

Research Article

A New Model for Competitive Knowledge Diffusion in Organization Based on the Statistical Thermodynamics

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In this study, we have constructed a new model for competitive knowledge diffusion in organization based on the statistical thermodynamics of physics. In order to achieve the purpose of research, we newly define the absorptive capacity coefficient, the creativity ability coefficient, the depreciation coefficient of knowledge, the ambiguity coefficient of knowledge, and the knowledge affinity coefficient of organizational culture. And various knowledge quantities such as knowledge energy, knowledge temperature, and diffusion coefficient for the knowledge diffusion equation were defined and simulations were carried out by the lattice kinetic method. And, based on the new model, we have successfully studied the impact of the characteristics of members, knowledge itself, and organizational culture on the diffusion of competitive knowledge. The results show that the diffusion velocity of knowledge in the organization increases as the knowledge absorbing ability of the members is larger, and the ambiguity of knowledge has a negative impact on the diffusion of knowledge. The degree of knowledge affinity of organizational culture is a decisive factor in the diffusion and accumulation of knowledge in the organization, and the cultural characteristics of the organization have a much greater influence on the diffusion of competitive knowledge than the personal characteristics of members. Therefore, the organization manager needs to pay more attention to building a better organizational culture than improving personal characteristics. Our research is helpful in analyzing the factors affecting competitive knowledge diffusion and constructing an effective knowledge management system.

1. Introduction

In the current era of knowledge-economy, knowledge is seen as an important intangible asset that can guarantee and sustain competitive advantage [1]. Therefore, knowledge has been recognized as the organization's lifeblood and has been identified as a key element in the organization's survival in today's dynamic and competitive era [2, 3]. Thus, a successful company in the present time can be said to consistently create new knowledge, spread its knowledge to the whole organization, and continuously introduce new technologies and products to the market [4]. Thus, knowledge management, like other asset management, has become an important part of organizational management, and many economists and management professionals are paying more attention to research

on knowledge management, such as the creation, transformation, and sharing of technical knowledge.

Davenport defines knowledge management as a process of acquiring, storing, sharing, and utilizing knowledge [5], and Nonaka and Takeuchi define knowledge management as creating new knowledge, spreading it to the entire organization and making it into a product or service system [6]. Abell and Oxbrow pointed out that important parts of knowledge management are the promotion of innovation and creativity through the connection of people and people and knowledge and people; information is transformed into knowledge [7], and Nonaka suggested that new knowledge comes from individuals and the core activity of a knowledge-innovation company is to transfer individual knowledge to other people for making individual knowledge into organizational

knowledge [4]. Among other processes of knowledge management, knowledge sharing has been identified as the most vital one, and it is adopted as a survival strategy [8]. If knowledge remains only as personal knowledge and cannot be transformed into organizational knowledge, such knowledge is easily corroded. Knowledge sharing could be defined as knowledge transfer between individuals, groups, teams, departments, and organizations [9]. Especially, sharing tacit knowledge that resides in the minds of people accumulated over time is very important [10]. Tacit knowledge is highly personal and difficult to formalize, articulate, and communicate fully, based on experience and job specific, transferred through conversation or narrative, and not captured by formal education or training [6, 11]. Tacit knowledge could be an important source of sustainable competitive advantage because competitors are not easy to imitate.

Although knowledge diffusion is very important for economic development, to effectively transfer knowledge is not an easy task because of the unstructured nature of the tacit knowledge and many barriers that hinder the successful flow of knowledge [12]. So, many studies have been carried out on the complex influencing factors of the knowledge diffusion process, such as the restricting factors of knowledge diffusion in organizations [13, 14], the effect factors of knowledge diffusion [15], and methods to promote knowledge diffusion [16].

Many researchers have discussed in detail the factors that affect the diffusion of knowledge in the organization, such as knowledge characteristics, knowledge source characteristics, and knowledge receiver characteristics, context characteristics, tacit characteristics of knowledge transferred, causal ambiguity, uncertainty of knowledge action, lack of absorptive capacity, organizational environmental disorder, and difficulty of communication among knowledge agents [1, 13–17]. Knowledge diffusion in networks has been studied widely. Cowan et al. have demonstrated that spatial clustering generates higher long-term knowledge growth rates by a completely random network characterized with a low path length and low cliquishness, and modeled knowledge growth in an innovating industry [18]. Morone and Taylor presented a general model for a knowledge diffusion rule based on a face-to-face network and suggested some mechanisms that dominate knowledge diffusion known as “social learning” [19]. Kiss et al. applied individual-based models from mathematical epidemiology to the diffusion of a contact network representing knowledge and the results showed that knowledge diffusion had better quality fits with a directed weight network [20].

Recently, attempts have been made to apply physical theories to knowledge management. Dragulescu and Yakovenko considered wealth distribution in a closed economy by employing a kinetic exchange model from the point of view of gaseous kinetic theory for the first time [21], and Chakraborti and Chakraborti studied the saving propensity affecting wealth distribution in market economy based on Boltzmann transport equation [22]. Zhang et al. processed knowledge flow in a similar way to the theoretical model of electric field [23], and Jun and Xi concluded that the knowledge flow process is essentially an interaction of strength and resistance by

adopting the concepts of knowledge potential, resistance, and field strength [24]. Lucas and Moll discussed a balanced economic growth path using the Boltzmann-type equation model [25]. In both natural and social phenomena, the mathematical modeling is very useful to explain their nature and it is important to establish accurate management strategies by analyzing and forecasting socioeconomic phenomena.

From the results of many articles on knowledge management, we can know that the characteristics of organizational members, organizational culture, and knowledge have an important influence on organizational knowledge accumulation in organizational knowledge management. However, previous studies have not studied the effects of these factors comprehensively and quantitatively. So, we are going to investigate the effects of these factors comprehensively in the process of dynamic change. And the knowledge we aim at in this paper means competitive knowledge. In other words, the diffusion of knowledge that can create economic value in an organization was discussed. Not all knowledge leads to economic value. Knowledge that anyone can easily understand and easily acquire from anywhere is knowledge that cannot create economic value. In other words, it is a competitive knowledge that requires many skills and know-how difficult to imitate and that can directly bring economic value. The goal of knowledge management is to improve the competitiveness of organization and ultimately to derive economic value. In this paper, we have introduced member performance index, organizational culture index, and knowledge complexity index, which can represent the change of these factors, and developed a new equation-based knowledge diffusion model by employing physical theory (diffusion and kinetics theory) and methods for the multiparticle system and analyzed the competitive knowledge diffusion characteristics in an organization.

