Simulation Study on the Effect of Employee Mobility on the Spreading of Tacit Knowledge among Industrial Enterprises Based on the Knowledge Spreading Model

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ABSTRACT: In the era of knowledge economy, the success of industrial commodity production and business activities in an industrial enterprise mainly depends on the knowledge level of employees and the effectiveness of knowledge management. Thus, industrial enterprises encourage employees to spread and share useful knowledge and information with others. Tacit knowledge spreads among industrial enterprises mainly through employee mobility with such knowledge. We introduce a new approach to describe the spread of tacit knowledge using epidemic models. We model and simulate the peculiarities of tacit knowledge spreading between two industrial enterprises by considering employee mobility. This model is compared with the susceptible-infected-susceptible model. We analyze the effects of employee mobility on the spreading of tacit knowledge and provide numerical simulations to support our results. Results show that employee mobility and the average degree of the knowledge exchange network in each industrial enterprise significantly influence the spreading of tacit knowledge among industrial enterprises. A threshold that governs whether tacit knowledge can spread among industrial enterprises exists. The results of the numerical simulations and analyses can guide industrial enterprises to improve knowledge and information management with regard to the theoretical and practical aspects, as well as provide a valuable platform for further analyzing knowledge and information management.

Keywords: Knowledge management, Industrial enterprise, Knowledge spreading model, Employee mobility, Simulation

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1. Introduction

The knowledge-based view of competitive advantage acknowledges knowledge management (KM) and information management as core subjects in industrial enterprises at present [1]. Knowledge that is significantly related to the specific roles, skills, and cognitive abilities of employees, and is culturally and socially embedded into their behaviors and practices, contributes to industrial production performance differentials among industrial enterprise competitors [2]. KM plays a significant role in industrial enterprises [3]. The major focus of KM in industrial enterprises is spreading and sharing useful knowledge among employees. Knowledge spreading among employees is the most important and challenging means to increase knowledge utilization value and KM effectiveness in an industrial enterprise [4]. Many multinational corporations currently exist, and industrial firms have established branches in different areas. Hence, the plurality of employees who have acquired tacit knowledge and employees without such knowledge will be generated simultaneously. Therefore, the key to knowledge spreading at present is considerably greater than that of traditional regional industrial enterprises that focus on company workshop [5]. Quoting Polanyi [6], Nonaka suggested that knowledge could be classified as explicit and tacit [7]. Tacit knowledge represents knowledge based on the experience of individuals; it is the core resource in the hu
Tacit knowledge propagates through direct contact among individuals. This process exhibits characteristics that are similar to those of spreading epidemic. Therefore, tacit knowledge spreads among industrial enterprises mainly through the mobility of employees with tacit knowledge. The manner of controlling employee mobility effectively contributes to spreading tacit knowledge among industrial enterprises and has become a subject that is worthy of further research in KM. However, despite the number of previous KM studies, paucity exists in theoretical and quantitative research that investigates the influence of employee mobility on knowledge sharing and KM [4-8]. Networks have recently constituted a fundamental framework for analyzing and modeling complex systems [9]. Therefore, the present study performs analyses by applying the transmission dynamics method in networks and then combines such analyses with computer simulations from the perspective of theoretical and quantitative research to guide KM effectively, particularly tacit knowledge spreading. In Section 2, we describe the model and derive the threshold that governs whether tacit knowledge can spread between two industrial enterprises. In Section 3, numerical simulations are presented to support the results. We study the effects of the average degree of the knowledge exchange network in each industrial enterprise and employee mobility on tacit knowledge spreading. Finally, conclusions are drawn in Section 4.

