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Supplementary Material for Wang, S. et al.: "The Dynamical Relation Between Individual Needs and Group Performance: A Simulation of the Self-Organising Task Allocation Process"

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The model description follows the ODD (Overview, Design concepts, Details) protocol (Grimm et al. 2006, 2020) supplement to the paper "The dynamical relation between individual needs and group performance: A simulation of the self-organising task allocation process". We implement this model with an agent-based modelling platform NetLogo 6.1 (Wilensky 1999).

Overview

Purpose

The purpose of the model is to study the dynamical relationship between individual needs and group performance when focusing on self-organising task allocation. For this, we develop a model that formalises Deci & Ryan's self-determination theory (SDT) (Ryan & Deci 2017, 2000; Ryan & Moller 2017; Gagné & Deci 2005) into an ABM creating a framework to study the social dynamics that pertain to the mutual relations between the individual and group level of team performance. Specifically, it aims to answer how the three individual motivations of autonomy, competence, and belonging affect team performance.

Entities, state variables, and scales

To describe the model that is being used to study the mutual relation between individual, group, and organisational components, we make use of three hierarchical entities: collective level, individual level, and social level.

The **collective-level** entities including *team* and *project*. We describe a *team* mainly with team size indicating the number of individuals or *members* forming the team. A *project* is a collection of *tasks* to be processed by the team as a whole and mainly characterised by the number of tasks.

There are two types of **individual-level** entities. One is the *tasks*, each task is characterised by identity number ($ID(t_j)$), required knowledge ($TK(t_j)$), and duration ($TD(t_j)$). The required knowledge ($TK(t_j)$) of a task t_j indicates the minimum mastery of knowledge needed to complete t_j,$tk_j^l \in [0,1]$, it represents the amount of one type of specialised knowledge or a specific skill. The task duration ($TD(t_j)$) shows the time needed to execute tasks, td_j represents the minimal execution time of the task t_j under the maximal motivation and knowledge, the actual execution time relates to the factual motivation and knowledge of agents.

The other is the *individual*. Supposed that a team consists of m individuals, each individual is denoted as a_i. Individuals (agents) are characterised by a set of state variables: identity number ($ID(a_i)$), competence ($AK(a_i)$), and motivation ($AM(a_i)$). Competence ($AK(a_i)$) refers to one's ability to complete a task, mainly related to the knowledge and skills possessed by the individual. Each agent a_i has certain knowledge and specific skills as prerequisites to complete tasks, different agents have different knowledge types and amounts. Assume that agent a_i has several types of knowledge, its competence is expressed as $ak_i^l \in [0,1]$, indicating how well a_i masters the lth dimension knowledge, $ak_i^l = 0$ represents a_i not know the lth dimension knowledge, while $ak_i^l = 1$ means a_i masters it. Additional to competence, the members' motivation is also a fundamental determinant of human behaviour (Latham & Pinder 2005), referring to the member's willingness to perform a task. The SDT (Ryan & Deci 2000) identifies three fundamental psychological needs underlying this motivation: competence, autonomy, and belonging (relatedness). Therefore, the motivation of agent a_i comprises of the satisfaction of these three needs, they are, the satisfaction of motivational need for competence ($MnCom(a_i)$), need for autonomy ($MnAut(a_i)$), and need for belonging ($MnBel(a_i)$). Learning of agents is an important process for adapting and developing team capabilities, besides, contrary to learning, forgetting is also an important method of adapting and responding to the organisational environment. A list of parameters for individuals is provided in Table 1.

