Asian J. of Management Science and Applications

ISSN online: 2049-8691 - ISSN print: 2049-8683
https://www.inderscience.com/ajmsa

Modeling and simulation of organisational knowledge creation process with consideration of dialogue

Morihiko Iinuma, Naoki Shiba, Miyako Homma, Toshio Saito

DOI: 10.1504/AJMSA.2022.10051646

Article History:

Received:	19 April 2021
Last revised:	23 December 2021
Accepted:	23 December 2021
Published online:	03 November 2022

Modelling and simulation of organisational knowledge creation process with consideration of dialogue

Morihiko Iinuma* and Naoki Shiba

College of Industrial Technology,
Nihon University,
1-2-1 Izumi-cho, Narashino,
Chiba, 275-8575, Japan
Email: iinuma.morihiko@nihon-u.ac.jp
Email: shiba.naoki@nihon-u.ac.jp
*Corresponding author

Miyako Homma

Panasonic Advanced Technology Development Co., Ltd.,
600 Saedo-cho, Tsuzuki-ku, Yokohama,
Kanagawa, 224-8539, Japan
Email: homma.miyako@jp.panasonic.com

Toshio Saito

College of Industrial Technology,
Nihon University,
1-2-1 Izumi-cho, Narashino,
Chiba, 275-8575, Japan
Email: saitou.toshio@nihon-u.ac.jp

Abstract: In adaptation to a changing environment, innovation is essential for continuing existence of an organisation. Of the many approaches available for research on innovation, the present study performed by taking the perspective of knowledge management. The central point of discussion is organisational knowledge creation, where it was considered and modelled with basic recognition of the important role of dialogue between organisation members, a role comprising the two phases of knowledge creation at the individual level and diffusion of the created knowledge. Exploratory investigation by simulation on factors that affect organisational knowledge creation shows that a trade-off exists between knowledge creation at the individual level and diffusion of the created knowledge, and that skilful maintenance of the balance between them is a key task in knowledge management.

Keywords: knowledge management; organisational knowledge creation; individual knowledge creation; knowledge diffusion; innovation; agent-based simulation.

Reference to this paper should be made as follows: Iinuma, M., Shiba, N., Homma, M. and Saito, T. (2022) 'Modelling and simulation of organisational knowledge creation process with consideration of dialogue', *Asian J. Management Science and Applications*, Vol. 7, No. 1, pp.1–22.

Biographical notes: Morihiko Iinuma is an Associate Professor of Industrial Engineering and Management at the College of Industrial Technology, Nihon University, Chiba, Japan. He received his Bachelor degree and Master degree in Engineering from Nihon University, in 1988 and 1990. His research interests are organisational learning, knowledge management, organisational innovation, and systems approach (include soft systems approach). In particular, his recent research interest is in the simulation of organisational knowledge creation using agent-based models.

Naoki Shiba is a Professor of Industrial Engineering and Management, College of Industrial Technology, Nihon University, Chiba, Japan. He received his PhD in Systems Science from Tokyo Institute of Technology in 1993. He joined Nihon University in 2007. His areas of research interests include information systems, decision support systems, game theory, and systems theory. His major research interest of recent years is in the methodology of social simulation research using agent-based models.

Miyako Homma is a Systems Engineer at Panasonic Advanced Technology Development Co., Ltd. She received her Bachelor degree and Master degree in Engineering from Nihon University, in 2013 and 2015. Her research interests are knowledge management and agent-based simulation.

Toshio Saito was a Professor in the Department of Industrial Engineering and Management, College of Industrial Technology, Nihon University, Chiba Japan. He received PhD in Systems Science in 1988 from Tokyo Institute of Technology, Tokyo Japan. His research interest is in the area of systems theory and its application to complex problems in management information systems and organisational sciences.

1 Introduction

In an operating environment undergoing extreme change, continuing the existence of an organisation requires continuous innovation. Within the perspective of knowledge management, one factor at the core of innovation is organisational knowledge creation (Nonaka and Takeuchi, 1995). The purpose of the present study is to investigate the conditions that enable the organisational knowledge creation that is the base of innovation, using an agent-based model.

This study assumes that, as noted by Nonaka and Takeuchi (1995), dialogue between experts plays a major role in organisational knowledge creation. The two basic types of inter-expert dialogues are those between organisation members and those with outside experts. In the present study, we focus especially on the former, modelling the organisational knowledge creation process through dialogue and investigating the logic related to the possibility of organisational knowledge creation triggered by dialogue.

Many types of knowledge are shared between members, and knowledge can be created through member interaction; then, that knowledge can be jointly held and can engender organisational knowledge creation. This, in other words, is a model of the concept of an organisation that engenders innovation. Many model types have been proposed that explain conceptually the mechanisms of knowledge transfer, sharing and creation processes, and well capture and describe the circumstances in organisations that successfully innovate (see, e.g., Boisot, 1995; Nonaka and Takeuchi, 1995). However, these models are at the conceptual level and do not include operational models that visibly show the dynamics of the knowledge transfer, sharing and creation processes.

In the present study, the necessary conditions for generation of innovation are considered to be a continuous cycle of organisational knowledge creation, development and decay that repeats, progresses and advances, thus thought of as sustained metabolism and dynamic changes in organisational knowledge. With this premise, we represent the organisational knowledge dynamics from two perspectives. One is a micro perspective focused on the organisation members who bear the knowledge, on the dialogue between the organisation members, and on formalisation of the knowledge transfer and creation process as an operational model. The other perspective is a macro perspective capturing the results of the model implementation, focused on temporal change in dominant knowledge in the organisation, and expressing the dynamics of organisational knowledge. In short, we express in an 'abstract model' (Gilbert, 2008) the process in which dialogue between organisation members gives rise to opportunity for knowledge transfer leading to knowledge creation, and on that basis actually implement and investigate a simulation of the kind of conditions under which knowledge is created, transferred and shared, and becomes organisational knowledge. In that process, rather than a transition in individual knowledge sets held by members, we capture comprehensively in the macro perspective the organisation member groups with multiple knowledge sets diffused through and coexisting in the organisation, and advance the investigation by observing the dynamic changes.

This study is structured essentially as follows. Section 2 concerns related research organised into the two domains of knowledge management and simulation, and presents the perspective of the present study. Section 3 describes the basic concept of the model proposed in this study for knowledge transfer and organisational knowledge creation through dialogue. Section 4 formularises the model derived from the concept described in Section 3. Section 5 investigates the results of simulation of the constructed model, and Section 6 discusses the interrelationship of the simulation results and reveals the factors affecting the organisational knowledge creation from the perspective of the proposed model.

2 Related studies and position of this study

The fundamental interest of this study is in constructing a model that expresses the dynamics of organisational knowledge and elucidating in an exploratory manner the factors that affect organisational knowledge creation. In this section, we therefore survey the prior studies on the two domains of organisational knowledge creation, first addressing conceptual models relating to knowledge creation presented in the knowledge management domain to elucidate the key concepts of organisational knowledge creation, and next addressing simulation researches that have implications for modelling of organisational knowledge creation, from which we note the matters of central interest and consider their limits.

2.1 Model of organisational knowledge creation in knowledge management

As noted by Lloria (2008), approaches to research on knowledge management can be divided into the three categories of intellectual capital model, knowledge creating model and knowledge management model. The basic interest of the present study is dynamics of organisational knowledge, including organisational knowledge creation, and among these approaches the most strongly related is that of the knowledge creating model. Prominent studies on the knowledge creating model include those of Nonaka and Takeuchi (1995) and Boisot (1995), which illuminated the knowledge creation process based on that model.