2. Model with Employee Mobility

Tacit knowledge spreading among industrial enterprises can be considered the evolution of this knowledge in a specific knowledge exchange network. Tacit knowledge spreading depends on the characteristics of tacit knowledge and the topology of a network. Therefore, the employees of an organization and their contacts are regarded as an undirected network, which is also considered a knowledge exchange network. We view employees of industrial enterprises as a homogeneously mixed population that consists of individuals. Each employee is regarded as a node, and each contact between two employees is represented as an edge that connects their nodes in the knowledge network. Obviously, if an employee with tacit knowledge joins an organization, then the employees of that organization may acquire tacit knowledge through contact and communication with the aforementioned new employee. Thus, tacit knowledge transmission occurs among employees and among industrial enterprises.

Considering that tacit knowledge spreading considerably resembles epidemic spreading, we adopt the susceptible-infected-susceptible (SIS) epidemic model to study the spreading of tacit knowledge. The employees of an industrial enterprise are divided into two classes, namely, employees who have acquired tacit knowledge and employees without such knowledge. The adoption of people of new behavior that follows a logistic-like function exhibits characteristics similar to those of many diffusion processes [10]. Thus, the progress of tacit knowledge spreading can be summarized as follows. During the initial stage, only a small number of employees with tacit knowledge exist, and the remaining employees are without such knowledge. As employees with tacit knowledge begin to propagate their knowledge, the number of employees without such knowledge is rapidly reduced. This situation results in a sharp increase in the number of employees with tacit knowledge. As tacit knowledge spreads further, the number of employees with tacit knowledge reaches a peak. Finally, the number of employees with tacit knowledge remains stable at a certain value.

The two industrial enterprises with employee mobility are labeled as industrial enterprises 1 and 2. Therefore, we consider a system with state variables $I_i$ and $T_i$, which represent the number of employees without tacit knowledge and the number of employees with tacit knowledge, respectively, in organization $i$ ($i = 1, 2$). We consider that employees without tacit knowledge can acquire such knowledge through contact with an employee who has acquired such knowledge at rate $\beta_i$ in industrial enterprise $i$. We also regard the introduction and departure of employees. We suppose that $B_i$ is the number of newly-introduced employees in unit time and that employees resign at rate $\mu_i$ in industrial enterprise $i$. Employees with tacit knowledge forget this knowledge and become employees without tacit knowledge at rate $\gamma_i$ in industrial enterprise $i$. Employees who have acquired tacit knowledge in industrial enterprise $i$ leave the organization $j (j \neq i; i, j = 1, 2)$ at per capita rate $\sigma_i$. In this case, $\langle k \rangle_i$ denotes the average degree of the knowledge exchange network in industrial enterprise 1, whereas $\langle k \rangle_j$ denotes the average degree of the knowledge exchange network in industrial enterprise 2. The model can be described as follows:

$$
\begin{align*}
\frac{dI_i(t)}{dt} &= B_i - \mu_i I_i(t) - \beta_i \langle k \rangle_i \frac{T_i(t)}{N_i(t)} I_i(t) + \gamma_i T_i(t), \\
\frac{dI_j(t)}{dt} &= B_j - \mu_j I_j(t) - \beta_j \langle k \rangle_j \frac{T_j(t)}{N_j(t)} I_j(t) + \gamma_j T_j(t), \\
\frac{dT_i(t)}{dt} &= \beta_i \langle k \rangle_i \frac{T_i(t)}{N_i(t)} I_i(t) - (\mu_i + \gamma_i + \sigma_i) T_i(t) + \sigma_i T_i(t), \\
\frac{dT_j(t)}{dt} &= \beta_j \langle k \rangle_j \frac{T_j(t)}{N_j(t)} I_j(t) - (\mu_j + \gamma_j + \sigma_j) T_j(t) + \sigma_j T_j(t).
\end{align*}
$$

