Modeling the Effect of Team Collaboration on the Creation of New Knowledge

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ABSTRACT
To survive global competition in a knowledge economy, respective fields of the enterprise knowledge must be upgraded constantly. There are two means to achieve this goal: inducing new knowledge from outside of the enterprise, or by creating new knowledge from within. The advantages of creating new knowledge from within are to create the core knowledge of the enterprise directly, easily protect commercial confidentialities, especially when the knowledge cannot be acquired from the outside, and since the knowledge is tailor made within enterprise, advantages such as higher applicability and higher compatibility can be achieved. When an enterprise has decided to create new knowledge from within, the following attributes must be contemplated: selecting suitable members, determining the kind of knowledge needed, knowledge complexity, knowledge level, the pressure of time, and the like. This study develops a mathematical model, which utilizes team collaboration in the creation of new knowledge, and helps select a suitable team under limited resources, while achieving the best benefit for knowledge creation. In light of the target knowledge, three knowledge dimensions must be considered concurrently, namely, knowledge complexity, the knowledge level of each employee, and the knowledge correlation between existing knowledge and target knowledge. Furthermore, the model can quantify the contribution of team collaboration on the creation of new knowledge, growth of the new knowledge of members, the time required to increase knowledge, and the total time required to create the target knowledge.

KEYWORDS: *knowledge management, knowledge complexity, knowledge level, knowledge correlation, knowledge creation*

JEL CLASSIFICATION: *C63*

1. INTRODUCTION

For enterprises to gain long term competitive advantage, and to increase their value, constant product innovation or service innovation is a must, whilst the success of the innovation relies deeply on creating more new knowledge to produce unbeatable products. When a difference arises between the enterprise's existing knowledge and the knowledge in need, a knowledge gap is produced. One of the main approaches to compensate for knowledge gaps is creating new knowledge from within the enterprise. Since the most important pieces of intangible knowledge are stored in the minds of employees, thus, when a team formed by the enterprise is creating new knowledge, suitable members must be selected in order to accomplish the task

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with swiftness and efficiency. The knowledge to be created involves complexity and levels, as well as the degree of correlation between the existing knowledge of the members and the target knowledge. Creating new knowledge through team collaboration is the most effective approach for enterprises, the main factor for which is the integration of collective wisdom. This includes experts from various fields who must learn from each other via the processes of diverse creative means, such as brainstorming, team discussion, and experimental proofs, and the like. In this way, teams can create innovative ideas or alternatives faster.

Based on the knowledge spiral theory proposed by Nonaka (Nonaka & Takeuchi, 1995), it is believed that the tacit knowledge of the members of an enterprise can be shared and grown within the organization via the four steps of Tacit to Tacit (Socialization), Tacit to Explicit (Externalization), Explicit to Explicit (Combination), and Explicit to Tacit (Internalization). Therefore, with team collaboration, the tacit knowledge of each individual can be shared and externalized. Explicit knowledge can be disseminated by combination of information technology. This kind of knowledge further interacts with other individual's tacit knowledge, and finally inspires brand new knowledge for enterprises. Therefore, employees can enhance their respective knowledge and skills via approaches such as brainstorming, learning, training, discussing, and the like. The knowledge exchange between team members can commence by the sharing of different levels of knowledge, or by the teaching of different complexities of knowledge, to achieve knowledge creation (Huang et al., 2007). A team from an enterprise can create new knowledge by utilizing existing knowledge initially present within the team as a base and build new knowledge upon it, and finally enhance the complexity and level of the existing knowledge (Korposh et al., 2011; Wei et al., 2009).

During the creation of the new knowledge, aside from the influencing factors such as knowledge complexity and level, the correlation between existing knowledge and target knowledge is also an important factor. In addition, time is crucial in creating new knowledge in order to enhance competitive advantage, since an enterprise has higher chance of winning the market with less time spent on creating knowledge. Therefore, by focusing on the influences of knowledge complexity, knowledge level, and knowledge correlation, this study develops a mathematical model of knowledge creation by teamwork. The model can analyze the process of knowledge creation, the increase of the knowledge of respective team members, and the time the team spends on creating the knowledge. The proposed model can provide enterprises with recommendations for the selection of the best innovative team.

