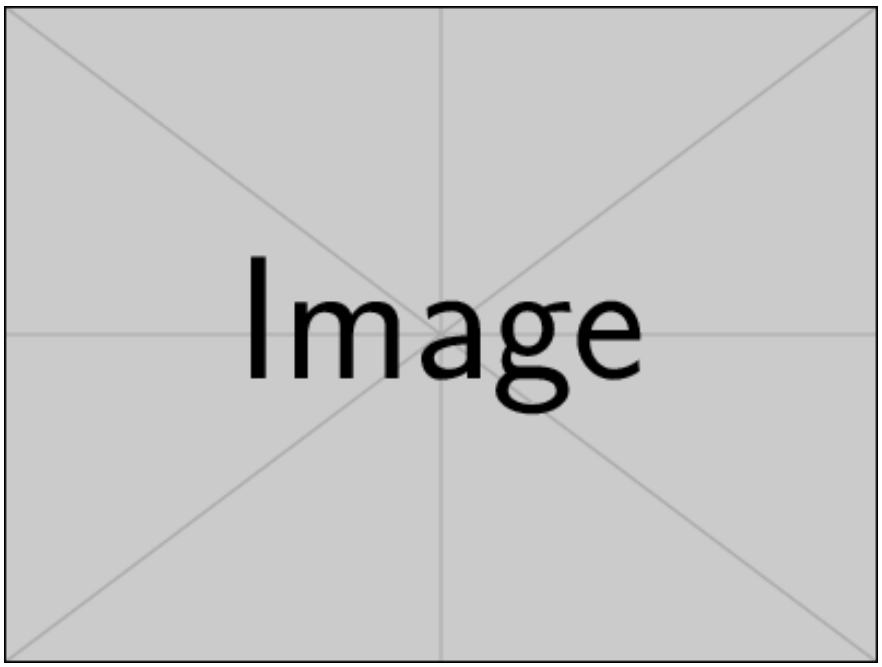

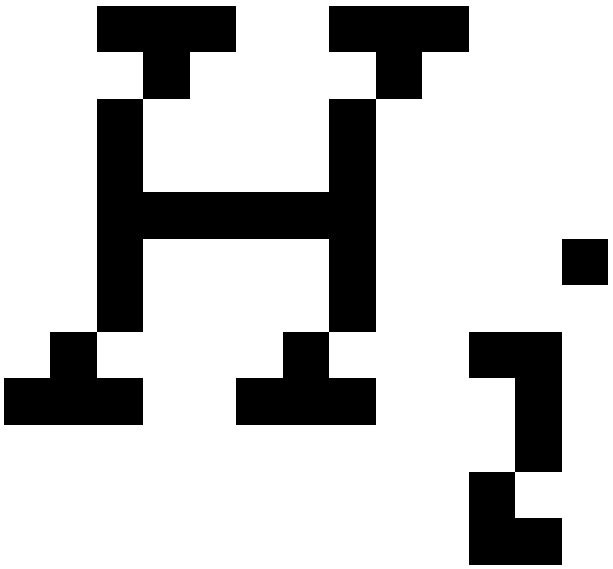

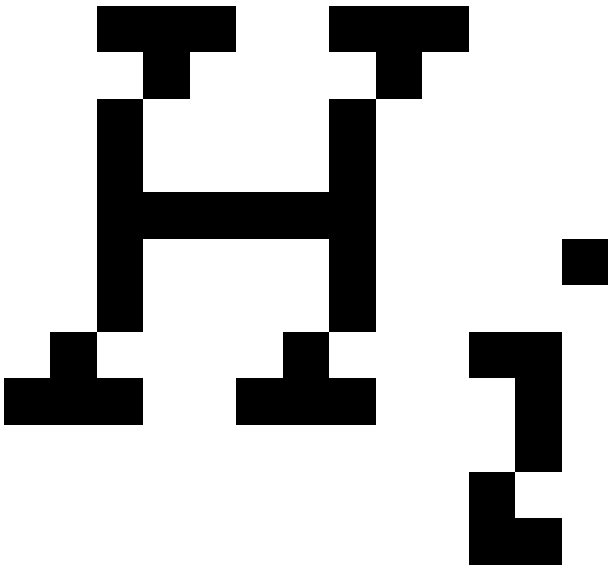

The forth step, according to the ranking steps of the probability degree, compare the size of ((), rank the importance of the impact variables to the target variables, and compare with the size relationships among (()) and zero. If is greater than 0, that means is the cause factor, otherwise, it is the result factor.