2. The Model of Competitive Knowledge Diffusion Based on the Statistical Thermodynamics

In this section, the factors affecting the diffusion of the competitive knowledge are analyzed in various aspects, and new characteristic quantity and indices are introduced. And the theoretical study was carried out to construct a new model using the thermodynamics and the lattice Boltzmann method of physics.

2.1. Analysis of Factors Affecting Competitive Knowledge Transfer. Knowledge is the insights, understandings, and practical know-how that people possess and it is the fundamental resource that allows people function intelligently. And people live in social organization and use knowledge. Therefore, knowledge transfer in an organization will have a close relationship with the characteristics of the organization members, the relationship between the members, and the characteristics of the organization.

2.1.1. Personal Characteristics of Organization Members. People are the sources of knowledge. The ability of humans to think creatively and uniquely, coupled with experiences

and talents, makes humans sources of knowledge. Therefore, knowledge sharing in the organization is closely related to the characteristics of an organization members that possessing such knowledge. The effects of personal characteristics on knowledge sharing in organizations have been studied extensively [26–28]. In this study, we distinguished the knowledge-absorbing ability and the innovation ability as the characteristics of the members for knowledge transfer research. Absorption capacity is associated with many other properties such as knowledge level, existing experience, self-efficacy, activity ability, hobbies, and psychology of the member. It refers to the ability to identify, learn, and digest knowledge by assessing external knowledge that can generate organizational benefits. Therefore, we introduce the variable a_k and try to distinguish the degree of absorption of the members through.

Innovation ability is the ability to combine and utilize acquiring knowledge and existing knowledge to create new competitive knowledge necessary to create profit for the organization. Innovation ability is related to knowledge utilization ability, organizational commitment, organizational cultural characteristics, integrity, belief, and will. We introduce the variable i_k and try to assess the degree of innovation capacity of the member. These personal characteristic coefficients are large when absorption capacity and innovation ability are high.

2.1.2. Relational Characteristics among Organizational Members. When analyzing knowledge transfer among people, functional, geographical, and organizational level difference between them has a significant impact on knowledge transfer [29]. The competitive knowledge in organizations is often associated with know-how and tacit knowledge. Tacit knowledge could be an important source of sustainable competitive advantage because competitors are not easy to imitate. So, we have chosen physical distance as one of the important factors in the diffusion of knowledge. The transfer of competitive knowledge is better as the physical distance between members is closer, especially because tacit knowledge is communicated only through face-to-face contact between people, and knowledge providers more easily transfer knowledge to physically closer recipients. On the other hand, if the levels of culture and value are similar among the interacting members, it has a good influence on knowledge transfer. So, cultural distances will also influence knowledge diffusion among members. The difference in knowledge level also affects transmission. Knowledge difference is a parameter that shows how much the supplier and receiver have common knowledge, and knowledge transfer becomes easier as knowledge difference gets closer. From these considerations, we are introducing the concepts of physical distance, knowledge distance, and cultural distance and trying to use them in the new models. Physical distance means the difficulty of communication, time requirements, and face-to-face costs. A study of the effects of physical distance revealed that patent citations occur frequently in certain regions [30]. Research by Galbraith and Lester et al. showed that the greater the distance between the parties, the slower and less technological transfer takes place [31, 32]. Knowl-

edge distance is the degree to which the source and recipient possess similar knowledge. It has been found that, for organizational learning to take place, the knowledge distance or “gap” between two parties cannot be too great [33]. Cultural distance is a concept that shows how much the knowledge holders and receivers share the same organizational culture and value system. Many studies on knowledge sharing have shown that the difference between labor value and organizational culture can have a significant impact on knowledge transfer [34]. As a result of analyzing the results of previous studies, it can be seen that knowledge sharing among agents will proceed better as the difference between physical distance, knowledge distance, and culture distance is smaller.

2.1.3. Organizational Cultural Characteristics. Many knowledge management literatures argue that organizational culture can have a significant impact on organizational knowledge sharing activities [35–37]. Organizational culture is defined as the beliefs and behaviors shared by the members of an organization regarding what constitutes an appropriate way to think and act in the organization [38]. Although, aligning knowledge management approaches to fit organizational culture have been suggested as good, it is better to create and manage an organizational culture that supports knowledge sharing and management activity. The reason is that organizational culture can be changed to create appropriate knowledge-related behaviors and value. The success of knowledge management can be achieved by modifying the culture of the organization in ways that encourage and support the desired knowledge attitudes and behaviors. Organizations that do not care about how knowledge is managed will not operate optimally. Knowledge is a resource that is submerged in human minds, so knowledge and sharing of knowledge require the will of people with knowledge.

Therefore, the organizations should establish an organizational culture that promotes knowledge sharing so that all members are aware of the importance of knowledge sharing and actively participate in this work. And the organization should provide appropriate motivation and rewards for members’ knowledge sharing, and encourage organizational learning, lively debate, and discussion in the organization. So, we have introduced the knowledge sharing culture coefficient o_k of the organization to assess the degree of knowledge sharing culture in an organization.

2.1.4. Characteristics of Competitive Knowledge. The characteristics of knowledge have an important influence on knowledge transfer. The competitive knowledge is not easily transferred. The knowledge transfer process usually involves the process of being moved, interpreted, and absorbed. The ambiguity of knowledge in this process affects the knowledge transfer. Ambiguity is an intrinsic property of knowledge, including tacitness and complexity. Tacit knowledge is gained by internal individual processes such as experience, reflection, internalization, or individual talents. So, it cannot be managed and taught in the same manner as explicit knowledge. Tacit knowledge is hard to communicate and is deeply rooted in action, involvement, and commitment within a specific context. In other words, transfer of tacit

knowledge requires much time and effort. The complexity of knowledge also influences knowledge transfer. If knowledge transfer expertise is high and complex training or function is required, transferring such knowledge also requires much time and effort. Therefore, the influence of the knowledge characteristics in the knowledge diffusion process was analyzed by using the ambiguity factor u_k of knowledge.