2. LITERATURE REVIEW

For enterprises, the key to gaining competitive advantage is to have the ability to create new knowledge. Via cooperation and development of knowledge, enterprises can elevate their creativity and competitiveness (Drucker, 1993). A survey on the Fortune Global 500 corporations pointed out that by adequately inducing key knowledge resources can affect the international competitiveness of companies (Karaszewski, 2008). Quinn stressed the strength of an enterprise nowadays depends on its wisdom and capability of service, in addition to physical properties, such as, land, factories, or facilities (Quinn, 1992). The business objective of an enterprise is no longer just to manufacture tangible products, but also, and perhaps more importantly, the intangible value and service of the company. The vital key is knowledge of intangible properties: including branding, reputation, product development, patents, design, technology, marketing, customer service, imagination and creativity (MBAlib, 2016). Peter Drucker suggested that the most valuable assets of an organization in the 21st century are the knowledge workers in the organization and the productivity thereof (Drucker, 1993). It is evident that by efficiently utilizing knowledge property, the business performance, profit, creativity, competitiveness, and even the sustainable management of an organization can be enhanced.

Nonaka proposed that in order to elevate competitive advantage, an enterprise needs to create new knowledge constantly, so that consecutive innovation can be achieved (Nonaka & Takeuchi, 1995). Enterprise knowledge is stored within an organization and its employees, in the form of tacit knowledge and explicit knowledge; tacit knowledge includes extremely personal experience, intuition, prognostication, mind models, and the like; while explicit knowledge comprises descriptive numerals, characters, oral descriptions, sounds, images, charts, formulas, and so on (Hedlund, 1994). Tacit knowledge is present inside the minds of the employees and is hard to record. This makes it difficult to transfer knowledge. Explicit knowledge is saved within files and is encryptable, which makes it easy to transfer this kind of knowledge (MAB lib, 2016). The knowledge spiral proposed by Nonaka (Nonaka & Takeuchi, 1995) pointed out that the tacit knowledge of the members of an enterprise can constantly undergo inner transfer operations within an organization, so that tacit knowledge and explicit knowledge can interact with each other and diffuse, thus increasing the size of the body of core knowledge of the enterprise via socialization externalization, combination and internalization.

Dove presented many advantages of collective learning (Dove, 2001); knowledge can be advanced through interactions between team members with different viewpoints, different ideas and different expertise, leading to much more complete, reasonable, and enhanced knowledge integration, as well as a stronger sense of consensus formed between members (Lin, 2007). Team members must establish mutual trust to enhance efficiency when creating knowledge cooperatively (An et al. 2014). Some scholars have suggested that some parts of tacit knowledge can be measured by the means of psychological and memory linkages, and the like (Meyer & Sugiyama, 2007).

The knowledge gap of an organization can be compensated by creating new knowledge from within the enterprise. However, in order to maximize effectiveness and efficiency, an organization needs to select the most suitable team, with collective learning, and through working cooperatively to create new knowledge. The knowledge possessed by enterprise can be core knowledge, cross department knowledge, diverse knowledge, knowledge of difficulties, employee experience knowledge, expert knowledge, technology knowledge, patent knowledge, work related know-how, etc. The process of creating knowledge comprises five steps: sharing of tacit knowledge, employees matching personal knowledge of new concepts with shared knowledge, adaptation of the knowledge created in the organization, prototypes of created knowledge, and finally diffusion of the new knowledge into newer frontiers (Nonaka & Takeuchi, 1995).

The breadth and level of technology possessed by an enterprise will affect the performance of the enterprise, and breadth and level have interactive effects (Moorthy & Polley, 2010). The breadth of knowledge includes: professionalism or length of technology development, multi-field integration, etc. This study references the breadth of knowledge to the complexity of knowledge, the amount of which is expressed with numerals. The higher the number, the more complex it gets (Roos & Roos, 1997). The level of knowledge includes: expertise level of the knowledge or technology. This study utilizes numeral representation to quantify this level. The higher number, the deeper it gets.

3. MODEL FORMULATION

As seen in the aforementioned studies, the two main aspects of knowledge are the complexity and level of knowledge. The complexity of knowledge refers to the difficulties of knowledge. The usual means of measurement include: technology level, experience level, cognitive capability, comprehensive capability, unique point of view, etc. The higher the complexity of knowledge is, the higher the difficulties of knowledge are. For instance, the knowledge complexity for piloting an airplane is definitely higher than that of driving an automobile. Alternatively, knowledge level refers to knowledge proficiency. The knowledge proficiency of the employees of an enterprise can always be determined. The higher the proficiency of knowledge is, the larger the level of knowledge. For instance, an aviation company's pilot has more experience than its copilot; therefore the knowledge level of the pilot is greater than that of the copilot.