Nonaka and Takeuchi (1995) proposed the SECI model as a model of organisational knowledge creation that comprises the four modes of knowledge conversion, that is, socialisation, externalisation, combination and internalisation, based on the premise that organisational knowledge is created from social interaction between tacit knowledge and explicit knowledge. By further incorporating the time dimension, the SECI model can be expressed as a five-phase model, which is an ideal model of organisational knowledge creation process. The five-phase model comprises sharing tacit knowledge, creating concepts, justifying concepts, building an archetype and cross-levelling knowledge by which a new cycle of knowledge creation begins.

Boisot (1995) applied the social learning cycle called the information space (I-Space) model to explicate the course of organisational knowledge creation, development and justification. This cycle comprises the six phases of scanning, problem-solving, abstraction, diffusion, absorption and impacting, with each phase positioned in a space having the three dimensions of abstract-concrete, undiffused-diffused and uncodified-codified, and expression of activities on changes in knowledge that extends from outside information acquisition to newly diffused knowledge.

The SECI model and the I-Space model differ in expression of activities involving organisational knowledge creation but also share major commonalities. They focus on knowledge itself and construct organisational knowledge creation models by modelling the activities that influence changes in its qualities and states, and they assume that creation of organisational knowledge is realised through organisational sharing of knowledge held at the individual level. Related to these points, Nonaka and Takeuchi (1995, p.59) noted that: "Organizational knowledge creation, therefore, should be understood as a process that 'organisationally' amplifies the knowledge created by individuals and crystallises it as a part of the knowledge network of organisation. This process takes place within an expanding 'community of interaction'". This interpretation is held to represent the essence of organisational knowledge creation, which in the present study is taken to be as follows.

1. dialogue between organisation members is considered important, as organisational knowledge creation is a phenomenon that occurs in a community of interaction
2. organisational knowledge creation comprises the two phases of knowledge creation at the individual level, and transfer and diffusion of that knowledge, as it is a process of organisational amplification of knowledge created by individuals.

2.2 Knowledge diffusion models and knowledge creation models

Next surveyed are studies that have used agent-based simulation relating to the two phases of organisational knowledge creation. Little research on knowledge creation at the individual level has been found, but there have been many studies on knowledge diffusion. Furthermore, we will point out the problems or the limits of these studies from the perspective of organisational knowledge creation in the present study described in the previous sub section.

Morone and Taylor (2004) utilised cellular automata to incorporate into a model changes in structure of a network composed by agents and investigated how knowledge diffused in a network in which the agents interact by word of mouth; the results showed that differences in initial knowledge provided to each agent affect knowledge diffusion. This model assumes that transfer of knowledge is dependent on difference between agents in level of knowledge.

Jang et al. (2019) modelled knowledge diffusion in a network structure without utilising cellular automata, with a combination of a genetic algorithm and an agent-based model, for the study of the co-evolutionary dynamics of knowledge diffusion and network structure. It is assumed in this model that knowledge diffusion is generated by the agent network. For particularly effective knowledge transfer, it is characterised by modelling with consideration given to the knowledge distance between two agents, and thus difference in knowledge holding.

Liu et al. (2017) proposed a knowledge diffusion model for dynamical networks that takes into consideration interaction frequency. This model is unique in the sense that knowledge exchange is not based on knowledge distance, but on interaction frequency. They explored the coevolution of knowledge diffusion and dynamical networks.

In expression of knowledge diffusion, Morone and Taylor (2004), Jang et al. (2019) and Liu et al. (2017) incorporated modelling with interaction between agents taken as network structure, but it may be noted that relatively little consideration is given to organisational factors. Furthermore, from the perspective of organisational knowledge creation in the present study, knowledge creation at the individual level and the diffusion of that knowledge are not taken into consideration.

Kowalska-Styczen et al. (2018) built on the existing research on knowledge diffusion and agent network structure to propose a model of knowledge transfer within organisation based on cellular automata. In this model, agents are organisation members having a given initial amount of common knowledge resulting from organisation's activities and further, a leader of knowledge and a follower are distinguished by differences in amount and quality of knowledge chunks, from which it may be taken that consideration is given to organisational factors that affect the manner of knowledge transfer. Viewed from the perspective of organisational knowledge creation in the present study, knowledge creation at the individual level and the diffusion of that knowledge are not taken into consideration.

Tur and Azagra-Caro (2018) model knowledge creation based on the idea that knowledge is a cumulative process and that new knowledge is created from the accumulation of knowledge. In other words, knowledge is accumulated as a result of interactions between agents, and knowledge creation is represented by calculating how much knowledge is created from that stock of knowledge. It is suggestive that this model views organisational creation at the individual level as a result of knowledge accumulation. This is because it clarifies the mechanism of knowledge creation at the individual level, which is one of the aspects of organisational knowledge creation in the present study. However, it considers created knowledge merely as a quantitative form of individual knowledge, and does not model the diffusion of created knowledge nor does its development into organisational knowledge.

Habib (2008) is noteworthy as a study that modelled knowledge diffusion and knowledge creation in organisations, with a case-study analysis using the Boisot I-Space model as a framework. Based on the findings obtained there, Habib (2008) proposed an agent-based model expressing the dynamics of knowledge creation. In this model, interactions between agents involved in knowledge transfer are incorporated in both formal and informal interaction into the model, and in light of its consideration of agent influence, communication capability and other properties it can be considered more representative of an organisational model. Applying the network theory, knowledge is expressed as a concept-linking network. Knowledge transfer is assumed to be performed in interaction between agents, and interaction is performed in formal or informal meeting. In interaction, moreover, a link between the concepts of the knowledge expressed in the network is transferred. Knowledge creation is expressed by generation of strongly connected components. In this model, the aspect of knowledge creation at the individual level through knowledge transfer is modelled. However, in the perspective of organisational knowledge creation, it is not modelled that the created knowledge is transferred and shared to become organisational knowledge.

3 Model concept

With the ideas of Nonaka and Takeuchi (1995); Boisot (1995) taken into consideration, the present study models the process of knowledge transfer and creation at the individual level through dialogue, as well as organisational knowledge creation by sharing created knowledge. Therefore, the model is different from those in previous studies on knowledge diffusion (Morone and Taylor, 2004; Jang et al., 2019; Kowalska-Styczen et al., 2018; Liu et al., 2017) and from those in previous studies on knowledge creation (Habib, 2008; Tur and Azagra-Caro, 2018). In this section, we describe the organisational characteristics considered in the modelling (Section 3.1), the concepts related to agent-based modelling in the present study (Section 3.2), and the concepts used to represent the knowledge dynamism in the organisation (Section 3.3).

3.1 Organisational characteristics

In the present study, an organisation is modelled under the assumptions that its constituent members are knowledgeable in multiple areas. In other words, it is an organisation such as a development division. We construct an abstract model relating to organisational knowledge transfer and creation in an organisation of this type. Its organisational features in brief are as follows.

1 New members regularly enter and members who have belonged for a certain period withdraw. At a firm, this would be equivalent to entry on employment and resignation on retirement.