On the other hand, rapid acceleration of technological innovation, economic structural changes, and fierce competition in the market economy accelerate the updating of knowledge. There is no absolute invariable knowledge. The new knowledge is being created and spreading at a very fast pace and the knowledge that we have believed to be true often changes. So, knowledge depreciation theory appeared [39]. The value of certain knowledge decreases over time. In other words, some of the accumulated knowledge of an organization turns into unnecessary knowledge as it becomes less competitive or useless over time. This decline is the depreciation of knowledge. Considering the depreciation characteristics, we introduced the depreciation coefficient d_k . Knowledge depreciation coefficient d_k is the value loss of knowledge over time; the larger the value, the faster the knowledge needs to be updated.

2.2. A Competitive Knowledge Diffusion Model by Thermal Diffusion Equation of Physics. A universal agent-based model of knowledge diffusion is a model that describes systematic phenomena from the behavior of each agent in the system, and mathematical modeling based on the agent is generally well known as system dynamics. Many studies on knowledge diffusion are based on agent-based modeling, which can cause many problems in computational cost and accuracy when applied to massive multiagent systems involving numerous agents [19, 40, 41]. The economy is a promising target for statistical mechanics applications because it is a large statistical system with millions of participating agents. If we formulate a mathematical model for the probability distribution of agent behavior based on statistical theory in physics, it can be much more advantageous to describe systematic phenomena by a simpler equation set.

Boltzmann kinematics is a physical theory suitable for multiparticle systems developed to overcome the deficiencies of Newtonian dynamics, which must solve a large number of differential equations. So, we tried to construct a knowledge diffusion equation using the Boltzmann kinetic-based thermal diffusion equation. Starting from the concept of this physical field, the knowledge field can be defined as a system consisting of different levels of knowledge for each point (agent) in space. Like all other fields, knowledge field can be seen as a function of time and space, but space in the knowledge field should be treated as a specific space different from space given only by physical distance.

Therefore, we constructed the coordinates of the special space for the knowledge field reflecting the abovementioned member relation characteristics. For this purpose, we have assumed the independence between the physical distance, the cultural distance, and the knowledge distance introduced above, and then constructed the x , y , and z axes based on that independence. Origin of coordinate (O) can be determined

from averaging the value by analyzing the physical location, cultural characteristics, and the degree of knowledge ownership of all agents in the organization. So, the position vector of all members in the knowledge field can be expressed as $\mathbf{r} = r_x \cdot \mathbf{i} + r_y \cdot \mathbf{j} + r_z \cdot \mathbf{k}$, and the distance between two agents can also be defined as $r_1 - r_2$.

Next, we considered the knowledge field as a kind of physical field and introduced some variables similar to the physics theory.

First, we introduce the energy of competitive knowledge (E_k) as a quantity that can characterize the level of competitiveness that is produced by having knowledge. However, there is one important property to consider. Not all knowledge leads to economic value. Knowledge that anyone can know and easily acquire from anywhere is knowledge that cannot create economic value. In other words, knowledge based on talents that few people know or cannot be imitated can produce economic value. From this, we focus on the ability to create economic value of knowledge in defining knowledge energies. In other words, we can establish the logic that the size of the competitive knowledge energy is changed depending on how much agent has the ability to create economic value. These knowledge energies change in the two agents when they collide, but the overall knowledge energies are preserved. In other words, it can be seen that the knowledge energies reduced by passing a certain amount of knowledge to other agents are transmitted to the other. The important thing here is that the preservation of knowledge energy does not mean that knowledge is preserved. It means the preservation of competitiveness by knowledge. Based on this logic, this conservation is similar to the energy conservation law of the gas motion theory, and the distribution of the knowledge energy in the steady state follows the Maxwell-Boltzmann equilibrium distribution of the gas motion theory.

$$f(E_k) = A \exp\left(\frac{-E_k}{T_k}\right), \quad (1)$$

where f is the knowledge energy distribution function and A is constant. T_k is the average knowledge energy of the system and can be defined as the knowledge temperature. In other words, if knowledge temperature is high, such knowledge can be considered to have relatively high competitiveness.

Next, we introduce a specific knowledge energy quantity C_k , which is defined as a quantity similar to the specific heat in the statistical thermodynamics from the knowledge temperature.

$$C_k = \left(\frac{\Delta E_k}{\Delta T_k}\right), \quad (2)$$

where C_k is related to the degree of absorption capacity a_k in the personal characteristics of the members mentioned above and specifically has an inverse relationship.

In general, many phenomena in various scientific disciplines are mathematically expressed using well-known partial differential equations. The diffusion equation has been

developed to describe behavior due to random movements of particles in physics and has been extended to various areas such as information science, life sciences, social sciences, and material sciences.

From the introduction of E_k , T_k , and C_k , we have been able to study the diffusion problem of knowledge based on statistical thermodynamics. Using the defined coordinate system and variables and the heat diffusion equation of thermodynamics, the competitive knowledge diffusion equation can be constructed as follows.

$$c_k(\mathbf{r}) \frac{\partial T_k(\mathbf{r})}{\partial t} = \frac{\partial}{\partial \mathbf{r}} \left(k_k \frac{\partial T_k(\mathbf{r})}{\partial \mathbf{r}} \right). \quad (3)$$

In this equation, the left side shows the change of the knowledge temperature with time and the right side shows the knowledge temperature change according to the agent position. In other words, this equation mathematically explains that the knowledge energy is shifted from the high to the low knowledge temperature by various factors. In the equation, k_k is defined as the knowledge conduction coefficient as a quantity that characterizes knowledge diffusion. k_k is closely related to the cultural characteristics of the organization and degree of ambiguity of knowledge among factors influencing the transfer of knowledge. Equation (3) considers only the exchange of knowledge between agents without knowledge generation or disappearance. Therefore, the creation of knowledge and the depreciation of knowledge discussed above must be considered in this diffusion equation. In previous R&D collaboration network study on knowledge diffusion performance [42, 43], knowledge accumulation by creation and depreciation was studied as follows.