In addition to the knowledge complexity and knowledge level, the correlation between existing knowledge possessed by the employee and the target knowledge is also a crucial factor affecting the efficiency of knowledge creation. The knowledge correlation can be represented as 0 to 1. The correlation coefficient is 0 when the knowledge possessed by the employee has no association with the target knowledge; the correlation coefficient is 1 when the correlation relationship is prominent. For instance, if an automobile company is going into aviation, since the company has no experience in aviation, thus the knowledge correlation is rather low. On the contrary, if the company is going into electric automobiles, the knowledge that is needed to be created, namely, electric automobile knowledge, relates more to the knowledge that the company possesses from the start.

To create new knowledge, the knowledge complexity and level must be concurrently increased, and the correlation between the existing knowledge and the target knowledge should be maximized. An enterprise can appoint a team to create new knowledge, and during the process of creating knowledge, the knowledge complexity, knowledge level, and knowledge correlation of each member increases gradually. When one of the member's knowledge complexity, knowledge level, and knowledge correlation matches the target knowledge, the team member has finished creating new knowledge. If target knowledge is yet to be achieved, the team needs to continue the task of knowledge creation. Figure 1 illustrates the described knowledge creation process.

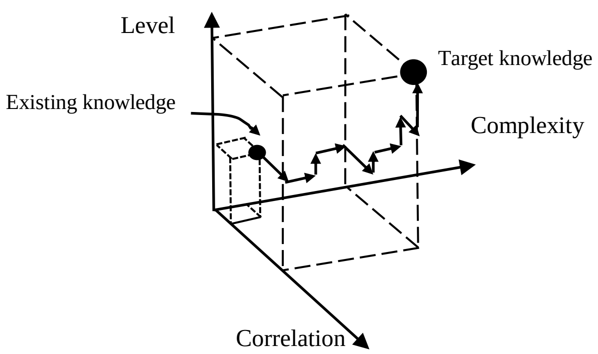

Figure 1. The Process of Knowledge Creation
Source: authors

From Figure 1, it is obvious that the process of knowledge creation is a gradual evolution. After one knowledge creation process has commenced, the knowledge complexity, level, and correlation of each team member can be enhanced. Thus, when the knowledge creation process has been reactivated, the amount of knowledge of each member will increase incrementally, therefore getting closer to the target knowledge. The knowledge creation process is repeated as such, until the knowledge of any single member matches the target knowledge. Finally, the team with the target knowledge can be assigned with the task of utilizing the stated knowledge for developing the new product.

This study provides a mathematical model of knowledge creation to quantify the above process of knowledge creation. The model can help enterprises choose the team most capable of achieving the target knowledge with the least amount of time, and then deploy the team to create the new knowledge and to develop the new product. The complete knowledge creation model is as described below.

The existing knowledge complexity and knowledge correlation of each member will affect the increment of the overall knowledge complexity; therefore the incrementing factor of the team's contribution to knowledge complexity TF_N is expressed as the sum of the product of the knowledge complexity and the correlation of each member, as described in Equation (1):

$$TF_N = a\sum_{i=1}^{s} N_i \alpha_i \tag{1}$$

Where N_i and α_i are the knowledge complexity and level of member i,
a is the coefficient and *s* denotes the number of members.

Similarly, the existing knowledge level and correlation of each member will affect the overall increment of the knowledge level; therefore, the incrementing factor of the team's contribution to the knowledge level TF_L is expressed as the sum of the product of the knowledge level and the correlation of each member, as described in Equation (2):

$$TF_L = b\sum_{i=1}^{s} L_i \alpha_i \tag{2}$$

Where L_i is knowledge level of member i, and *b* denotes the coefficient.

After knowledge creation activity, the increment of knowledge complexity of each member will be proportional to the existing knowledge complexity, the difference between the existing and target knowledge complexity, and team collaboration. Therefore, the amount of the increment of knowledge complexity ΔN_i can be expressed as in Equation (3) after each member *i* has created new knowledge via teamwork. Since the logarithmic function is a one-on-one incremental function, it is easy to preserve the relative size of the value; thus, Equation (3) uses the logarithmic value for the sake of convenient comparison.

$$\Delta N_i = \ln(c * N_i * e^{d(N_i - N^*)} + e^{TF_N}) * m \tag{3}$$

Where N* is the target knowledge complexity,
c, *d* and m denote coefficients.