2 Organisation members each hold knowledge in multiple areas and act with individual behavioural characteristics.

3 Knowledge transfer is performed in dialogues between the organisation members, and although a quite uncommon occurrence, a new area of knowledge is created by chance in the dialogue between the members with a wealth of existing knowledge. This is based on the idea that knowledge creation is the result of knowledge accumulation (Tur and Azagra-Caro, 2018)

4 The new area of knowledge, like previously existing knowledge, is diffused through the organisation by dialogue between members.

5 The existence of members who find and support the value of the new area of knowledge strongly affects its diffusion. These intra-organisational backers are equivalent to early adopters who play the major role in innovation diffusion described by Rogers (2003).

Through the concepts described in 3 and 4 above, knowledge creation at the individual level that is considered a requirement for organisational knowledge creation, and the organisational knowledge creation induced by transfer and sharing knowledge created at the individual level are modelled.

3.2 Mapping to agent-based model

Kowalska-Styczen et al. (2018) used two-dimensional (2D) cellular automata to model knowledge transfer, but they did not consider the movement of agents in space, and each agent interacts only with agents in the von Neumann neighbourhood, so the interaction partners were fixed and restricted. In the present study, unlike Kowalska-Styczen et al. (2018), on the cell space, we incorporated the movement of agents to make the diversity of interactions (dialogue with various partners) more realistic. Organisational characteristics such as the behaviour of agents placed on two-dimensional (2D) grid of cells are mapped as follows:

1 Organisation members are agents that can move freely in the cell spaces.

2 The characteristics, knowledge and capabilities held by the organisation members are expressed as internal states of the agents.

3 Actions of organisation members are expressed as the movement of agents in the cell space and chance encounters with other agents.

4 Dialogue between organisation members emerges from chance encounters between agents, and brings the opportunity that leads to knowledge transfer and individual level knowledge creation.

5 Backers of knowledge created at the individual level are engendered in a certain proportion. These agents transfer the created knowledge with priority.

From the conditions for dialogue occurrence described in 3 and 4 above, the organisation members can take the cell space as a place to perform informal dialogue.

3.3 Knowledge categories and knowledge groups

In the present study, it is assumed that organisational members have knowledge in multiple fields, and that knowledge in each field is composed of multiple elemental knowledge. These knowledge fields are modelled as three knowledge categories, and for the purpose of examining organisational knowledge creation, two of the three are considered as categories of existing knowledge and one of them as a category of newly created knowledge.

As a way of expressing intra-organisational knowledge dynamics, let us incorporate the concept of the knowledge group, which is a collection of agents holding some amount or more of elemental knowledge in a certain knowledge category. As one instance, agents who hold some amount or more of elemental knowledge in knowledge category 1 are identified as members of knowledge group 1. Agents who possess more than a certain amount of elemental knowledge in a certain knowledge category can be considered as experts in that field, so a knowledge group with a large number of members means that there are many experts in that field, which is a dominant field in the organisation. On the basis of this concept, the relative superiority or inferiority of knowledge in an organisation can be measured by the number of members constituting the associated knowledge group, and an agent having a certain amount or more of elemental knowledge in two or more knowledge categories is then a member of two or more knowledge groups.

In the present study, the number of knowledge group members is focused on in order to observe the diffusion of created knowledge, which is one aspect of organisational knowledge creation, and also the diffusion of existing knowledge.

4 Model formalisation

Here we formalise the model based on the concepts described in the previous section, with $A = \{1, 2, 3, \ldots, P_A\}$ and $I = \{P_A + 1, P_A + 2, P_A + 3, \ldots, P_A + P_I\}$ as collections of active and inactive agents, respectively, and P_A and P_I representing the populations of active and inactive agents, respectively. Then the parameter of the ratio of P_A to the total population is defined as

$$\lambda = \frac{P_A}{P_A + P_I} \tag{1}$$

where $0 \le \lambda \le 1$.

Each agent is placed at initial time $t = 0$ in a 2D square grid of size $m \times m$ at random without repeated placement in the same cell. The 2D grid, as in many models, takes the form of a torus with both the east and west ends, and the north and south ends linked.

4.1 Agent state variables

Agent $i \in \{1, 2, \ldots, P_A + P_I\}$ at discrete time $t \in \{0, 1, 2, \ldots\}$ is in the state

$$c_i(t) = \left(a_i(t), K_i(t), b_i(t)\right), \tag{2}$$

where $a_i(t)$ represents the agent's age, and at each discrete time $t \in \{0, 1, 2, \ldots\}$, $a_i(t) \in \{0, 1, 2, \ldots, 29\}$, $K_i(t)$ represents the agent's knowledge profile at time t, and $K_i(t)$ is the 3 × 5 dimensional matrix constituted by the variable $\delta_{ce}(t)$ taking the value 0 or 1, i.e.,

$$K_i(t) = \begin{pmatrix} \delta_{11}(t) & \delta_{12}(t) & \delta_{13}(t) & \delta_{14}(t) & \delta_{15}(t) \\ \delta_{21}(t) & \delta_{22}(t) & \delta_{23}(t) & \delta_{24}(t) & \delta_{25}(t) \\ \delta_{31}(t) & \delta_{32}(t) & \delta_{33}(t) & \delta_{34}(t) & \delta_{35}(t) \end{pmatrix}, \tag{3}$$

and each $\delta_{ce}(t)$ represents knowledge category $c \in \{1, 2, 3\}$ at time t with or without the presence of elemental knowledge $e \in \{1, 2, 3, 4, 5\}$ as

$$\delta_{ce}(t) = \begin{cases} 1, & c \text{ with presence of element } e \\ 0, & c \text{ without presence of element } e. \end{cases} \tag{4}$$

Each of the two $K_i(t)$ row vectors

$$\begin{aligned} K_i^{(1)}(t) &= \left(\delta_{11}(t), \delta_{12}(t), \delta_{13}, \delta_{14}(t), \delta_{15}(t)\right) \\ K_i^{(2)}(t) &= \left(\delta_{21}(t), \delta_{22}(t), \delta_{23}, \delta_{24}(t), \delta_{25}(t)\right) \end{aligned} \tag{5}$$

represents the knowledge profile of one of the two different categories held by the organisation from the initial time, and

$$K_i^{(3)}(t) = \left(\delta_{31}(t), \delta_{32}(t), \delta_{33}, \delta_{34}(t), \delta_{35}(t)\right) \tag{6}$$

represents the new knowledge profile engendered by knowledge creation.

In the following, the knowledge sum of the category c knowledge bits held by agent i at time t is represented by $KS_i^{(c)}(t)$:

$$KS_i^{(c)}(t) = \sum_{e=1}^{5} \delta_{ce}(t). \tag{7}$$

Further, the knowledge sum held by agent i at time t is represented by $KS_i(t)$ as the sum of knowledge bits in all categories at that time:

$$KS_i(t) = KS_i^{(1)}(t) + KS_i^{(2)}(t) + KS_i^{(3)}(t). \tag{8}$$

The binary variable $b_i(t)$ represents whether each agent is a backer of the new knowledge (new knowledge backing property) at time t:

$$b_i(t) = \begin{cases} 1, & \text{if } i \text{ is a backer} \\ 0, & \text{if } i \text{ is not a backer} \end{cases} \tag{9}$$

where $b_i(t)$ does not change until a change in agent generation (see below).

4.2 Initial value of state variables

The initial value $a_i(0)$ of the age of agent $i \in \{1, 2, \ldots, P_A + P_I\}$ will be

$$a_i(0) = i \bmod 30. \tag{10}$$

Thus, the age will be the remainder from integer division of each agent index i by 30. If $P_A + P_I$ is set sufficiently large, then at time $t = 0$, each age will have approximately the same number of agents.