The density of employees who have acquired tacit knowledge and employees without tacit knowledge can be de
scribed in terms of \( i_t \) and \( i_{i_t \gamma} \), respectively. Moreover, we have obtained the following normalization condition:

\[
\begin{align*}
\frac{d i_t}{d t} &= b_t - \mu i_t(t) - \beta_t k_t i_t(t) i_{i_t \gamma}(t), \\
\frac{d i_{i_t \gamma}}{d t} &= b_{i_t \gamma} - \mu_{i_t \gamma} i_{i_t \gamma}(t) - \beta_{i_t \gamma} k_{i_t \gamma} i_t(t) i_{i_t \gamma}(t) + \gamma_{i_t \gamma} i_{i_t \gamma}(t), \\
\frac{d i_{i_t \gamma}}{d t} &= \beta_{i_t \gamma} k_t i_t(t) i_{i_t \gamma}(t) - \left( \mu_t + \gamma_t + \sigma_t \right) i_t(t) + \sigma_t i_{i_t \gamma}(t), \\
\frac{d i_{i_{i_t \gamma}}} {d t} &= \beta_{i_i \gamma} k_{i_t \gamma} i_t(t) i_{i_{i_t \gamma}}(t) - \left( \mu_{i_t \gamma} + \gamma_{i_t \gamma} + \sigma_{i_t \gamma} \right) i_{i_t \gamma}(t) + \sigma_{i_t \gamma} i_{i_{i_t \gamma}}(t) \\
\end{align*}
\tag{2}
\]

In this model, \( b_t = \frac{R_0}{N_t} \), \( b_{i_t \gamma} = \frac{R_0}{N_{i_t \gamma}} \). We calculate the expression of the threshold by applying the next-generation method [11]. Similar to the basic reproductive number [12], the number of secondary cases generated by a primary spreader is considered the threshold, which is a measure of the power of employees with tacit knowledge to attack an organization that is completely without such knowledge. Moreover, the equilibrium without tacit knowledge of the system (2) is \( P_0 = \begin{pmatrix} 0, 0, i_0^0, i_{i_0}^0 \end{pmatrix}^T \), where \( k = 0, 1, \ldots, n \).

We define

\[
F = \begin{bmatrix} \beta_t k_t i_t & 0 \\ 0 & \beta_{i_t \gamma} k_{i_t \gamma} \end{bmatrix}, \quad V = \begin{bmatrix} \sigma_t + \mu_t + \gamma_t & -\sigma_t \\ -\sigma_t & \sigma_t + \mu_{i_t \gamma} + \gamma_{i_t \gamma} \end{bmatrix}.
\]

Hence, the threshold for (1) is

\[
R_0 = \rho(FV^{-1}) = \frac{\beta_t k_t i_t(\gamma_t + \mu_t + \sigma_t) + \beta_{i_t \gamma} k_{i_t \gamma} i_t(\gamma_t + \mu_t + \sigma_t) + G}{2(\gamma_t + \mu_t + \sigma_t)(\gamma_{i_t \gamma} + \mu_{i_t \gamma} + \sigma_{i_t \gamma}) - \sigma_t \gamma_{i_t \gamma}},
\]

\[
G = \left[ \begin{bmatrix} \beta_t k_t i_t(\gamma_t + \mu_t + \sigma_t) - \beta_{i_t \gamma} k_{i_t \gamma} i_t(\gamma_t + \mu_t + \sigma_t) \end{bmatrix}^2 + 4(\beta_t k_t i_t)^2 \sigma_t \gamma_{i_t \gamma} \right]^{1/2}.
\]

In the preceding equations, \( \rho(FV^{-1}) \) represents the spectral radius of matrix \( FV^{-1} \). In addition, \( i_0^0 = \frac{R_0}{\mu_t} \), \( i_{i_0}^0 = \frac{R_0}{\mu_{i_t \gamma}} \).