Similarly, the increment of the knowledge level of each member is proportional to the existing knowledge level, the cubic power of the difference between the existing and target knowledge level, and team collaboration. Therefore, the increment of knowledge level ΔL_i is expressed as in Equation (4). For the sake of comparison, the logarithmic value is obtained.

$$\Delta L_i = g * \ln L_i * \ln(TF_i * (\varphi + (L_i - L^*))^3) \tag{4}$$

Where L* is the target knowledge level,
g, *φ* denote coefficient.

After knowledge creation via teamwork, the increment of knowledge correlation is also proportional to the knowledge complexity, knowledge level, and knowledge correlation of each member. Therefore, the increment of knowledge correlation $\Delta\alpha$ can be expressed as Equation (5).

$$\Delta\alpha = p\sum_{i=1}^{s} N_i^2 * L_i * \alpha_i \tag{5}$$

Where α_i is the knowledge correlation of member i,
p denotes coefficient.

During the process of knowledge creation, the time needed for incrementing the knowledge complexity of each member is proportional to the increment of the knowledge complexity ΔN_i, but is inversely proportional to the knowledge complexity and correlation of the members. The higher the knowledge complexity of the member is, the higher the knowledge correlation is, resulting in less time spent on creating new knowledge. Therefore, for each team member *i* participating in team collaboration for knowledge creation, the time needed for enhancing knowledge complexity can be expressed as Equation (6).

$$\Delta T_{Nx[i]} = q * (s_1 \Delta N_i^2 + s_2 \Delta N_i + s_3) / (\alpha_i * N_i) \tag{6}$$

Where q, s_1, s_2, s_3 denote coefficient.

Similarly, the time needed for incrementing the knowledge level of each member is proportional to the increment ΔL_i of the knowledge level, but is inversely proportional to the knowledge level and correlation possessed by the member. The higher the knowledge level possessed by the member is, the higher the knowledge correlation is, resulting in less time spent on creating new knowledge. Therefore, for each team member *i* participating in team collaboration for knowledge creation, the time needed for incrementing the knowledge level is expressed as Equation (7).

$$\Delta T_{Lx[i]} = r * (s_4 \Delta L_i^2 + s_5 \Delta L_i + s_6) / (\alpha_i * L_i) \tag{7}$$

Where r, s_4, s_5, s_6 denote coefficient.

Thus, the total time needed for creating knowledge complexity T_N is the accumulation of the time needed by the i^th^ member for incrementing the complexity $\Delta T_{Nx[i]}$ (Equation 8); similarly, the total time needed for creating knowledge level T_L is the accumulation of the time needed by the ith member for incrementing the level $\Delta T_{Lx[i]}$ (Equation 9).

$$T_N = T_N + \Delta T_{Nx[i]} \quad (8)$$

$$T_L = T_L + \Delta T_{Lx[i]} \quad (9)$$

As mentioned before, the increment of knowledge is a process of gradual evolution. Several cycles of effort are required to achieve the desired goal. Therefore, after every process of knowledge creation, the amount of knowledge of the i^{th} member will be added with the increments; thus, the amount of knowledge of the members can be updated as described below.

$$N_i=\min\{Max\_N,\ N_i+\Delta N_i\} \quad (10)$$

$$L_i=\min\{Max\_L,\ L_i+\Delta L_i\} \quad (11)$$

$$\alpha_i=\min\{1,\ w_1\alpha_i+w_2\Delta\alpha\} \quad (12)$$

Where w_1, w_2 denote coefficient,

Max_N denote the maximum value of complexity,

Max_L denote the maximum value of level.

This study proposes that during the process of knowledge creation, if any of the members have achieved the target knowledge, the creation of target knowledge has been accomplished, resulting in the end of the task of knowledge creation; if not, then the next cycle of knowledge creation should be activated. Therefore, the knowledge creation process might be repeated several times by the same team to accomplish the task of creating the target knowledge.
After the target knowledge has been created, the total time T spent on creating the knowledge is the maximum value of T_N and T_L, which represent the time needed to complete complexity and level, respectively.

$$T = \max\{T_N, T_L\} \quad (13)$$

Therefore, the overall process of knowledge creation can be expressed as the algorithm stated below.

Step 1: Set the target knowledge complexity as L^*, level as N^*, and correlation as $\alpha^*=1$. Maximum value of complexity is *Max_N*, and the maximum value of level is *Max_L*. Set the initial value of the amount of knowledge of each member as: complexity N_i, level L_i, and correlation α_i. Set the total time needed for creating target knowledge complexity as T_N=0; and set the total time needed for creating target knowledge level as T_L=0

Step 2: Compare whether the target knowledge has been achieved or not. If the amount of knowledge of one of the members is higher or equal to the target knowledge, then the creation of target knowledge has been completed.
i.e.