$$k_{i,t+1} = (1 - \delta)k_{i,t} + \alpha_i k_{i,t}^\gamma, \quad (4)$$

where $k_{i,t}$ and $k_{i,t+1}$ are the knowledge accumulation amounts at time t and $t + 1$, and δ is the knowledge depreciation rate. α_i can be interpreted as an innovation ability, and γ is constant. Due to learning, the larger the coefficient γ is, the more rapidly productivity increases. From Equation (4), we can express the source term of the knowledge diffusion equation as follows:

$$S = i_k(\mathbf{r})T_k(\mathbf{r})^\lambda - d_k(\mathbf{r})T_k(\mathbf{r}). \quad (5)$$

And we should also consider the knowledge affinity characteristics that indicate the degree of knowledge culture of the organization. As mentioned above, knowledge-friendly cultures value knowledge, create appropriate incentives for creating new knowledge, and improve members' creativity and encourage knowledge sharing. Therefore, knowledge affinity factors will affect knowledge sharing and creation. Specific knowledge energy capacity is related to knowledge absorption capacity. So, we finally constructed the knowledge diffusion equation as follows.

$$\frac{1}{a_k(\mathbf{r})} \frac{\partial T_k(\mathbf{r})}{\partial t} = \frac{\partial}{\partial \mathbf{r}} \left(o_k u_k k_k \frac{\partial T_k(\mathbf{r})}{\partial \mathbf{r}} \right) + o_k i_k(\mathbf{r}) T_k(\mathbf{r})^\lambda - d_k(\mathbf{r}) T_k(\mathbf{r}), \quad (6)$$

where a_k , i_k , and d_k are coefficients that represent the absorptive capacity, innovation ability of the members, and knowledge depreciation, and u_k and o_k are ambiguity coefficient of competitive knowledge and knowledge affinity coefficient of organizational culture discussed above, respectively. λ is the learning curve factor of the agent. Equation (6) allows us to build a new competitive knowledge diffusion model that takes into account the personal characteristics, relationship characteristics, and organizational cultural characteristics discussed above.

2.3. Numerical Solving Method of Knowledge Diffusion Equation by Lattice Kinetic Method. Lattice Boltzmann model is a relatively new simulation technique for complex fluid systems and has attracted interest from researchers in computational physics because of its powerful numerical solving ability. Unlike the traditional computational fluid dynamics methods, which solve the conservation equations of macroscopic properties (i.e., mass, momentum, and energy) numerically, lattice Boltzmann method models the fluid consisting of fictive particles, and such particles perform consecutive propagation and collision processes over a discrete lattice mesh. Therefore, the lattice Boltzmann method is based on the idea of lattice gas cellular automata (LGCA) to simulate the fluid motion by a simplified microscopic model in discrete time steps using a discrete phase space, i.e., discrete velocity and location. The motion of the particles is represented by a particle distribution function. The Boltzmann transport equation can be written as follows [44]:

$$\frac{\partial f}{\partial t} + \mathbf{e} \cdot \nabla f = \Omega \quad (7)$$

where f is the distribution function, \mathbf{e} is the velocity, and Ω is the collision operator. It is difficult to solve this equation because Ω is a function of f , and in a general case, it is an integro-differential equation. The starting point of the lattice Boltzmann method (LBM) is the kinetic equation.

$$\frac{\partial f_i(\mathbf{r}, t)}{\partial t} + e_i \cdot \nabla f_i(\mathbf{r}, t) = \Omega, \quad i = 1, 2, 3, \dots, M, \quad (8)$$

where f_i is the particle distribution function denoting the number of particles at the lattice node \mathbf{r} at the time t moving in direction i with the velocity e_i along the lattice link $h = e_i \Delta t$ connecting the nearest neighbors, and M is the number of directions in a lattice through which the information propagates. The term Ω_i represents the rate of change of f_i due to collisions and is very complicated [45]. The simplest model for Ω_i is the Bhatnagar-Gross-Krook (BGK) approximation [44–46].

$$\Omega_i = -\frac{1}{\tau} [f_i(\mathbf{r}, t) - f_i^0(\mathbf{r}, t)], \quad (9)$$

where τ is the relaxation time and $f_i^0(r, t)$ is the equilibrium distribution function. In the knowledge diffusion Equation (6), the equilibrium distribution function is given by

$$f_i^0(\mathbf{r}, t) = w_i T_k(\mathbf{r}, t), \quad (10)$$

where w_i are the known weights, and at the same time $\sum_{i=1}^M w_i = 1$.

Additionally, the knowledge temperature T_k at the lattice node r and for time t is calculated using the formula as follows:

$$T_k(\mathbf{r}, t) = \sum_{i=1}^M f_i(\mathbf{r}, t). \quad (11)$$

The evolution equation for Equation (9) can be written by using the distribution function as follows:

$$\begin{aligned} f_i(\mathbf{r} + \Delta\mathbf{r}, t + \Delta t) = & f_i(\mathbf{r}, t) + \frac{\Delta t}{\tau} [f_i^0(\mathbf{r}, t) - f_i(\mathbf{r}, t)] \\ & + \Delta t w_i a_k(\mathbf{r}) \left(o_k i_k(\mathbf{r}) T_k(\mathbf{r})^\lambda - d_k(\mathbf{r}) T_k(\mathbf{r}) \right). \end{aligned} \quad (12)$$

Lattice selection is very important in the lattice kinetic model for knowledge diffusion. In the knowledge space discussed above, we can see that agent interaction proceeds between adjacent spaces. In other words, the exchange of knowledge between knowledge transferor and recipient is considered as progressing knowledge exchange from the agent with the shortest physical distance, cultural distance, and knowledge distance. Therefore, we can use the lattice Boltzmann method for natural scientific problems. We used two-dimensional knowledge space to perform numerical experiments on knowledge transfer in an organization and to verify the lattice dynamics model for knowledge transfer.