The initial value $K_i(0)$ of the knowledge profile of agent i is

$$K_i(0) = \begin{pmatrix} 1 & \delta_{12} & \delta_{13} & \delta_{14} & \delta_{15} \\ 1 & \delta_{22} & \delta_{23} & \delta_{24} & \delta_{25} \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix}, \tag{11}$$

and the value of each δ_{ce} ($c = 1, 2$, $e = 2, 3, 4, 5$) independently follows a uniform distribution on the set $\{0, 1\}$. Thus, the initial value of the knowledge profile of categories 1 and 2 will be $\delta_{11} = \delta_{21} = 1$ and otherwise will be a random variable of value 0 or 1 (representing presence or absence of each elemental knowledge) varying with the same probability of 1/2.

The initial value $b_i(0)$ of the new knowledge backing property of agent i will be 1 as a random variable with the probability of parameter ε:

$$\Pr\left(b_i(0) = 1\right) = \varepsilon \qquad (0 \leq \varepsilon \leq 1). \tag{12}$$

4.3 Dynamics of state variable

An agent ages by 1 every 4 steps, but when the age reaches 30, the generation changes and the age therefore becomes 0. Thus,

$$a_i(t+1) = \begin{cases} \left(a_i(t)+1\right) \bmod 30, & \text{if } t \bmod 4 = 3 \\ a_i(t), & \text{otherwise.} \end{cases} \tag{13}$$

Each agent $i \in A \cup I$ at each time t moves to a cell in the Moore neighbourhood unoccupied by another agent and after moving will at random select another agent $j \in (A \cup I) \,/\, \{i\}$ present in a cell in the Moore neighbourhood and in accordance with the combination of individual behavioural characteristics (active/inactive) perform dialogue with the appropriate following probability.

1 if i, j both are active ($i, j \in A$), then probability 1

2 if i is active and j is inactive ($i \in A$ and $j \in I$), then probability 1/2

3 if i is inactive and j is active ($i \in I$ and $j \in A$) then probability 1/2.

4 If i, j are both inactive ($i, j \in I$) then probability 0.

If dialogue between i and j commences at time t, then in accordance with characteristics (active/inactive) and knowledge profile of each, knowledge transfer or creation of the following nature will occur.

1 If i, j are both active ($i, j \in A$), then

- Case 1: if the total knowledge amount of one is larger than that of the other by 2 or more, then if the total knowledge amount of i is larger ($KS_i(t) - KS_j(t) \geq 2$), knowledge transfer will be from i to j and the knowledge profile $K_j(t)$ of j will change (see below), and similarly if the total knowledge amount of j is larger.

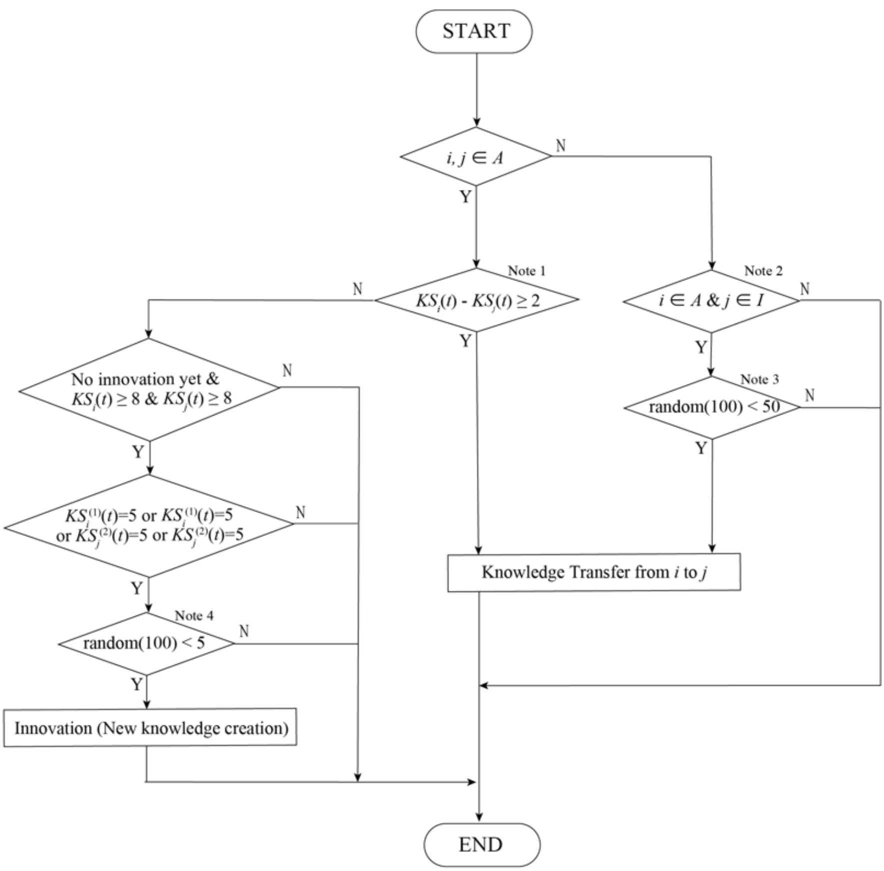
- Case 2: if no knowledge creation has as yet occurred and the total knowledge amount of each of the two agents is 8 or more ($KS_i(t) \geq 8$ and $KS_j(t) \geq 8$), then if in the existing knowledge categories of either or both in at least 1 category all of the knowledge is present($KS_i^{(1)}(t)$ =5 or $KS_i^{(2)}(t)$ =5 or $KS_j^{(1)}(t)$ = 5 or $KS_j^{(2)}(t)$ = 5), with 5% probability new knowledge creation will occur and for both i, j the knowledge profiles $K_i(t)$, $K_j(t)$ will change (see below).

2 If one is active and the other inactive ($i \in A$ and $j \in I$ in the following, similarly in reverse).

With probability 1/2, knowledge transfer from i to j occurs, and for j the knowledge profile $K_j(t)$ changes (see below).

Figure 1 shows a flow chart interaction between two agents in detail.