Parameter	Code	Description	Range	Distribution
Types of knowledge	Num_types	Number of types of knowledge included in the team	Natural number	constant
λ_i	Lamda	The balance between knowledge and motivation	[0,1]	constant
τ_i	Tau	Tolerance of difference in knowledge	[0,1]	constant
σ_i	Sigma	Reactivity of agent's perceived autonomy	[0,1]	constant
μ_i	Mu	Decay rate of agent's perceived autonomy	[0,1]	constant
ϱ_i	Varrho	The extent of motivation influenced by history	[0,1]	constant
α_i	Alpha	Impact of collaboration on connection strength	[0,1]	constant
β_i	Beta	Impact of the connection strength on belonging	[0,1]	constant
ψ_{exc}	PsiExc	The extent of excitation	[0,1]	constant
ψ_{inh}	PsiInh	The extent of inhibition	[0,1]	constant
γ_i	Gamma	Learning ability	[0,1]	constant
ζ_i	Zeta	Forgetting rate	[0,1]	constant
I_c	Ic	The importance of competence	[0,1]	discrete value
I_a	Ia	The importance of autonomy	[0,1]	discrete value
I_b	Ib	The importance of belonging	[0,1]	discrete value

Table 1: Parameters for individuals

As a **social-level** entity, the *connection* describes the influence relationship among individuals. Here, we utilise connection strength between agents to represent the amount of influence. The social interaction which is involved in the process of task allocation relies on the connection between individuals, and then it reacts to this connection. Every agent has afferent (incoming) connections from other agents and efferent (outgoing) connections to other agents.

Process overview and scheduling

In a team, when tasks need to be assigned, how do members allocate tasks through self-organisation instead of being interfered with by other managers? Here, based on the WORKMATE (Zoethout et al. 2006), we extend and describe the team task-performing process as the following seven steps:

- The project arrivals at the team.
- Make an *initial choice*. Whether an agent is capable and willing to do a particular task is related to four elements, they are, individual motivation, competence, and the threshold of motivation and competence. If the agent's knowledge is over the task required knowledge, which means the agent is competent to perform the task, and if motivation exceeds the threshold (T_am), which indicates agents are willing to use this knowledge to execute the task. When both individual competence and motivation are higher than their threshold, the agent will make an I Do (I-DO, I want to do it) choice, on the contrary, it will make the You DO (Y-Do, I don't want to do it) choice. There are two following rules to determine whether the agent takes the task or not.

  Rule 1: If $AK(a_i) \geq T_{ak}$ and $AM(a_i) \geq T_{am}$ Then I-Do

  Rule 2: If $AK(a_i) < T_{ak}$ and $AM(a_i) < T_{am}$ Then Y-Do

  Where T_{am} is the motivation threshold, and T_{ak} is the knowledge requirement of tasks, which equals tk_j^l.

  The algorithm pseudocode of making an initial choice is shown in Algorithm 1 at the page 3.

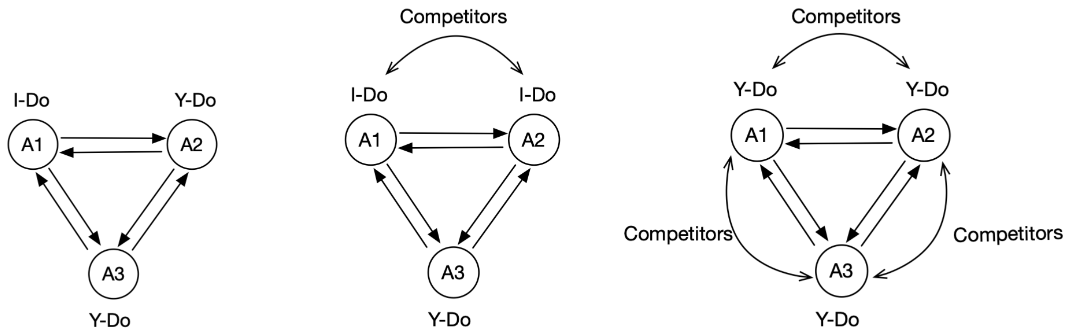
Algorithm 1: Making an initial choice

Input : Individual competence(AK) and motivation (AM), the motivation threshold (T_{am}) and knowledge threshold (T_{ak} equals task requirement), the parameter λ to balance the knowledge and motivation