For a D2Q9 model, a particle is restricted to stream in a possible of directions, including the one staying at rest, and these velocities are referred to as the microscopic velocities and denoted by \mathbf{e}_i , where $i = 0, \dots, 8$.

$$\mathbf{e}_i = \begin{cases} (0, 0), & i = 0, \\ (1, 0), (0, 1), (-1, 0), (0, -1), & i = 1, 2, 3, 4, \\ (1, 1), (-1, 1), (-1, -1), (1, -1), & i = 5, 6, 7, 8. \end{cases} \quad (13)$$

For each particle on the lattice, we associate a discrete probability distribution function $f_i(\mathbf{r}, \mathbf{e}_i, t)$ or simply $f_i(\mathbf{r}, t)$, $i = 0, \dots, 8$, which describes the probability of streaming in one particular direction. And their corresponding weights w_i are as follows:

$$w_k = \begin{cases} 4/9, & k = 0 \\ 1/9, & k = 1 \text{ to } 4 \\ 1/36, & k = 5 \text{ to } 8 \end{cases} \quad (14)$$

If the agents on the outskirts of the computational domain do not carry out meaningful knowledge transfer to/from outside, then the boundary conditions for knowledge temperature can be written as $T_k|_{\text{outside}} = T_k|_{\text{outstrike}}$. Boundary condition for the distribution function is set by nonequilibrium extrapolation scheme [47].

$$f_k|_{\text{outside}} - f_k^{\text{eq}}|_{\text{outside}} = f_k|_{\text{outstrike}} - f_k^{\text{eq}}|_{\text{outstrike}}. \quad (15)$$

From these considerations, we have been able to construct a new knowledge diffusion model and analyze knowledge diffusion characteristics using Equations (4) and (10) and D2Q9 model. In our research, the initial knowledge temperature T_k is a random variable following the uniform distribution with the interval [0,10]. The absorption capacity parameter a_k was discussed between 0 and 1. Innovation ability variable i_k is distributed uniformly over some interval [0,1] and λ is set to 0.1. If the upper bound of learning curve coefficient is set above that value, the knowledge stock did not converge as time goes on. Knowledge depreciation parameter d_k is given a value of 0.01. The knowledge transfer coefficient was simulated by varying between 0 and 1 depending on the degree of organizational sharing culture. In our research, the nodes represent agents within the organization and 10000 agents are regularly distributed on the 100×100 grid. The simulation was performed using MATLAB 2016a.

3. Simulation Results and Discussion

In this section, we have studied the diffusion and accumulation of competitive knowledge in organizations according to the changes in the personal absorption characteristics of organizational members, the characteristics of knowledge itself, and the degree of knowledge affinity of organizational culture based on knowledge diffusion equations and the lattice kinetic simulation. In order to investigate the effect of knowledge absorptive characteristics of members on the knowledge sharing, the change of mean knowledge temperature in the organization according to time was investigated by changing the knowledge absorption coefficient of the agent. Figure 1 shows the change of organizational average knowledge temperature vs. time on different absorption coefficients of the agent.

From Figure 1, it can be seen that as the absorption coefficient of the agents increases, the average knowledge temperature of the organization increases relatively quickly and reaches saturation temperature. In other words, all the agents in the organization raise their knowledge level by the interaction with other agents, but the speed is related to the absorption ability. Over time, the knowledge diffusion rate decreases and the average knowledge temperature of the organization becomes saturating state. In other words, if the members of the organization live together in the same organization for a long time, the level of mutual knowledge becomes similar through the process of information exchange, so that the diffusion of valuable knowledge is gradually reduced. Also, from Figure 1, it can be seen that as the knowledge absorption coefficient decreases, the negative effect on knowledge diffusion becomes greater. In the present age of the knowledge

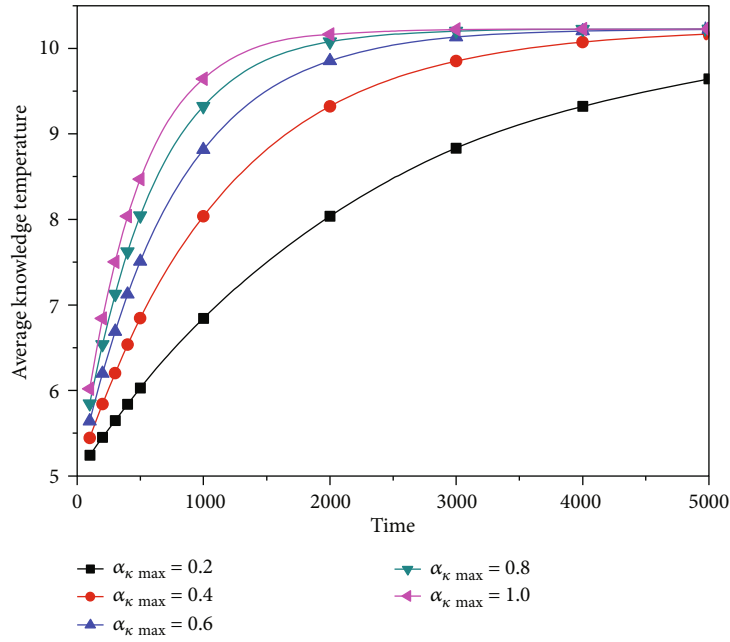


FIGURE 1: Organization-mean knowledge temperature on different absorption capacity coefficients.

economy, knowledge is being renewed rapidly, and the spread of the latest technologies in the organization at the right time is closely linked to value creation. Therefore, in order to quickly share and utilize valuable knowledge in an organization, members' ability to absorb knowledge should be high.

If the organization cannot create new competitive knowledge based on acquiring knowledge from the outside, they will fall into the age of development and such organization cannot guarantee the long-term competitiveness. Especially, because knowledge is constantly updated and competitors are constantly evolving, creation of new knowledge is essential. The individual's creative ability will have a significant impact on the accumulation of knowledge in the organization as an intrinsic characteristic of the members. So, we studied the effect of the members' creative ability on the accumulation of competitive knowledge in the organization. Figure 2 shows the average knowledge temperature value of the agents over time while varying the maximum innovation coefficient of the agents.