If \( R_0 < 1 \), then equilibrium \( P_0 \) is asymptotically stable; otherwise, \( P_0 \) is unstable. Accordingly, the value of \( R_0 = 1 \) is the threshold that governs whether tacit knowledge can spread among employees between two industrial enterprises. If \( R_0 < 1 \), then knowledge spreading is terminated, and knowledge gradually disappears among employees in industrial enterprises. If \( R_0 > 1 \), then knowledge can spread among employees in industrial enterprises. The value of \( R_0 = 1 \) is the threshold, and it indicates that if the number of employees without tacit knowledge is less than 1, to whom knowledge is spread by an employee with such knowledge before he/she forgets this knowledge, then this knowledge advantage gradually disappears. By contrast, knowledge can spread among employees between two industrial enterprises.

If industrial enterprises apply a closed-end management strategy and employees are not mobile between industrial enterprises, then \( \sigma_i = \sigma_{i_t} = 0 \). Hence, full model (1) can be rewritten as the "single industrial enterprise" model given by

\[
\begin{align*}
\frac{d i_t(t)}{d t} &= B_t - \mu_i(t) i_t(t) - \beta_t k_t i_t(t) i_{i_t \gamma}(t), \\
\frac{d T_i(t)}{d t} &= \beta_t k_t i_t(t) i_{i_t \gamma}(t) - (\mu_i + \gamma_t) T_i(t), \\
\frac{d i_{i_t \gamma}(t)}{d t} &= \beta_{i_t \gamma} k_{i_t \gamma} i_t(t) i_{i_{i_t \gamma}}(t) - (\mu_{i_t \gamma} + \gamma_{i_t \gamma}) i_{i_{i_t \gamma}}(t) + \sigma_{i_t \gamma} i_{i_{i_t \gamma}}(t), \\
\end{align*}
\tag{3}
\]

We can obtain

\[
R_0 = \frac{\beta_t k_t i_t^0(\gamma_t + \mu_t + \sigma_t)}{\mu_t + \gamma_t}, \quad R_0 = \frac{\beta_{i_t \gamma} k_{i_t \gamma} i_{i_t \gamma}(t + \mu_{i_t \gamma} + \sigma_{i_t \gamma})}{\mu_{i_t \gamma} + \gamma_{i_t \gamma} + \sigma_{i_t \gamma}}.
\]

The value of \( R_0 = 1 \) (\( i = 1, 2 \)) is the threshold that governs whether tacit knowledge can spread in industrial enterprise \( i \). If \( R_0 < 1 \), then the spreading of knowledge is terminated, and knowledge gradually disappears in industrial enterprise \( i \). If \( R_0 > 1 \), then knowledge can spread in industrial enterprise \( i \).

If \( \sigma_i = 0 \), \( \sigma_{i_t} > 0 \), then \( R_0 = R_0^1 \),

when \( \beta_t k_t i_t^0(\gamma_t + \mu_t + \sigma_t) > \beta_{i_t \gamma} k_{i_t \gamma} i_{i_t \gamma}(\gamma_t + \mu_t + \sigma_t) \).

Moreover, when \( \beta_t k_t i_t^0(\gamma_t + \mu_t + \sigma_t) < \beta_{i_t \gamma} k_{i_t \gamma} i_{i_t \gamma}(\gamma_t + \mu_t + \sigma_t) \),

\[
R_0 = \frac{\beta_{i_t \gamma} k_{i_t \gamma} i_{i_t \gamma}(\gamma_t + \mu_t + \sigma_t)}{\gamma_t + \mu_t + \sigma_t} = R_0^2 \left( \mu_i + \gamma_i - \sigma_i \right) + \frac{\sigma_t \gamma_t}{\mu_t + \gamma_t + \sigma_t}.
\]

Similarly, if \( \sigma_i > 0 \), \( \sigma_{i_t} > 0 \), then \( R_0 = R_0^3 \left( \mu_i + \gamma_i - \sigma_i \right) \)

when \( \beta_t k_t i_t^0(\gamma_t + \mu_t + \sigma_t) > \beta_{i_t \gamma} k_{i_t \gamma} i_{i_t \gamma}(\gamma_t + \mu_t + \sigma_t) \).