If ($N_i \geq N^*$ and $L_i \geq L^*$ and $\alpha_i=\alpha^*$)

then $T = \max\{T_N, T_L\}$; *stop*

else go to Step 3

Step 3: Calculate the increment of knowledge, the time needed thereof, and the total time, including (a) TF_N , (b) TF_L, (c) ΔN_i , (d) ΔL_i, (e) $\Delta T_{Nx[i]}$, (f) $\Delta T_{Lx[i]}$, (g) $\Delta\alpha$, (h) T_N and T_L.

Step 4: After conducting knowledge creation, the amount of knowledge of each member is updated.

$N_i = \min\{Max\_N,\ N_i + \Delta N_i\}$

$L_i = \min\{Max\_L,\ L_i + \Delta L_i\}$

$\alpha_i = \min\{1,\ w_1\alpha_i + w_2\Delta\alpha\}$

$go\ to\ Step\ 2$

4. CASE IMPLEMENTATION

To validate the effectiveness of the model developed in this study, cases are provided in this section to illustrate the application of the model. Assume that the knowledge complexity, knowledge level, and knowledge correlation are represented by integers in the range of 0 to 100, 0 to 100, and 0 to 1, respectively. The higher the value gets, the higher the complexity, level, and correlation of knowledge are.

Let Max_N=100, Max_L=100, a=b=0.01, c=2, d=0.1, m=1, g=0.12, φ=100, p=1/1900000, q=r=10, s_1 =1.2, s_2= s_3= 1, s_4 =0.14, s_5= s_6= 1, w_1= w_2=1.

Case I: A team of 5 members is asked to create target knowledge

Assume that a team of 5 members is assigned to create the target knowledge; the whole knowledge creation process is illustrated as follows:

Step 1: Set the target knowledge complexity as N^*=45, level as L^*=35, and correlation as α^*= 1. The initial value of the amount of knowledge of each member, including the complexity, level, and correlation of knowledge, are stated in Table 1.

Table 1. Initial Values of Knowledge of Team Members

Member	N_i	L_i	α_i
1	22	36	0.5
2	31	32	0.8
3	33	25	0.6
4	35	12	0.8
5	48	47	0.8

Source: authors

Step 2: Compare to see if the target knowledge has been acquired. Since the amount of knowledge of each member is insufficient, commence the target knowledge creation activity.

Step 3: Calculate the increment of knowledge, the time needed thereof, and the total time, including (a) TF_N , (b) TF_L, (c) ΔN_i , (d) ΔL_i, (e) $\Delta T_{Nx[i]}$, (f) $\Delta T_{Lx[i]}$, (g) $\Delta\alpha$, (h) T_N and T_L. Calculate the value from each of the (a)-(h) and the results of the team contribution to the incrementing factor of knowledge complexity TF_N=1.22, the team contribution to the incrementing factor of knowledge level TF_L=1.058, and the increment of knowledge correlation $\Delta\alpha$=0.07792. Table 2 lists the increment of complexity and level, the time needed for the increment of complexity and level, and the accumulated time spent on complexity and level.

Step 4: The amount of knowledge of each member is updated after knowledge creation. Based on Equations (10), (11), and (12), knowledge complexity, knowledge level and knowledge correlation are obtained, as shown in Table 3.

Table 2. Increments of Team Members after First Knowledge Creation

Team A	ΔN_i	ΔL_i	$\Delta T_{Nx[i]}$	$\Delta T_{Lx[i]}$	T_N	T_L
1	2.053941	5.97806	7.378501	6.656259	7.3785	6.65626
2	2.92725	5.73115	5.729758	4.42563	13.1083	11.0819
3	3.146993	5.23614	8.096603	6.716355	21.2049	17.7982
4	3.372069	3.90263	6.434674	7.328033	27.6395	25.1263
5	4.890151	6.56614	9.006886	3.617586	36.6464	28.7439

Source: authors

Table 3. Knowledge of Members after First Knowledge Creation

Member	N_i	L_i	α_i	Is target achieved
1	24.053942	41.9781	0.57792	NO
2	33.92725	37.7312	0.87792	NO
3	36.146992	30.2361	0.67792	NO
4	38.37207	15.9026	0.87792	NO
5	52.890152	53.5661	0.87792	NO