From Figure 2, it can be seen that the average knowledge temperature in the organization increases as the knowledge innovation ability of the members increases. In other words, the higher the knowledge innovation capability of the members, the greater the knowledge accumulation in the organization. And knowledge accumulation increases with time, but it reaches saturation state. The reason is that after a certain period of time, the balance between the creation of knowledge and depreciation of knowledge is maintained. In other words, while new knowledge is created, some knowledge in the organization loses its competitiveness and decreases in value as time goes by. When the maximum knowledge creation coefficient is less than 0.4, the average knowledge temperature does not increase but rather decreases. This result shows that the knowledge creation coefficient of the members should be constantly high in order to

secure competitiveness in the organization. The accumulation of knowledge in an organization means the competitiveness of the organization. From the results in Figure 2, we can also see that the higher the creative abilities of the members, the greater the competitiveness that the organization can possess.

Next, we examined the influence of competitive knowledge ambiguity, which is a characteristic of knowledge itself, in the diffusion of knowledge in the organization. Figure 3 shows the knowledge temperature distribution contours at $t = 100$ on different knowledge ambiguity coefficients.

From Figure 3, it can be seen that the difference between the maximum and minimum values of the knowledge temperature becomes smaller as the number of knowledge ambiguities becomes smaller. The complexity and tacitness of knowledge increase as the ambiguity factor increases. In other words, when the ambiguity decreases, knowledge spreads smoothly in the organization. Figure 4 shows the knowledge temperature distribution contours at different knowledge ambiguity coefficients when the knowledge diffusion reaches equilibrium.

Figure 4 shows that although knowledge diffusion has reached an equilibrium state, knowledge differences among members still exist because of the ambiguity of knowledge, and the difference is large when the ambiguity factor is large. On the other hand, when the ambiguity of knowledge is low (for example, Figure 4(c)), knowledge sharing among members smoothly progresses, and the ratio of members with high knowledge increases. Therefore, in order to improve the knowledge sharing among the members, the organization should try to make the implicit knowledge explicit and ensure sufficient learning and practice for the knowledge, which requires complex and highly skilled finesse.

In order to investigate the effect of organizational culture characteristics on the competitive knowledge growth and sharing of the organization, we analyze the change

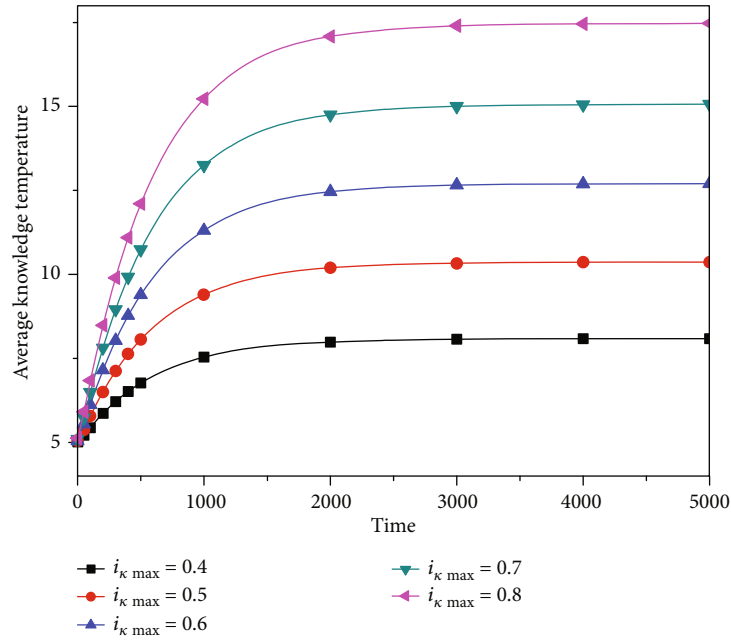


FIGURE 2: Average knowledge temperature on different knowledge innovation coefficients.

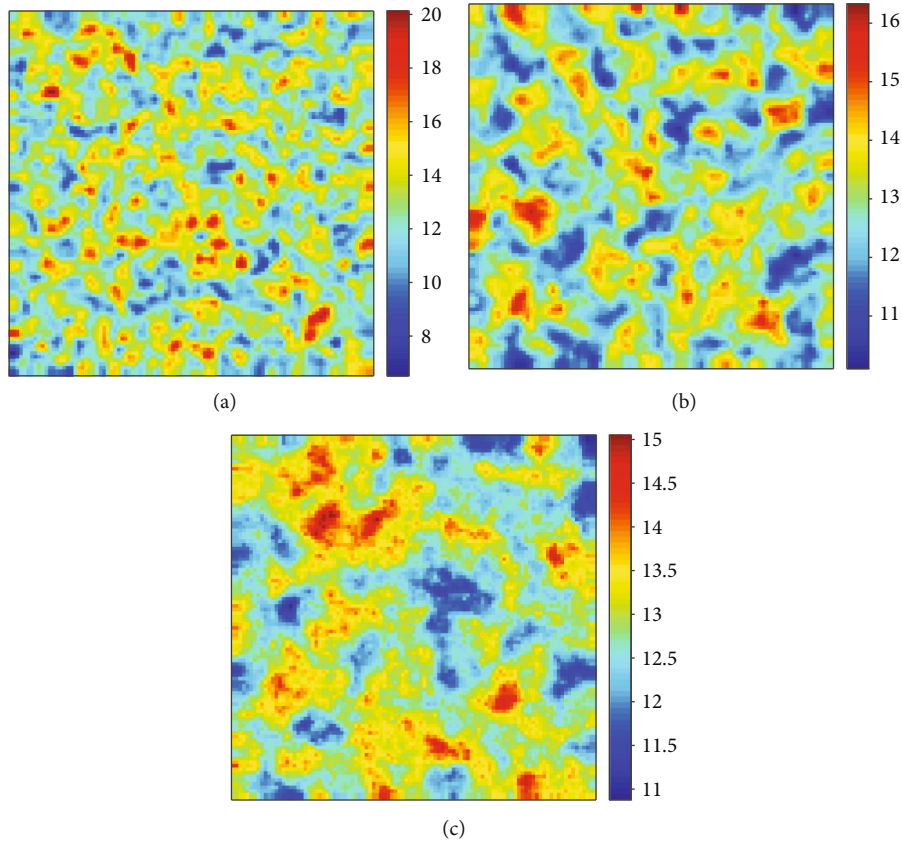


FIGURE 3: Knowledge temperature distribution contours at $t = 100$ (a ($u_k = 1$), b ($u_k = 0.5$), c ($u_k = 0.1$)).

characteristics of the organization-average knowledge temperature vs. time by changing values of the organizational knowledge affinity coefficient from 0.4 to 1 with 0.2 interval.