Figure 1 Flowchart of interaction between agent *i* and *j*



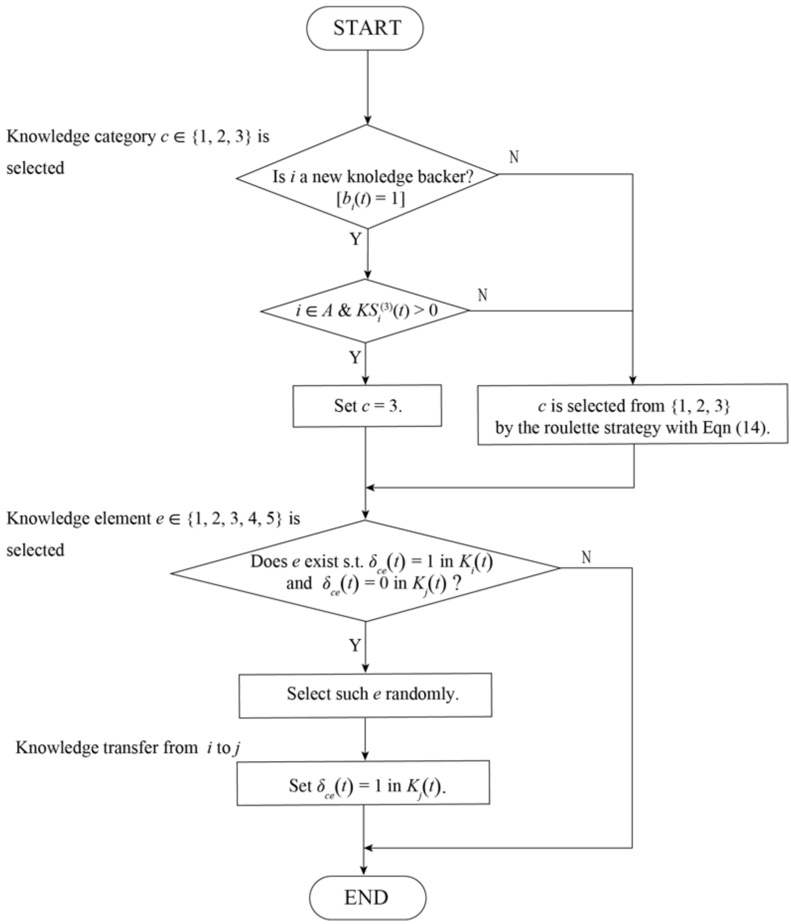
Note 1) In the case $KS_j(t)$ - $KS_i(t) \geq 2$ in the following, similarly in reverse.

Note 2) In the case $i \in I$ & $j \in A$ in the following, similarly in reverse.

Note 3, 4) "random(100)" generates a non-negative random integer less than 100. Therefore, *i* and *j* perform dialog (knowledge transfer or innovation) with the certain probability (1/2 or 5%, respectively).

We next describe in more detail the changes induced in knowledge profile by knowledge transfer and creation.

Figure 2 Flowchart of knowledge transfer from agent i to j



4.4 *Changes in knowledge profile engendered by knowledge transfer*

If knowledge transfer from agent i to agent j occurs at time t, then 1 bit selected by the following rule from the knowledge profile $K_i(t)$ of i is added to j, whereas the knowledge profile $K_i(t)$ of i does not change. The knowledge profile $K_j(t)$ of j before the transfer changes to $K'_j(t)$. The knowledge category $c \in \{1, 2, 3\}$ engendered by the knowledge transfer is determined by the following rule.

1 If agent i with new knowledge backer ($b_i(t) = 1$) is active ($i \in A$) and i's category 3 knowledge exists ($KS_i^{(3)}(t) > 0$), then $c = 3$ is selected.

2 At other times:

Stochastic selection by the roulette strategy is applied to the total amount of knowledge of each category of i. The probability $\Pr(c)$ of selection of knowledge in category $c \in \{1, 2, 3\}$ is thus

$$\Pr(c) = \frac{KS_i^{(c)}(t)}{KS_i(t)}. \tag{14}$$

Of the knowledge bits of category c selected by the above rule, from among the knowledge bits held by i but not by j, 1 bit is selected at random. Thus, if elements e exist such that selection of element $e \in \{1, 2, 3, 4, 5\}$ in the knowledge profile $K_i(t)$ of i is $\delta_{ce}(t) = 1$ and in knowledge profile $K_j(t)$ of j is $\delta_{ce}(t) = 0$, then one such e will be selected randomly. If no such element e exists (thus, if j already holds all elements held by i of the category c selected at random by roulette strategy), no knowledge transfer will occur.

Figure 2 shows a flow chart of knowledge transfer from one agent to another in detail.

4.5 Changes in knowledge profile engendered by knowledge creation

The agent i and j's knowledge profiles $K_i(t)$ and $K_j(t)$ become $K_i'(t)$ and $K_j'(t)$, respectively, after knowledge creation. Because knowledge creation in both by their interaction, as described above, occurs if knowledge creation has not previously occurred, the category 3 knowledge bits of both are 0 before knowledge creation. Thus, the knowledge profiles of i and j are both

$$K_l^{(3)} = (0, 0, 0, 0, 0) \qquad l = i,\ j, \tag{15}$$

and by the knowledge creation, these are then

$$K_l'^{(3)} = (1, 1, 1, 1, 1) \qquad l = i,\ j. \tag{16}$$

Thus, all bits are placed in new knowledge for both agents in category 3, which at the initial time was not held by the organisation.

At time t, all agents performed the above dialogue and as a result of the change in $K_i(t)$ for each agent i, the knowledge profile is then $K_i(t+1)$ in the next step.

4.6 State variables setting at generation change

As described above, each agent on reaching the age of 30 receives the initial age setting of 0. Thus, if agent $i \in A \cup I$ is age $a_i(t) = 29$ at time t and $t \bmod 4 = 3$, the age then becomes $a_i(t+1) = 0$, and in addition the knowledge profile and new knowledge backing property are then reset to

$$K_i(t+1) = \begin{pmatrix} \delta_{11} & \delta_{12} & \delta_{13} & \delta_{14} & \delta_{15} \\ \delta_{21} & \delta_{22} & \delta_{23} & \delta_{24} & \delta_{25} \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix} \tag{17}$$

but each δ_{ce} ($c = 1, 2, e = 1, \ldots, 5$) is then converted to 1 as a random variable with the probability of parameter κ:

$$\Pr(\delta_{ce} = 1) = \kappa \qquad (0 \le \kappa \le 1). \tag{18}$$

The agent new knowledge backing property $b_i(t + 1)$, by the same method as for the initial value, is reset at the time of agent generation change. Thus, the value of $b_i(t + 1)$ is reset in accordance with probability parameter ε:

$$\Pr(b_i(t+1) = 1) = \varepsilon \qquad (0 \le \varepsilon \le 1). \tag{19}$$

4.7 Definition of knowledge groups

As described in Section 3.3, the concept of knowledge groups is introduced to express intra-organisational knowledge dynamics. A knowledge group $KG_c(t)$ for each knowledge category c ($c = 1, 2, 3$) at the time t is defined as the set of agent $i \in \{1, 2, \ldots, P_A + P_I\}$ which has σ ($\sigma = 0, 1, \ldots, 5$) bits of elements or more in knowledge category c, that is,

$$KG_c(t) = \left\{ i \,\middle|\, i \in \{1, 2, \ldots, P_A + P_I\} \text{ and } KS_i^{(c)}(t) \ge \sigma \right\}. \tag{20}$$

σ is a parameter which denotes the threshold of knowledge amount. As described in the next section, σ will be set to four throughout the simulations. Therefore, $KG_c(t)$ is the set of agents which have four or five elements of category c at the time t.

5 Simulations

To verify the behaviour of the model constructed in the present study, we first perform the following basic model simulation. By changing the parameters on the basis of the results of the simulation with this model, we obtain exploratory elucidation of the factors relating to organisational knowledge creation. In the simulation, we consider the two organisational knowledge creation phases, knowledge creation at the individual level and diffusion of the created knowledge. As was mentioned in the previous section, we defined that the knowledge group is a collection of agents holding some amount or more of knowledge in a certain knowledge category. In this simulation, we assume that ‘some amount’ should be four because an agent with four bits of five, i.e. 80% of knowledge in a certain knowledge category, has sufficient knowledge with respect to the category. Therefore, an agent with four bits or more in a certain knowledge category becomes a member of the knowledge group of the category.