The possibility degree ranking is explained in the following steps:

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Firstly, estimate the possibility degree of . The interval number is,,,.

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(5)

$$a_1, a_2, \cdots, a_n$$

$$a_i = \left[a_i^-, a_i^+ \right]$$

$$P = (p_{ij})_{n \times n}$$

$$p_{ij} = P(a_i \geq a_j)$$

$$a_1, a_2, \cdots, a_n$$

Secondly, based on interval number (), construct the possibility degree complementary matrix ,, .

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Thirdly, follow the numerical relationships among and component ordering(),estimate the priority vector of .

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, (6)

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This study uses the Delphi method and the expert scoring method, and then 30 senior administrators of high-tech manufacturing enterprises are invited in order to score the direct relationships of the independent variables on the target variables and the independent variables, and the independent variables in the form of interval number range. The score range is between (weakest) and (strongest). Matlab is used to simulate the causal relationships among variables, and the calculation results of the center degree and the reason degree of DEMATEL are obtained, as shown in Table 3. The ranking results of DEMATEL verifies the theoretical hypothesis from 1 to 3 preliminarily. Table 3 shows that the simmelian ties are the centrality variable and the causal variable, and the high performance work practice system is the outcome variable. For the target variable (dependent variable) of knowledge fermenting, the high performance work practice system is the centrality variable and the causal variable, the knowledge fermenting is the outcome variable. Finally, for the target variable (dependent variable) of knowledge spiral, the knowledge fermenting is the centrality variable and the causal variable, and the knowledge spiral is the outcome variable.

Table 3 The ranking result of the relationships among variables based on DEMATEL

	Independent Variables	**The reason degree, The center degree**	**Results**
High performance work practice system	Simmelian ties	The reason degree	Simmelian ties >0> High performance work practice system
		The center degree	Simmelian ties
Knowledge fermenting	High performance work practice system	The reason degree	High performance work practice system >0> Knowledge fermenting
		The center degree	High performance work practice system
Knowledge spiral	Knowledge fermenting	The reason degree	Knowledge fermenting >0> Knowledge spiral
		The center degree	Knowledge fermenting

Note: Execute software for MATLAB software

(2) Based on the interval number DEMATEL method to verify the causal relationships among the four variables in the theoretical framework preliminarily, the differential evolution algorithm is further adopted. Based on the collected sample of 132 teams and 520 team members, this study searches for outstanding individual samples globally, so that the excellent sample which will enter the next generation of population can be used as empirical sample of *SEM* based on Bayesian estimation. The main purpose of the differential evolution algorithm is to find out the optimal solution vector, which can search for the excellent individual sample with good fault tolerance and strong learning ability as a whole, so that the better individuals with strong learning ability can enter the next generation group, and thus play the optimization and global

search capability (Liyanan etc., 2016; Guohaixiang etc., 2014; Deb, 2000). Firstly, based on the differential evolution algorithm, this study uses MATLAB and Stata software to set the execution parameters (as shown in Table 4), and searches for excellent individual sample with good fault tolerance and strong learning ability by the whole, so that the better individuals with strong learning ability can enter the next generation group(Liyanan etc., 2016; Guohaixiang etc., 2014; Deb, 2000). This ensures that the excellent sample which will enter the next generation of population can be used as empirical sample of SEM based on Bayesian estimation exert to optimization and global search function, and explore the causal relationships among the four variables. Secondly, this study reveals the mechanism among the simmelian ties, high performance work practice system, and knowledge fermenting. Finally, the transmission mechanism of the simmelian ties on the knowledge spiral with the high performance work practice system and knowledge fermenting as the conduction variables are revealed.