We studied the diffusion characteristics of knowledge according to organizational knowledge affinity coefficient defined above. Figure 5 shows the change in average

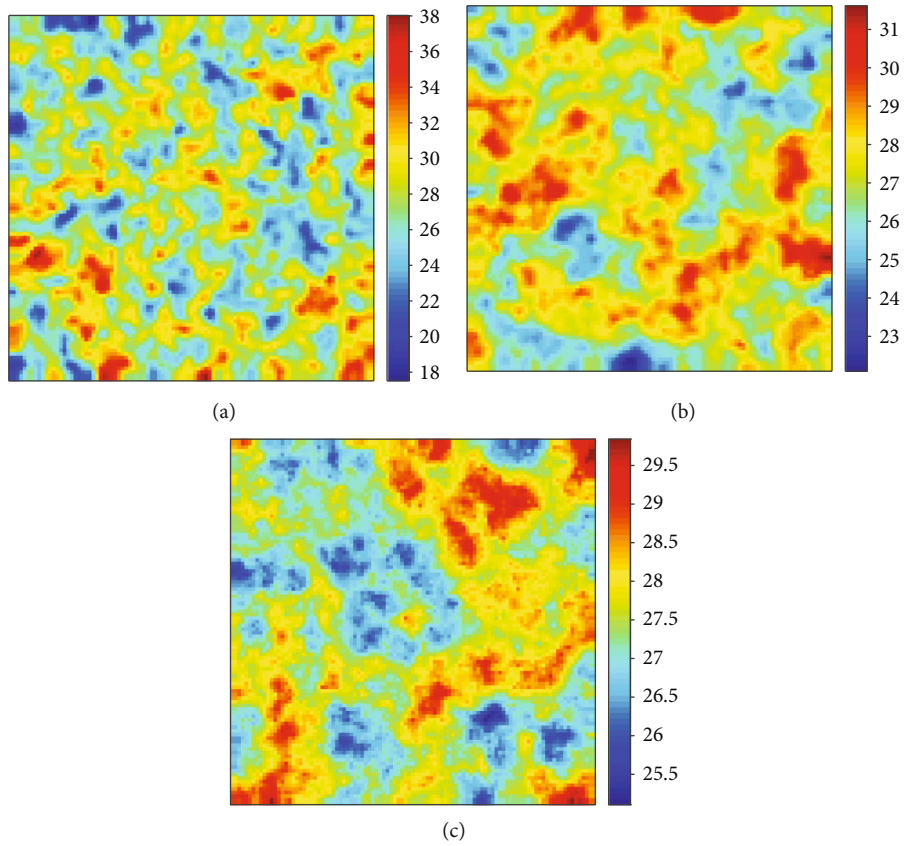


FIGURE 4: Knowledge temperature distribution contours at $t = 100$ (a ($u_k = 1$), b ($u_k = 0.5$), c ($u_k = 0.1$)).

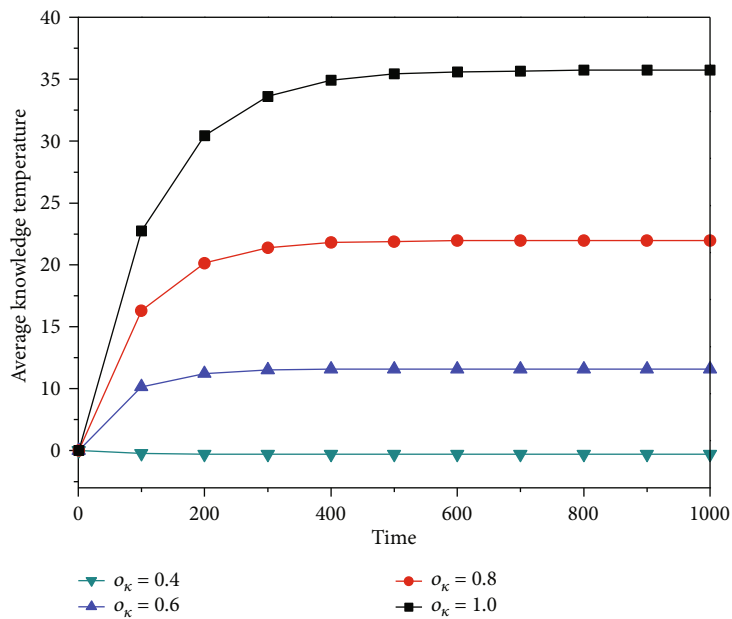


FIGURE 5: Organization-average knowledge temperature vs. time on different organizational knowledge affinity coefficients.

knowledge temperature over time on the different knowledge affinity coefficients. As can be seen in Figure 5, the knowledge average knowledge temperature of the organization repre-

sents a very large change characteristic according to the knowledge affinity coefficient of the organizational. In other words, it shows that knowledge affinity degree of