5.1 Model setting 1: basic model simulation

5.1.1 Simulation purpose and parameter setting

In this section, the analysis will be divided into individual level knowledge creation phase and knowledge diffusion phase. For the former, for each ε, we investigate the mean value, standard deviation, and maximum and minimum values of the agent number in knowledge group 3 at the completion time of the simulation, as well as the number of cases of knowledge non-creation at the individual knowledge creation. For the latter, the average number of agents in each knowledge group at each ε is compared. From these, the characteristics of the basic model in organisational knowledge creation will be ascertained.

The following parameter settings were used in 100 iterations of 240-step simulations:

- $P_A + P_I = 120$
- $\lambda = 0.5$
- $m = 20$
- $\varepsilon = 0, 0.1, 0.2, 0.3, 0.4$
- $\kappa = 0$.

5.1.2 Simulation results

5.1.2.1 Individual level knowledge creation phase

Table 1 shows the results for the knowledge creation phase on the individual level, for each ε, in terms of the mean, standard deviation, minimum and maximum agent number in knowledge group 3 (agent group with 4 bits or more of newly created knowledge) at the time of simulation completion, and the number of non-creation occurrences (the number of simulation paths in 100 iterations with no knowledge group 3 members).

Table 1 State of knowledge group 3

ε	*Mean*	*SD*	*Min*	*Max*	*Non-creation occurrences*
0.0	6.2	8.3	0	43	15
0.1	34.2	27.9	0	98	15
0.2	62.9	34.3	0	105	15
0.3	78.4	38.7	0	113	15
0.4	88.4	39.4	0	115	15

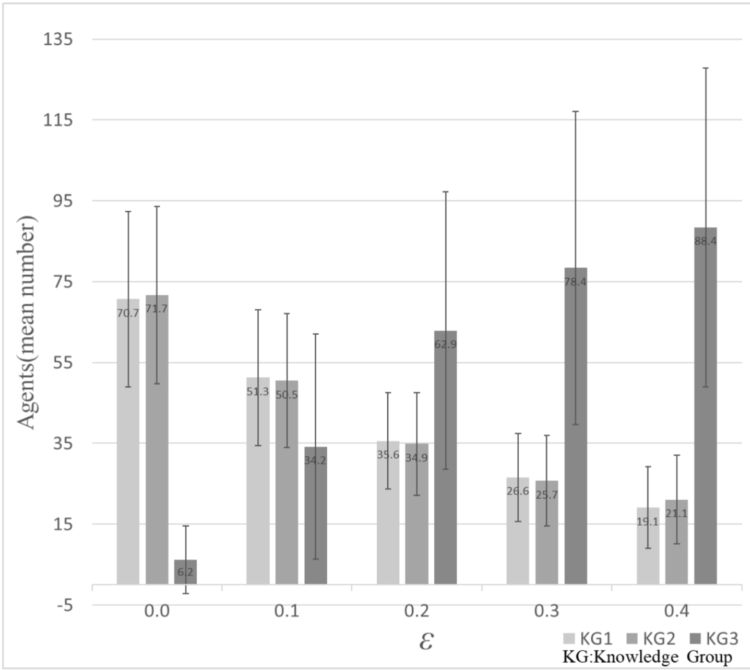
These results thus show that knowledge non-creation occurred at a rate of 15% and that this rate occurred uniformly regardless of the value of ε. In the basic model, these results may be attributable to the participation of newly added agents wholly lacking existing knowledge in the organisation during the simulation. In other words, it shows that agents in the initial state held existing knowledge but alone that may be insufficient to preclude occurrence of knowledge non-creation, and that the state of existing knowledge possession by new agents may affect knowledge creation at the individual level.

5.1.2.2 Knowledge diffusion phase

Figure 3 shows the mean number of agents in each knowledge group for each ε at the time of simulation completion. If organisational knowledge creation can be defined as newly created knowledge becoming the superior knowledge in an organisation, these results show that in the absence of any backer ($\varepsilon = 0$), newly created knowledge can only remain in the minority. A tendency for knowledge to be superior at a backer rate of 10%

to 20% was also observable. Thus, it is clear that for organisational knowledge creation, a certain minimum ratio of backers is necessary in the knowledge diffusion phase.

Figure 3 Mean agent number in each knowledge



5.2 *Model setting 2: simulation on knowledge creation phase at individual level*

5.2.1 *Simulation purpose and conditions*

This simulation was performed to address the individual level knowledge creation phase problem of occurrence of the phenomenon of a knowledge non-creation at a rate of 15% shown by the basic model. More specifically, as one of the factors involved in individual level knowledge creation, the rate of new-agent holding of knowledge relating to existing knowledge was varied and the number of knowledge non-creation occurrences was investigated to determine the relation to knowledge creation at the individual level.

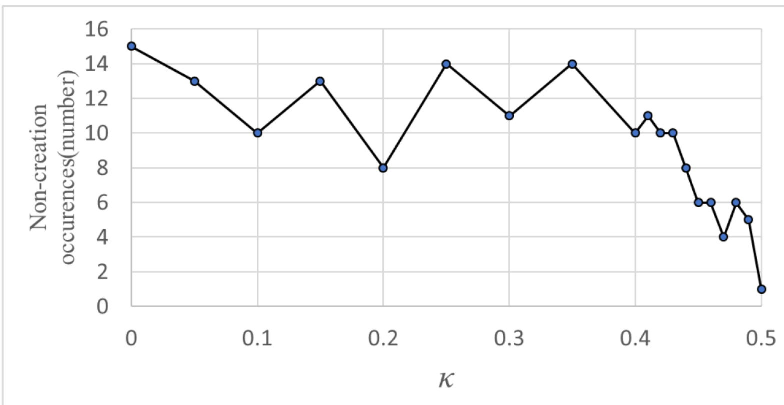
The following parameter settings were used in 100 iterations of 240-step simulations:

- $P_A + P_I = 120$
- $\lambda = 0.5$
- $m = 20$
- $\varepsilon = 0.2$ (ε selection random, in light of basic model simulation showing no effect of ε on number of knowledge non-creation occurrences)
- $\kappa = 0.0$, 0.1, 0.2, 0.3, and 0.4 to 0.5 in increments of 0.01 (where the increment setting of 0.01 for 0.4 to 0.5 is to permit observation of movement in light of relatively large variation in the knowledge non-creation number).

5.2.2 Simulation results

Figure 4 shows the number of knowledge non-creation occurrences at each κ. The results showed that the number of occurrences of knowledge not being created can be reduced by increasing the rate of existing knowledge holding by new agents at the time of participation. In particular, the sharp reduction observed from an existing knowledge holding rate κ of approximately 40% or greater indicates that it is necessary to ensure a rate of at least approximately 40% in existing knowledge holding of new agents in order to reliably maintain knowledge creation at the individual level, which is a condition for organisational knowledge creation.

Figure 4 Knowledge non-creation occurrences at individual level (see online version for colours)



5.3 Model setting 3: simulation of created knowledge diffusion phase and exploration of conditions for organisational knowledge creation

5.3.1 Simulation purpose and conditions

To observe the diffusion phase for knowledge created at the individual level, we performed an investigation with the experimental results divided into two parts. With one part we examined the relation between the rate of existing knowledge holding by new agents, as an important factor for knowledge creation at the individual level, and the number of knowledge group 3 agents. With the other part, we examined the relation between new agent existing knowledge holding rate and number of created knowledge extinctions.