The relevant principles, modeling steps, and processes of the differential evolution algorithm are as follows(Liyanan etc., 2016; Guohaixiang etc., 2014; Deb, 2000):

The differential evolution algorithm includes four basic operations of initializing population, variation, cross, and selection. The modeling steps and processes of the differential evolution algorithm are as follows(Jinweijian,Huhanhui, 2011; Gaopeiran,Luxinyuan, 2014;Jiangqian etc., 2016):

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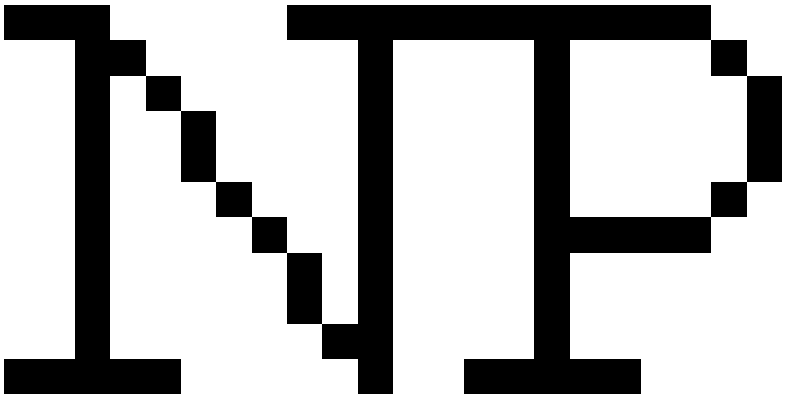
Figure 3 The basic process of differential evolution algorithm

First, coding.



$$\vec{X}_{i,G} = \left[X_{1,i,G}, X_{2,i,G}, \cdots, X_{D,i,G}\right]$$

Second, the individual structure.

is the population size, the i-th individual in the population is recorded asin the G-th generation, Among them, D is the dimension contained by individuals.

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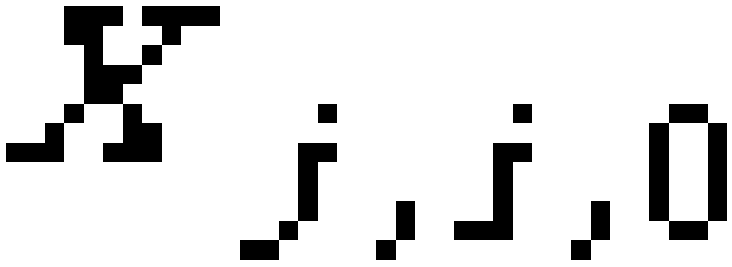

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Third, initializing the population. The population initialization formula is as follows:. Among them, is the G=0 generation, which is also the value of the i-th individual of the j-th dimension of the population, and is generated randomly;

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is the lower bound of the j-th dimension of the search space.

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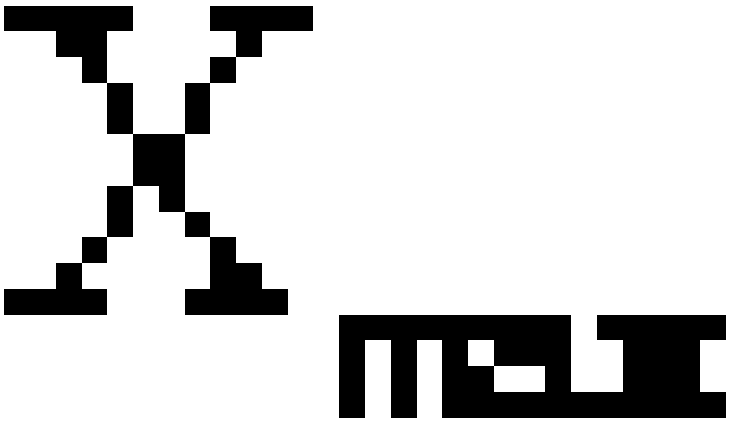
is the upper bound of the j-th dimension of search space.



andrespectively is the vector expression form of the lower bound and upper bound of the search space.

Fourth, variation. The variation formula is as follows:

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Among them,

is the k-th individual to be mutated in the current population ,

are the randomly selected individuals in the current population to meet k[?] m [?] i [?] j;is the individual after variation; F[?][0,1] is the scaling factor. The adoption of DE/x/y/z represents different variation modes, in which DE is the differential evolution algorithm ;X is the basic item in front of the difference term, and z is the cross-mode.