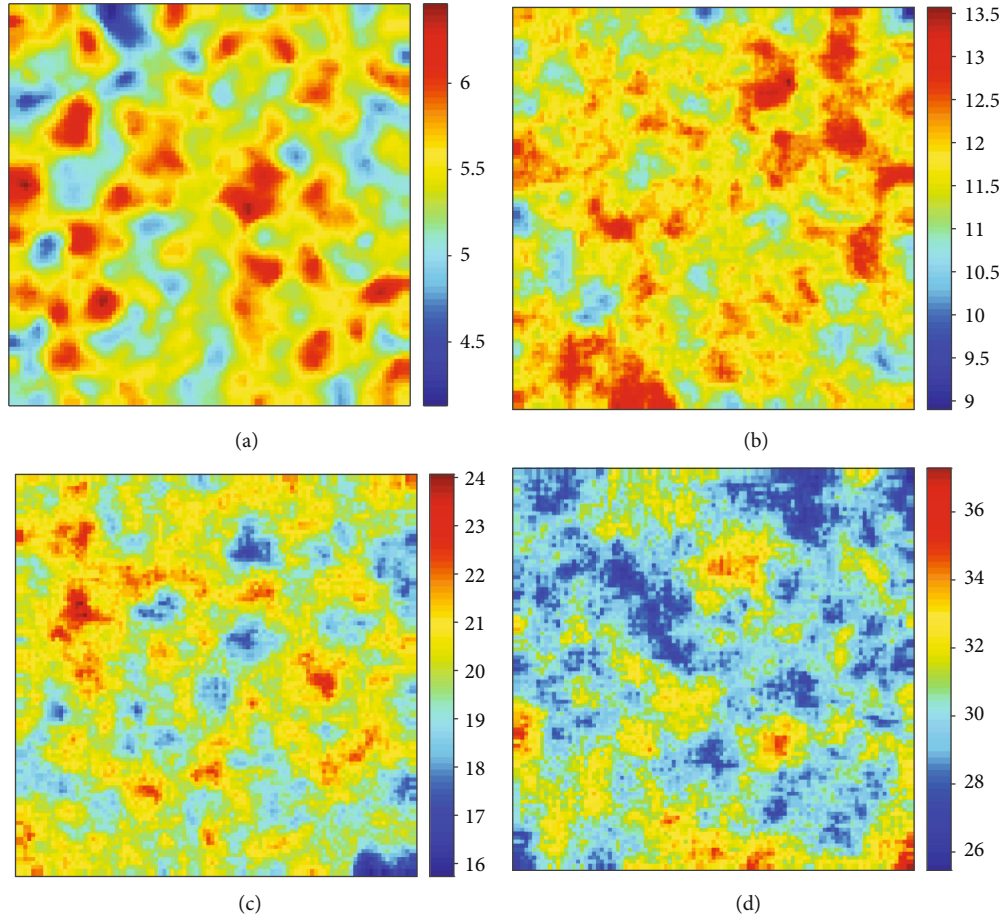


FIGURE 6: Knowledge temperature distribution contours on different organizational knowledge affinity coefficients (a ($o_k = 0.4$), b ($o_k = 0.6$), c ($o_k = 0.8$), d ($o_k = 1$)).

organizational culture has a great influence on the diffusion and growth of knowledge.

In addition, from the saturation knowledge temperature on the different organizational knowledge affinity coefficients, we can see that the average saturation knowledge temperature change magnitude becomes larger when the knowledge affinity coefficient increases, and the knowledge growth does not proceed at less than 0.4. This implies that the higher the knowledge affinity level of organization, the better influence on knowledge growth and accumulation. On the contrary, we can also know that organizational culture that is not interested in knowledge has a negative impact on the growth and accumulation of knowledge, and in a serious case, knowledge accumulation becomes smaller and obsolete due to depreciation and time lapse. On the other hand, comparing the results in Figures 1, 2, and 5 shows that the affinity coefficient of the organizational culture has a much greater influence on the average knowledge temperature than the influence of the characteristic coefficients of the agent.

Figure 6 shows the knowledge temperature distribution contours at equilibrium in the various knowledge affinity coefficients of the organizational culture. As shown in Figure 6, when the affinity coefficient is small, the diffusion of valuable knowledge is not progressed well, and relatively

high knowledge temperatures are partially extreme. On the contrary, when the knowledge affinity coefficient increases, knowledge spreads well and high knowledge temperature distribution ratio increases. In other words, the higher the affinity coefficient of the organization, the better the diffusion of knowledge in the organization, and the valuable and competitive knowledge sharing among the agents is facilitated. From these results, we can conclude that the main factor affecting competitive knowledge diffusion and accumulation within an organization is the degree of knowledge affinity of organizational culture.

Many researchers have emphasized the importance of organizational culture in knowledge management, and several studies have shown that people and cultural issues are the most difficult problems to resolve, but produce the greatest benefits [48]. Ruggles examined 431 organizations in the United States and Europe to investigate factors that impede knowledge sharing and found that organizational culture is the most important factor, and it is necessary to confirm the organizational culture to activate knowledge sharing [49]. Our knowledge diffusion research results based on the new model support the previous research theoretically.

Therefore, it is more effective to create and manage an organizational culture that supports knowledge sharing and management activities rather than adjusting the knowledge

management approach to fit the organizational culture. Since knowledge is a resource in the human mind, so the viewpoints and attitudes of people on the organization have an important influence on knowledge and knowledge sharing. It is therefore important to build a knowledge-friendly culture that values knowledge and encourage a knowledge-sharing culture in which all members recognize the importance of knowledge sharing. Our new model can help managers find good management methodologies by simulating the dynamic characteristics of competitive knowledge accumulation and sharing by providing accurate values for the variables discussed above in a particular organization based on empirical analysis and data.

4. Conclusion

In this study, we have constructed a new model for competitive knowledge diffusion in organization based on the statistical thermodynamics of physics and successfully studied dynamic characteristics of competitive knowledge diffusion and the effect of the characteristics of member, knowledge, and organizational culture on knowledge sharing and diffusion in the organization. In order to achieve the purpose of research, we newly define the coefficient of absorptive capacity, the creativity ability coefficient, the depreciation coefficient of knowledge, the knowledge ambiguity coefficient of knowledge, and the knowledge affinity coefficient of organizational culture. And various knowledge quantities such as knowledge energy, knowledge temperature, and diffusion coefficient for the knowledge diffusion equation were defined and simulations were carried out by the lattice kinetic method. The main achievements of our research are as follows.

- (1) A new model for studying the dynamic characteristics of competitive knowledge diffusion in organizations is constructed based on the statistical thermodynamics of physics
- (2) The diffusion velocity of competitive knowledge in the organization increases as the knowledge absorbing ability of the members is larger. The higher the creative abilities of the members, the greater the maximum competitiveness that the organization can possess
- (3) The ambiguity of competitive knowledge has a negative impact on the diffusion of knowledge
- (4) The degree of knowledge affinity of organizational culture is a decisive factor in the diffusion and accumulation of competitive knowledge in an organization

Comprehensively, organizational cultural characteristics are much more influential on the diffusion of competitive knowledge than the personal characteristics of the members. Therefore, organizational managers need to pay greater attention to building a superior organizational culture than improving personal traits.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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