Source: authors

It is apparent that none of the increments of knowledge of the members achieved the target knowledge, thus the next cycle of knowledge creation commences. After several cycles of knowledge creation, the target knowledge is finally achieved (see Table 4). It has been shown that the 5th member achieved the target knowledge first, and during team collaboration, each member underwent noticeable increments in the amount of knowledge thereof. Time needed for the team to achieve target complexity is T_N =108.387401, and the time needed for the team to achieve target level is T_L = 71.8887. Therefore, the total time needed for the team to create target knowledge is T=108.387. And the 5th member is a key member. Therefore, we know that during the process of selecting members, by choosing the individual with higher knowledge complexity, deeper knowledge level, and higher knowledge correlation, the individual can lead the team to finish the task of new knowledge creation faster.

Table 4. Knowledge of Members after Several Cycles of Knowledge Creation

Member	N_i	L_i	α_i	Is target achieved
1	29.08025	55.3121	0.89535	NO
2	40.923519	50.6009	1	NO
3	43.653591	42.184	0.99535	NO
4	46.403599	25.4412	1	NO
5	**64.469604**	**68.0161**	**1**	**Yes**

Source: authors

Case II: Three teams are asked to create the target knowledge

Assume that three teams, each comprised of five members, are asked to create the target knowledge concurrently, and the target knowledge still has complexity of N^* =45, level of L^*=35, and correlation of $\alpha^* = 1$. The initial value of the complexity, level, and correlation of knowledge of each member are listed in Table 5. After three cycles of knowledge creation activity, target knowledge creation is achieved, as depicted in Table 5. The final time spent by each team is: T for Team 1=122, T for Team 2=124, and T for Team 3=110. Therefore, Team 3 creates the target knowledge in the least time. Since time is one of the main factors for becoming competitive in business, the enterprise that can create knowledge in the least amount of time will beat the odds of the other competitors. Therefore, the team that can finish knowledge creation in the least amount of time should be chosen. Hereby, in this case Team 3 should be put in charge of the task of new knowledge creation. After further analysis it can be determined that after the third cycle, the fifth member of Team 1 achieved the target knowledge first. This is the key member of Team 1, as indicated by the bold font in Table 5. The fifth member in Team 2 is also the first one to achieve the target knowledge; therefore the fifth member of Team 2 is the key member of Team 2, as indicated by the bold font in Table 5. The third, fourth, and fifth members of Team 3 achieved the target knowledge first; therefore they are the key members in Team 3, as indicated by the bold font in Table 5. Evidently, the member whose three attributes are closest to those of the target knowledge should be chosen first when choosing the members. Otherwise, the member whose two attributes are closest to those of the target knowledge should be chosen. Since members 3, 4, and 5 of Team 3 have better capabilities, thus Team 3 finished knowledge creation faster than did Team 1 and Team 2. For Team 1 and Team 2, only the fifth members of the respective teams have better capabilities. As a result, Team 1 and Team 2 were not able to create knowledge as fast as Team 3 did. This discovery directly proves that enterprises aiming to hire the best personnel are completely correct.

Table 5. Increments of Three Teams of Knowledge Creation

		Team 1					Team 2					Team 3				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Initial Value	N_i	22	31	33	35	48	20	25	28	34	60	22	27	37	42	43
	L_i	36	32	25	12	47	64	61	45	28	21	49	36	80	27	32
	α_i	0.5	0.4	0.6	0.8	0.8	0.6	0.5	0.4	0.6	0.9	0.6	0.7	0.8	0.6	0.7
1th Cycle	N_i	24	33.9	36.1	38.4	52.9	21.9	27.3	30.6	37.2	66.3	24	29.5	40.6	46.2	47.3
	L_i	41.9	37.7	30.2	15.9	53.5	71.4	68.3	51.5	33.5	26	55.8	42.1	88.1	32.5	37.9
	α_i	0.57	0.47	0.67	0.87	0.87	0.67	0.57	0.47	0.67	0.97	0.7	0.8	0.9	0.7	0.8
2nd Cycle	N_i	26.3	37.2	39.6	42.1	58.4	23.9	29.9	33.5	40.9	73.3	26.4	32.3	44.6	50.9	52.1
	L_i	48.3	43.8	35.9	20.3	60.4	79.2	75.9	58.5	39.5	31.4	63.1	48.8	96.6	38.6	44.3
	α_i	0.68	0.58	0.78	0.98	0.98	0.79	0.69	0.59	0.79	1	0.86	0.96	1	0.86	0.96
3rd Cycle	N_i	28.9	40.8	43.6	46.4	**64.5**	26.3	32.8	36.8	45	**81.1**	29.1	35.5	**49.2**	**56.1**	**57.5**
	L_i	55.1	50.4	42	25.3	**67.8**	87.4	84	65.9	46	**37.4**	70.9	55.9	**100**	**45.1**	**51.1**
	α_i	0.86	0.76	0.96	1	**1**	0.97	0.87	0.77	0.97	**1**	1	1	**1**	**1**	**1**
T_N		122					124					110				
T_L		81.4					71.1					60.9				
T		122					124					**110**				