Fifth, cross. The crossover probability is Cr[?][0,1]. There are two forms of crossover:

The exponential model formula is as follows:

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(8)

The binomial Model formula is as follows:

(9)

$$j_{rand} \in [1,2,\cdots,D]$$

Among them,

is the random selection value.

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Sixth, choose. the individual and the target individual

which are obtained after crossing are successively substituted into the target function for comparison, and the relevant formula of the selection process is as follows:

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(10)

Table 4 The execution parameters

Serial Number	Execution Parameter Name	Execution Parameter Details
1	Test function	17 global minimum benchmark function as test
2	Dimensions of benchmark function test	30
3	Population size.	50
4	Maximum evolutionary generations of each function	10000
5	Number of times of each function independent running	25

Note : the execution softwares are Matlab software and Stata software. According to the different test functions,the final execution parameters are all done in the mean value processing.

(3)The execution parameters are all processed by averaging, and the modeling steps and processes of structural equation modeling based on Bayesian estimation are referenced(Wuminglong, 2013; Rongtaisheng, 2009). Firstly, the structural equation model of the set exploration is adopted to identify the final suitable form of structural equation model, the index of goodness of fit index of structural equation model and the significant level corresponding to the path coefficient. Then, the confidence interval of path coefficients and mean of path coefficients are calculated by using the structural equation model based on Bayesian estimation, and this study processes the small sample date and correlation distribution. The Markov Chain Monte Carlo sample generation method is adopted for sample and population sampling, and verifies causal relationships among the simmelian ties, high performance work practice system, knowledge fermenting, and knowledge spiral in the theoretical framework, and reveals the transmission mechanism of the simmelian ties on knowledge spiral with the high performance work practice system and knowledge fermenting as conduction variables. Finally, Amos software is used to estimate the relationships among the four variables in the theoretical framework, and also estimate the path coefficients and mean values (whether both the confidence interval of 95% of the significant level and the mean value of significant level include 0 or not.) based on Bayesian estimates, and the path coefficients and standardized mean values (whether both the confidence interval of 95% of the significant level and the mean value of significant level include 0 or not.) based on Bayesian estimates which are analyzed in Table 5.

In order to verify the theoretical hypothesis better, this study uses SEM to highlight the significance of path coefficients and mean values, and to determine which levels they are significant at among 0.001, 0.01 and 0.05. The significances of the path coefficients and the mean values follow the significance level of the corresponding path coefficients of the modified structural equation model. Based on the empirical analysis of Amos software (as shown in Table 5) ,the strong simmelian ties have significantly positive effects on the high performance work practice system (mean value is 0.308, significance level is $p<0.05$), so the theoretical hypothesis is verified. The weak simmelian ties have positive effects on high performance work practice systems, but the

effects are not significant (mean value is 0.017, significance level is p¿0.1), and the theoretical hypothesis is verified. The high performance work practice system has significantly positive effects on the knowledge fermenting (mean value is 0.323, significance level is p<0.01), and the theoretical hypothesis is verified. The knowledge fermenting has significantly positive effects on the knowledge spiral (mean value is 0.4401, significance level is p<0.01), and the theoretical hypothesis is also finally verified. The fitting optimization index corresponds to the corrected SEM model.

Table5 The results of path coefficients estimation of SEM based on Bayesian estimation

Paths	Path coefficients based on Bayesian estimation (significa
Strong simmelian ties - High performance work practice system;	0.308(p<0.05)
Weak simmelian ties - High performance work practice system	0.017(p>0.1)
High performance work practice system - Knowledge fermenting;	0.323(p<0.01)
Knowledge fermenting - Knowledge spiral	0.401(p<0.01)

Note: Executable software is Amos software.