When \( \beta_t k_t i_t^0(\gamma_t + \mu_t + \sigma_t) < \beta_{i_t \gamma} k_{i_t \gamma} i_{i_t \gamma}(\gamma_t + \mu_t + \sigma_t) \), \( R_0 = R_0^2 \).
In summary, promoting employee mobility appropriately and significantly influences the spread of tacit knowledge among employees between two industrial enterprises.

3. Simulations and applications of the model

We present numerical simulations to support the aforementioned obtained theoretical results. According to the rule of 150, an industrial enterprise must ensure that the total number of employees is less than 150 if doing so will result in efficient operation and will become an incubator of information and knowledge transmission [13-14]. If the number of employees is more than 150, then industrial enterprises are divided to contribute to KM efficiently. Therefore, we consider 100 to be the total number of employees in industrial enterprise 1 and 50 to be the total number of employees in industrial enterprise 2. That is, $N_1 = 100$, $N_2 = 50$. The most useful knowledge is within the grasp of a few people in an organization, and knowledge-spreading activities are uncommon. Thus, over half of knowledge assets are wasted because knowledge is not shared fully, which is common in small and medium-sized industrial firms [15]. Accordingly, the initial number of employees who have acquired tacit knowledge is assumed as 4 in industrial enterprise 1 and 1 in industrial enterprise 2.

That is $\theta_1 = 96$, $\theta_1^0 = 4$, $\theta_2 = 4$, $\theta_2^0 = 1$.

The previously selected number of employees with tacit knowledge and the number of employees without such knowledge vary at the initial time within a reasonable range. The range is independent of the obtained results. We suppose that the total number of employees in industrial enterprise 1 is twice that in industrial enterprise 2; hence, we consider $B_1 = 2B_2 = 0.02$, $\mu_1 = 2\mu_2 = 0.001$.

First, we select $\gamma_1 = \gamma_2 = 0.05$, $\beta_1 = \beta_2 = 0.01$, $2\sigma_1 = \sigma_2 = 0.1$, $\langle k \rangle_1 = 30$, and $\langle k \rangle_2 = 15$.

In this study, we use “day” as the unit of time. If the maximum number of contact of an employee is 30 per day in organization 1 and 15 per day in organization 2, then, $R_0 = 1.3158 > 1$. Figure 1 shows that the number of employees who have acquired tacit knowledge changes with time. The number of employees with such knowledge varies at the initial time within a reasonable range. The range is independent of the obtained results. We suppose that the total number of employees in industrial enterprise 1 is twice that in industrial enterprise 2; hence, we consider $B_1 = 2B_2 = 0.02$, $\mu_1 = 2\mu_2 = 0.001$.

Second, we consider $\langle k \rangle_1 = 20$, $\langle k \rangle_2 = 10$.

Then, $R_0 = 1.2583 > 1$. Figure 2 shows that the number of employees who have acquired tacit knowledge changes with time. The number of employees with such knowledge increases gradually with time, and tends to be stable at 121. That is, tacit knowledge can spread among employees and among the industrial enterprises. The results of the numerical simulations obviously coincide with the threshold value.

Next, we consider $\langle k \rangle_1 = 15$, $\langle k \rangle_2 = 5$.

Then, $R_0 = 0.6667 < 1$. Figure 3 shows that the number of employees who have acquired tacit knowledge changes with time. The number of the employees with such knowledge decreases gradually to 0, and knowledge gradually disappears among employees between two industrial enterprises. The results of the numerical simulations obviously coincide with the threshold value. Figures 1, 2, and 3 indicate that, the average degree of a knowledge exchange network in an organization significantly affects tacit knowledge spreading and KM effectiveness. The greater the average degree of a knowledge exchange network, the larger the threshold. If this knowledge can spread among employees between two industrial enterprises, that is, $R_0 > 1$, at the end of the knowledge spreading process, then the number of employees without this knowledge is reduced to zero. This result indicates that several employees who have acquired tacit knowledge have left the two industrial enterprises. We mainly analyze the final number of employees with tacit knowledge, which can be used to measure the influence of such knowledge. From Figures 2 and 3, we can determine that the greater the average degree of a knowledge exchange network, the higher the final number of employees with tacit knowledge.