Source: authors

4.1 Sensitivity Analysis

In order to explore the effects of certain factors on the results, this section conducts a sensitivity analysis. It analyzes the effects of different parameter values on the overall performance of knowledge creation to see if the results differ. Continuing with the preceding case, fifteen participants are divided into three teams, with five members each. The three teams are Team 1, Team 2, and Team 3. The amount of knowledge of each member is stated in Table 6. Assume the coefficient of correlation is $\alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = \alpha$, where α should in turn be 0.1, 0.2, …, 0.9, 1.0, the time spent on incrementing knowledge complexity T_N and the time spent on incrementing knowledge level T_L for Team 1, Team 2, and Team 3.

Table 6. Initial Knowledge Values of the Three Teams

	Team 1					Team 2					Team 3				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
N_i	22	31	33	35	48	20	25	28	34	60	22	27	37	42	43
L_i	36	32	25	12	47	64	61	45	28	21	49	36	80	27	32
α_i	α	α	α	α	α	α	α	α	α	α	α	α	α	α	α

Source: authors

Table 7 demonstrates the effect of varying knowledge correlation α on the T_N and T_L of each team. Table 7 shows that for the same set of correlation value α, the T_N of each team is larger than the T_L thereof, meaning the difficulty of incrementing knowledge complexity is higher; therefore, the time spent on incrementing knowledge complexity is longer (the shaded numerals in Table 7). When the correlation α=0.1, the T_N of Team 3 = 1397.233. This is the shortest time spent among the groups; therefore, Team 3 should be selected. When the correlation α=0.2, Team 2 should be selected. When the correlation α=0.3, Team 3 should be selected. When the correlation α=0.4, Team 1 should be selected. When the correlation α=0.5, Team 3 should be selected. When the correlation α=0.6, Team 3 should be selected. When the correlation α=0.7, Team 2 should be selected. When the correlation α=0.8, Team 1 should be selected. When the correlation α=0.9, Team 1 should be selected. When the correlation α=1.0, Team 1 should also be selected. For the varying correlation value, Team 1 has been chosen four times, Team 3 has also been chosen four times, and Team 2 has only been chosen two times.

In addition, each team discloses that T_N will be larger whenever α gets smaller. In other words, whenever the knowledge of the team members has smaller correlation with the new target knowledge, there is a larger knowledge gap that must be crossed and there are more hardships to overcome. Therefore, more time is needed to achieve target knowledge. Conversely, the knowledge gap gets smaller whenever α increases. In other words, the task becomes easier to accomplish. These findings suggest correlation significantly affects the time needed for time creation. This discovery also matches with the phenomenon in practice.

Table 7. Comparison of Time Needed for Creating New Knowledge

	Team 1		Team 2		Team 3		Team Selected
α	T_N	T_L	T_N	T_L	T_N	T_L	
0.1	1460.374	675.7881	1435.965	630.0123	1397.233	543.0351	Team 3
0.2	694.2655	348.3114	651.6099	315.6325	658.7971	277.4657	Team 2
0.3	428.2785	228.8352	398.8287	205.4833	398.425	178.9417	Team 3
0.4	285.4431	162.461	303.5714	157.8563	302.713	137.6134	Team 1
0.5	231.3155	132.4414	214.703	117.7583	208.1152	100.2408	Team 3

α	Team 1 T_N	Team 1 T_L	Team 2 T_N	Team 2 T_L	Team 3 T_N	Team 3 T_L	Team Selected
0.6	162.3342	99.04657	149.8683	87.15074	137.4472	70.59828	Team 3
0.7	108.3139	70.90433	99.64925	61.71684	119.9348	61.35618	Team 2
0.8	64.77047	45.75044	89.17577	54.64048	72.81921	39.87176	Team 1
0.9	58.69454	41.1003	83.59362	50.45602	66.66013	36.13764	Team 1
1	0	0	81.21976	48.45561	64.01226	34.34694	Team 1