Output: The initial choice of individuals for tasks IC_{mn}

for *the agent* $a_i \leftarrow 0$ **to** m **do**
  for *the task* $t_j \leftarrow 0$ **to** n **do**
    if $AK < T_{ak}$ **then**
      if $AM < T_{am}$ **then**
        Calculate the V_{I-node} and V_{y-node} of a_i with equation 13 and 14 // illustrating Zone 1 in Figure 2
      else
        Calculate the V_{I-node} and V_{y-node} of a_i with equation 15 and 16 // illustrating Zone 2 in Figure 2
      end if
    else
      if $AM < T_{am}$ **then**
        Calculate the V_{I-node} and V_{y-node} of a_i with equation 19 and 20 // illustrating Zone 4 in Figure2
      else
        Calculate the V_{I-node} and V_{y-node} of a_i with equation 17 and 18 // illustrating Zone 3 in Figure 2
      end if
    end if
    return $V_{I-node}(a_i)$ *and* $V_{y-node}(a_i)$
    if $V_{I-node}(a_i) > V_{y-node}(a_i)$ **then**
      $IC_(a_i, t_j) \leftarrow 1$
    else
      $IC_(a_i, t_j) \leftarrow 0$
    end if
  end for
  return $IC \leftarrow IC_(a_i, t_0), IC_(a_i, t_1), \ldots, IC_(a_i, t_{n-1}, IC_(a_i, t_n)$ // indicating the Initial choice of a_i for all t_j
end for
return IC_{mn}

- Interact between agents. Based on step (2), every agent will have its initial choice, the initial choice of all agents for each task could be categorised into three situations (see Figure 1): In the first situation (a), there is no competition for tasks within the team, it is a complementary situation, which means only one member wants to do a particular task, and no interaction will occur. In the second situation (b) more members want to do a particular task, and competition for the task arises. In this situation, the members will interact with each other until one of them is influenced to change their choice. In the third situation (c) none of the members wants to do the particular task. Because the task needs to be completed for the project to finish, all members interact to influence others to do the task until one of them changes their choice and accepts the task. On the basis of this initial choice, the agents start influencing each other. The influencing process aims to reach a complementary situation in which the agent can actually do the task that it wants while influencing the other agents to do the tasks it doesn't want to do. This process applies to all tasks and all agents involved in a project.



(a) No competition (b) Competition exists (c) No one chooses the task

Figure 1: The initial choice of all members for a task.

- Reach the *final allocation*. the interaction process will continue until the complementary allocation outcome is reached, which shows each task is assigned and only assigned to one agent. The algorithm pseudo-code of reaching a final allocation is shown in Algorithm 2.

Algorithm 2: Reaching a final allocation

Input : The Matrix IC_{mn}, the V_{I-node} and V_{y-node} of all individuals
Output : The final allocation of individuals for tasks FA_{mn}
Hypothesis: Each task can only be allocated to one agent

for $j \leftarrow 0$ **to** n **do** // for each column of the Matrix IC_{mn}
    $IDO(t_j) \leftarrow \sum_{j=0}^{m} IC_{mn}(:, j)$
    if $IDO(t_j) = 1$ **then** // it means only one individual wants to do task t_j
        $FA_{mn}(:, j) \leftarrow IC_{mn}(:, j)$ // the finial allocation equals the initial choice of agents for t_j
    else
        while $IDO(t_j) > 1$ **do** // more agent want to do t_j
            Interact between agents whose $IC_(a_i, t_j) = 1$ until one of them is influenced to change its choice
            $IC_(a_i, t_j) \leftarrow 0$
            $IDO(t_j) \leftarrow \sum_(j = 0)^m IC_{mn}(:, j)$
            $FA_{mn}(:, j) \leftarrow IC_{mn(:,j)}$
        end while
        while $IDO(t_j) = 1$ **do** // none of the agents wants to do the particular task for t_j
            Interact between agents whose $IC_(a_i, t_j) = 0$ until one of them is influenced to change its choice
            $IC_(a_i, t_j) \leftarrow 1$
            $IDO(t_j) \leftarrow \sum_(j = 0)^m IC_{mn}(:, j)$
            $FA_{mn}(:, j) \leftarrow IC_{mn(:,j)}$
        end while
    end if
end for
return FA_{mn}

- Perform the allocated task after finalising the interaction process.