To explore the conditions for organisational knowledge creation, and thus those for knowledge creation at the individual level and its diffusion at the organisation, we investigated the relation between new agent rate of existing knowledge holding and number of agents in each knowledge group.

The following parameter settings were used in 100 iterations of 240-step simulations:

- $P_A + P_I = 120$
- $\lambda = 0.5$
- $m = 20$

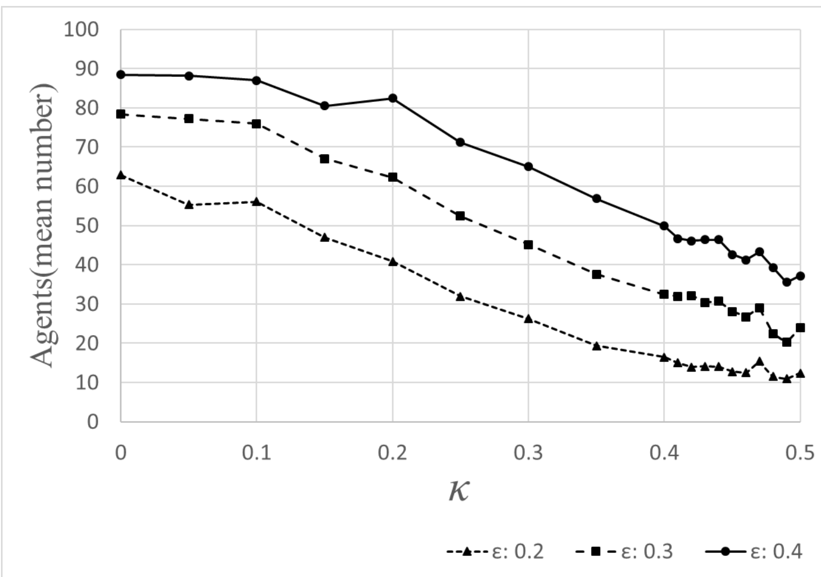
- $\varepsilon = 0.2, 0.3, 0.4$
- $\kappa = 0.0, 0.1, 0.2, 0.3$, and 0.4 to 0.5 in increments of 0.01.

5.3.2 Simulation results

5.3.2.1 Relation between diffusion of knowledge created at the individual level and new agent rate of existing knowledge holding

Figure 5 shows the relation between new agent existing knowledge holding rate κ and knowledge group 3 agent number, for different values of ε. These results show that, regardless of the proportion of created knowledge backers, created knowledge diffusion does not increase with a rise in rate of new agent holding of existing knowledge.

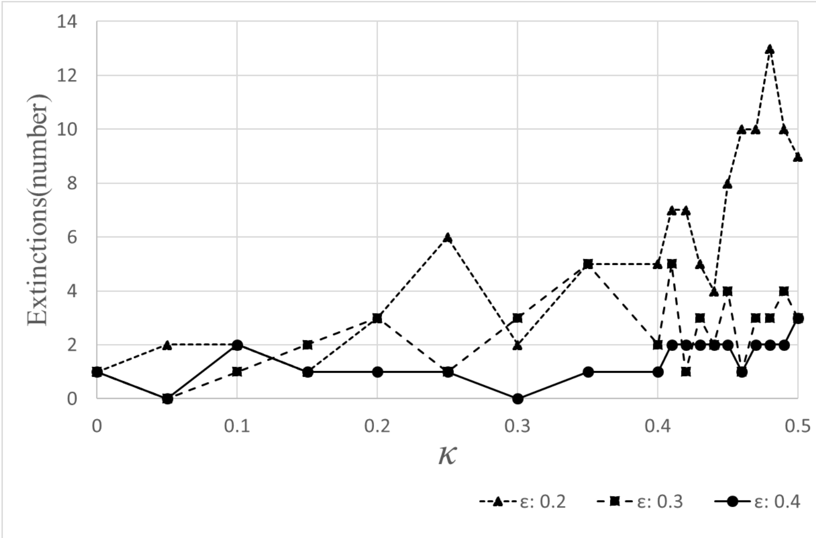
Figure 5 Existing knowledge holding rate and knowledge diffusion (see online version for colours)



5.3.2.2 Relation between extinction of knowledge created at the individual level and new agent existing knowledge holding rate

As shown in Figure 6, created knowledge extinctions increased with as the rate of existing knowledge holding increased with 20% backers, whereas with 30% and 40% backers, the effect of new agent rate of existing knowledge holding apparently tended to be small.

Figure 6 Existing knowledge holding rate and knowledge extinction



5.3.2.3 Exploration of conditions for organisational knowledge creation

Figures 7 to 9 show that the probability of created knowledge conversion to organisational knowledge (dominant knowledge of organisation) heightens with increasing backer ratio.

Figure 7 Existing knowledge holding rate and knowledge group agent number (backers 20%)

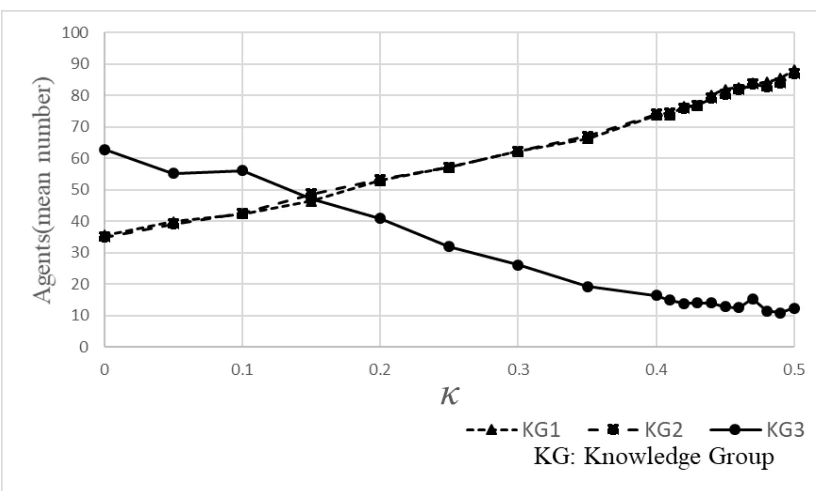


Figure 8 Existing knowledge holding rate and knowledge group agent number (backers 30%)