Finally, we perform sensitivity analysis of the threshold in terms of parameters $\sigma_1$ and $\sigma_2$ to illustrate further the effects of employee mobility on tacit knowledge spreading and KM. Figure 4 clearly shows that $R_0$ increases as each parameter $(or)$ increases, whereas the influence of $s$ greater on than that of $f$. Figure 5 clearly indicates that the final number of employees with tacit knowledge increases as each parameter $(or)$ increases, whereas the influence of $s$ greater on the final number of employees with tacit knowledge than that of $f$. If we change the parameter values or the initial conditional values within a reasonable range, then conclusions of the sensitivity
analyses are roughly the same.

Figure 1. The total number of employees with tacit knowledge changes over time $t$ with $\langle k \rangle_1 = 30$, $\langle k \rangle_2 = 15$

Figure 2. The total number of employees with tacit knowledge changes over time $t$ with $\langle k \rangle_1 = 20$, $\langle k \rangle_2 = 10$

Figure 3. The total number of employees with tacit knowledge changes over time $t$ with $\langle k \rangle_1 = 15$, $\langle k \rangle_2 = 5$

Figure 4. The threshold $R_0$ in terms of parameters $\sigma_1$ and $\sigma_2$ with $\gamma_1 = \gamma_2 = 0.05$, $\beta_1 = \beta_2 = 0.01$, $\langle k \rangle_1 = 30$, $\langle k \rangle_2 = 15$.

Figure 5. The final size of employees with tacit knowledge in terms of parameters $\sigma_1$ and $\sigma_2$. 
4. Conclusion and future work

In a rapidly growing and competitive socio-economic environment, industrial enterprises are urged to encourage employees to spread and share tacit knowledge with other industrial enterprises. This knowledge sharing is regarded as the key to achieving competitive advantage and KM effectiveness. In this study, we analyzed the dynamics of tacit knowledge spreading among industrial enterprises by considering employee mobility. We provided the structure chart of the tacit knowledge spreading process to describe in detail how employees with such knowledge engaged with employees without tacit knowledge. Then, we study the spreading process of tacit knowledge among employees between two industrial enterprises. This study aims to model and simulate the tacit knowledge spreading process among industrial enterprises. Interesting outcomes were produced by this study. The contributions of this research are as follows. (1) The studied model of tacit knowledge spreading studied has considerable practical importance because mobility is a necessary factor that should be included. The simulations and analyses showed that appropriately encouraging employees with tacit knowledge to become mobile among industrial enterprises significantly influenced tacit knowledge spreading among employees between two industrial enterprises. (2) We proposed a tacit knowledge spreading model on networks based on the SIS epidemic model and derived the threshold that governed whether tacit knowledge could spread among employees between two industrial enterprises. Numerical simulations were presented to support the theoretical results. The results can guide KM of industrial enterprises from perspectives of theoretical and quantitative research with regard to theoretical and practical aspects. (3) This study regarded the employees of an organization and the contact among them as a knowledge exchange network and analyzed the effect of knowledge network topology on tacit knowledge spreading. The greater the average degree of a knowledge exchange network, the larger the threshold and the final number of employees with tacit knowledge.

The results offer new insights into tacit knowledge spreading; thoughts, emotions, and motivation involved in decision making; and KM and commodity business performance of industrial enterprises, among others. The team of Barabási determined that many social networks were scale-free, which followed the power-law degree distribution [16]. In the future, we will extend our research to scale-free networks, and the degree to which they will fit power-law distribution. Further investigation on tacit knowledge spreading models and the effect of such spreading on static networks will provide a new means to reveal the secrets of tacit knowledge spreading in KM of industrial enterprises.

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