4.Conclusions and Enlightenment

This study constructs the theoretical framework of the transmission mechanism of the simmelian ties on the knowledge spiral,and sets the high performance work practice system and knowledge fermenting as the conduction variables. This study takes the high-tech manufacturing enterprises as the empirical analysis objects, adopts the differential evolution algorithm, interval number extension DEMATEL method, structural equation model(SEM)based on Bayesian estimation. The empirical analysis results and implications are as follows:

1. The strong or weak simmelian ties have significant effects on high performance work practice system. Firstly, the reason is that the strong simmelian ties have the characteristics of network stability and height polymerization ,which enable common understanding of existing knowledge among knowledge workers. As Burt (2004) suggested, if there are strong ties among multiple knowledge workers and the common group in the network, the common group will affect the information sharing among the knowledge workers, and eventually there will be a large amount of similar knowledge among the knowledge workers. The consistency of knowledge background and organizational culture further enthance the practical effect of the high performance work practice system on knowledge and skills. Secondly, the weak simmelian ties broaden the channels of knowledge workers to communicate with the outside, which are helpful to the acquisition of diversified knowledge, thus the weak simmelian ties acts on the high performance work practice system to improve the overall learning ability of the knowledge workers. Finally, The strong and weak simmelian ties jointly promote the implementation of job rotation, cross-departmental communication and employee training under the high performance work practice system, and participate in enhancing the coding and decoding ability of organizational members. The strong and weak simmelian ties also clarify the positioning of the overall knowledge niche of the high performance work practice system and optimize the allocation system resources. If this result is further extended, the conclusion suggests that enterprises should actively choose to build strong and weak simmelian ties according to their own high performance work practice system goals. The strong simmelian ties can better meet the immediate and determined human resource management practice goals of the enterprises, while the weak simmelian ties can meet the long-term needs of the enterprises for the sustainability and development of human resources.

2. The job rotation, cross-departmental communication, and employee training are contained in the high performance work practice system. They play a significant role in promoting knowledge fermenting. The conclusion is further deepened and discussed in the research results of Minbrava (2008) and other scholars. Minbrava (2008) and other scholars believe that the high performance work practice system can improve the knowledge sharing environment among knowledge workers, and improve their knowledge learning willingness and ability. In addition, this study confirms that the high performance work practice system not only has the

above-mentioned effects, but also plays a more important role in the process of knowledge fermenting and evolution. In the process of knowledge fermenting, the high performance work practice system improves the skills of knowledge workers and stimulates their enthusiasm for work. The high performance work practice system also promotes mutual trust among knowledge workers, and facilitates them to update and increase their knowledge. Therefore, the high performance work practice system provides a good knowledge ontology and a perfect knowledge development environment for the enterprises' knowledge fermenting, and the high-performance work system is guided by the inheritance thought of the knowledge strain to promote the growth and diffusion of knowledge and update new knowledge capita, just like the knowledge enzyme palys the certain catalytic effect. In conclusion, each enterprise should advocate and encourage the establishment of high performance work practice system in order to strengthen employee training, increase the frequency of cross-departmental communication, and ensure the sharing, flow, diffusion and absorption of knowledge. The enterprises should provide excellent knowledge ontology and knowledge development environment for knowledge fermenting, enabling the enterprises to finally achieve knowledge innovation.

3. The knowledge fermenting plays a significantly positive role in promoting knowledge spiral. The socialization, externalization, combination and internalization of knowledge spiral is essentially the process of sublimation of knowledge through individuals, teams, even organizations, and cross-organizations. At the same time, knowledge also go through four stages of preparation, gestation, insight, and test(Jihuisheng etc., 2011), while knowledge fermenting accelerates the preparation and gestation of knowledge and ideas. Concretely speaking, The knowledge fermenting creates a suitable knowledge growth environment (knowledge fermenting environment), and under the role of catalyst (knowledge enzyme), the knowledge fermenting through the absorption of knowledge ontology (knowledge matrix), under the development strategy guided by the knowledge sourdough to make the knowledge continue to update , but also constantly inject new elements and energies, which provide the source power for the knowledge spiral. Therefore, in order to accelerate the process of organizational knowledge and technological innovation, improve the stock and quality of the whole knowledge, enterprises should provide perfect knowledge tools, rewards and punishment systems, knowledge culture and so on for the knowledge fermenting. The enterprises also need to improve the "craft" of knowledge fermenting in a good organization environment and promote the knowledges piral process.

All of the above methodologies were approved by all human participants

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