Source: authors

Figure 2 compares the T_N and T_L of the respective teams, where the horizontal axis represents correlation α, the vertical axis represents the value, the orange curve is T_N , and the green curve is T_L . It can be discovered that the T_N is larger than T_L for all three teams. When correlation is extremely low, the time needed for incrementing knowledge complexity is way larger than the time needed for incrementing knowledge level. However, as correlation becomes larger, the difference between T_N and T_L becomes smaller. It should also be noted that as α increments, the total time needed for incrementing knowledge complexity and level, T_N and T_L , demonstrates a decreasing trend. This indicates that as the knowledge correlation becomes higher, the time spent on knowledge complexity and level become shorter.

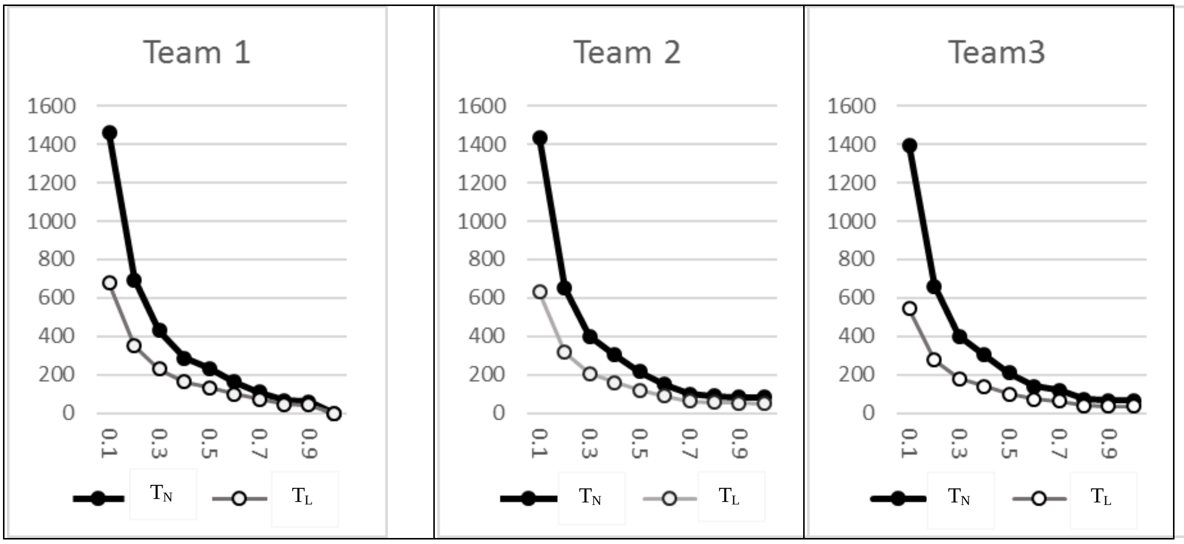

Figure 2. Comparisons of T_N and T_L of Teams under Varying Correlations

Source: authors

4. CONCLUSIONS

Global competition forces enterprises to create new knowledge for developing their core capability, so that the competitive advantages of enterprises can be enhanced. One of the means to achieve this is by purchasing patents or licenses from the outside, but the price is often rather high. By developing knowledge from within, enterprises cannot only monitor the process of creation, but they also render the predictions of competitors futile, and thus surprise the competitors. Therefore, this study develops a mathematical model, which explores the process of the collaboration of the teams chosen by an enterprise for new knowledge creation. The model considers the following three factors: the existing knowledge complexity, level, and the correlation of the team members with the target knowledge. The effect of team interaction on knowledge creation is analyzed, including increments in knowledge, time needed for knowledge increments, and the overall time for creating target knowledge. Finally, two cases are discussed to demonstrate the applicability of the model, and a sensitivity analysis of the variables is also conducted. The first case reveals that an individual with higher knowledge complexity, deeper knowledge level, and higher knowledge correlation, can lead the team to finish the task of new knowledge creation faster. The second case suggests that member whose three attributes are closest to those of the target knowledge should be chosen first when choosing the members. Otherwise, the member whose two attributes are closest to those of the target knowledge should be chosen. Moreover, the sensitivity analysis discovers that as the knowledge correlation becomes higher, the time spent on knowledge complexity and level become shorter. The proposed model can help managers select the most suitable team to create the target knowledge needed for a new product or service.

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