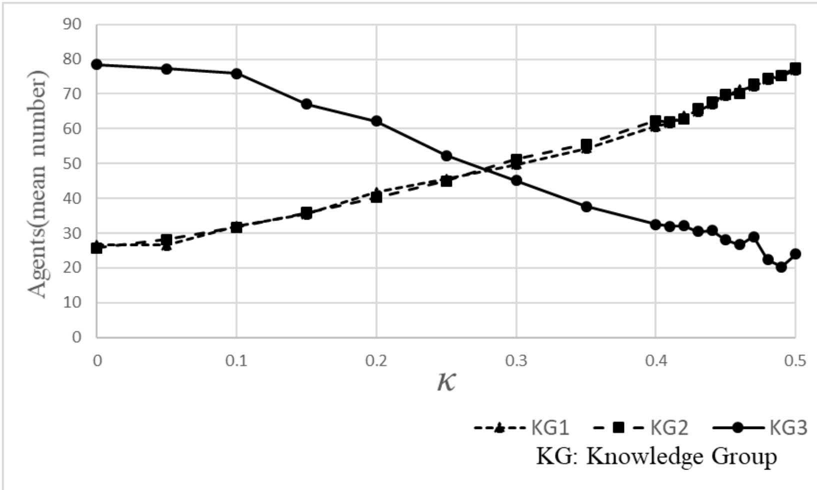
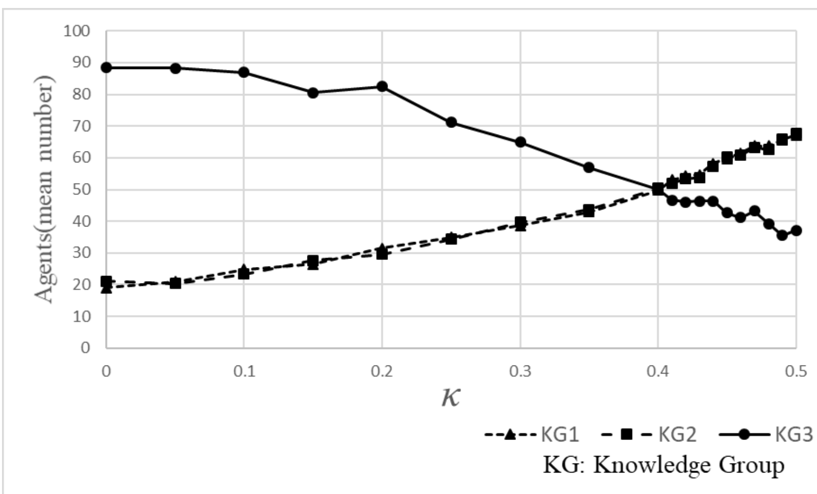


Figure 9 Existing knowledge holding rate and knowledge group agent number (backers 40%)



6 Discussion

In knowledge creation at the individual level, the situation where knowledge creation does not occur can be avoided if the new members joining the organisation hold more of the existing knowledge of the organisation. However, the new member's greater hold of existing knowledge has the aspect of preventing the diffusion of knowledge created at the individual level. In other words, if organisational knowledge creation consists of two phases, i.e., the knowledge creation phase at the individual level and the diffusion phase of that knowledge, there is a trade-off between the two phases due to the factor of existing knowledge of the organisation held by the new members. This tradeoff can be dealt with as a problem in knowledge management for achievement of innovation.

To resolve this problem, it is necessary to consider the balance between the amount of knowledge held by new members and the proportion of members supporting the created knowledge (Figures 7 to 9). This is one of the keys to the effective realisation of organisational knowledge creation.

Furthermore, the application of this model and simulation results for actual organisations can be presented as follows. Because of the simplicity of the model, it is expected to be used to facilitate understanding of the tendency of organisational knowledge creation. This can be done by interpreting the meaning of each parameter in terms of the state of each organisation and considering the results as possible outcomes. For example, if a certain organisation has a culture that is tolerant of new knowledge (i.e., it is likely to generate a large number of backers of new knowledge) and is proactive about innovation (i.e., facilitating knowledge creation at the individual level), it is possible to understand that it is better to recruit new members who have a wealth of existing knowledge in the organisation. It is possible to understand that if the organisation does not have a culture that is tolerant of new knowledge (i.e., it is unlikely to produce a large number of backers of new knowledge), then personally created knowledge is likely to be inhibited during the diffusion phase, so new members should be those who do not possess much existing knowledge, and at the same time, it is necessary to foster or recruit members who can become backers of new knowledge.

Nevertheless, if as noted at the outset engendering innovation requires sustained organisational knowledge metabolism and dynamic changes, then it is important to constantly replenish the presence of new members with existing knowledge and maintain opportunity for knowledge creation at the individual level. It is moreover desirable to build an organisational culture and spirit of endeavour that strengthen its knowledge diffusion phase. For the latter, those who seek to achieve innovation will for example advance in its direction while finding backers and integrating their 'local reasons' in a process of 'legitimacy' (Takeishi et al., 2014).

Finally, we discuss the future research. Firstly, by further incorporating the organisational context into the model, it will be possible to explore the organisational conditions of organisational knowledge creation. For example, intra-organisational networks of group leaders are to influence the group's performance (Zhao and Ismail, 2018) and the group leader may also have an influence in organisational knowledge creation. In knowledge diffusion phase, it is very interesting that the question of what balance of created knowledge and existing knowledge diffused by group leaders through networks is effective for organisational knowledge creation. Secondly, the mechanism of knowledge creation at the individual level is to be investigated. In the present study, the model is based on the idea that knowledge is created through the accumulation of knowledge (Tur and Azagra-Caro, 2018). However, there is also the idea that creative inconsistency is more effective. In this case, it is necessary to construct the model in which members have a lot of knowledge but the similarity of the knowledge is low.

References

Boisot, M. (1995) *Information Space: A Framework for Learning in Organizations, Institutions and Culture*, Routledge, London.

Gilbert, N. (2008) *Agent-Based Models*, Sage, Thousand Oaks, CA.

Habib, J. (2008) 'The dynamics of knowledge creation within innovation process from case studies to agent based modelling', *ICIS 2008 Proceedings*, [online] https://aisel.aisnet.org/cgi/viewcontent.cgi?article=1183&context=icis2008 (accessed 7 December 2020).

Jang, J., Ju, X., Ryu, U. and Om, H. (2019) 'Coevolutionary characteristics of knowledge diffusion and knowledge network structures: a GA-ABM model', *Journal of Artificial Societies and Social Simulation*, Vol. 22, No. 3 [online] http://jasss.soc.surrey.ac.uk/22/3/3.html (accessed 20 December 2020).

Kowalska-Styczen, A., Malarz, K. and Paradowski, K. (2018) 'Model of knowledge transfer within an organisation', *Journal of Artificial Societies and Social Simulation*, Vol. 21, No. 2 [online] http://jasss.soc.surrey.ac.uk/21/2/3.html (accessed 21 November 2020).

Liu, J., Zhou, Q., Guo, Q., Yang, Z., Xie, F. and Han, J. (2017) 'Knowledge diffusion of dynamical network in terms of interaction frequency', *Scientific Reports*, Vol. 7, p.10755 [online] DOI:10.1038/s41598-017-11057-8 (accessed 10 August 2021).

Lloria, M. B. (2008) 'A review of the main approaches to knowledge management', *Knowledge Management Research & Practice*, Vol. 6, No. 1, pp.77–89.

Morone, P. and Taylor, R. (2004) 'Knowledge diffusion dynamics and network properties of face-to-face interactions', *Journal of Evolutionary Economics*, Vol. 1, No. 3, pp.327–351.

Nonaka, I. and Takeuchi, H. (1995) *The Knowledge Creating Company*, Oxford University Press, Oxford.

Rogers, E.M. (2003) *Diffusion of Innovations*, 5th ed., Free Press, New York.

Takeishi, A., Aoshima, Y. and Karube, M. (2014) 'Reason for innovation: legitimizing resource mobilization for innovation in the cases of the Okochi memorial prize winners', in Itami, H. et al. (Eds.): *Dynamic of Knowledge, Corporate Systems and Innovation*, pp.165–189, Springer, Heidelberg.

Tur, E.M. and Azagra-Caro, J.M. (2018) 'The coevolution of endogenous knowledge networks and knowledge creation', *Journal of Economic Behavior & Organization*, Vol. 145, pp.424–434.

Zhao, X. and Ismail, K.M. (2018) 'I am who I connect with: the interplay of a group leader's leadership identity, intra-organisational ties and group outcomes', *Asian Journal of Management Science and Applications*, Vol. 3, No. 2, pp.117–131.