- Agents adjust their competence and motivation, the former resulting from executing certain tasks or using particular knowledge, the latter is affected by the allocated tasks and previous processing experience.
- The next project arrives, repeating the self-organising process from step (1).

Design concepts

Basic principles: this model builds on the ability of individuals to make decisions whether or not to perform certain tasks based on their competence and motivation (Wilke & Meertens 1994). According to Self-Determination Theory (SDT), three fundamental psychological needs are underlying this motivation: competence, autonomy, and belonging. When team members make decisions whether or not to perform certain tasks, their competence and motivation to perform different tasks are key factors in making this decision (Wilke & Meertens 1994).

Emergence: the emergent effect we are interested in when using the model for the purpose described in the paper is the performance and satisfaction of the team under different individual needs, i.e., when three types of motivational needs have distinct importance in the team. Currently, performance is measured by recording the performance time, including coordination time and execution time.

Heterogeneity: the agents of the team are heterogeneous, their motivation and competence are dynamic. The learning and forgetting experience of agents, as well as the interaction between agents, will cause agents to continue to undergo adaptive changes.

Adaptation: motivation and competence are different when facing different tasks. Also, individual needs may be fulfilled to a varying extent after dealing with distinguished tasks, and accordingly, their motivations will change adaptively.

Objectives: for a task-performing system, the competence and motivation of each agent are constantly adjusted according to the outcome of allocation and execution. Under different conditions, every agent within the team will develop differently through continuous processing of the project, and the team's performance and satisfaction will also change accordingly.

Interaction: pairs of individuals interact if they cannot reach the complementary situation in which every task is selected and only by one person. In the course of task allocation, the social interaction involved will not only affect the extent to which agents want to do and do not want to do tasks but also change the connections strength between agents.

Learning and forgetting: the process of handling tasks and using knowledge is a process of the learning experience for individuals, this acquired experience could be attributable to increased knowledge about the task being performed (Jarkas & Horner 2011). The more frequently someone performs a task, the better they get at it. The knowledge of the agent will improve after the task has been executed because an agent will learn the particular knowledge by doing tasks, the learning amount relates to the times of uses of certain knowledge. Similarly, all of the knowledge not being used will be gradually forgotten with time.

Stochasticity: this model deliberately avoids introducing stochasticity to minimise the impact of randomness on task allocation. There is only one potential source of randomness may exist, when the initial choice of agents is the same, and the willingness and unwillingness calculated according to their motivation and competence are the same or the difference of the values between individuals is negligible, in this case, the task would be randomly allocated to one of those agents.

Observation: for model analysis, the group-level data were recorded with time to answer how three individual needs affect team performance. Observation includes metrics measuring the team performance (coordination time and performance time), and metrics that reflect the group satisfaction.

Details

Initialisation

The model is aimed to explore the dynamical relationship between three individual needs and group performance. The model is by default initialised by creating an artificial team composed of three individuals, each individual has three different kinds of knowledge. For simplifying the experiment, all parameters of individuals within the same team are identical, parameters are set as the following Table 2.

As a proof of concept in our first experimental design, we start with a team composed of members that have a small difference concerning their knowledge. Having differences in knowledge is more realistic, and it provides a better start condition for having meaningful interactions than a situation where the agents would be perfectly identical. The following Table 3 shows the knowledge of the three agents. Averaged over this knowledge of the agents have a similar knowledge level.

The three agents have to complete a project. These projects can be more or less difficult, depending on the minimum level of knowledge that is required for an agent to be capable of performing a task. In our experimental design, we implemented a moderate project (Table 4). The tasks of the moderate project can be performed by at least two agents.

Parameter	Value
Types of knowledge	3
λ	0.5
τ	0.2
σ	1
μ	0.7
ϱ	1
α	0.8
β	1
ψ_{exc}	1
ψ_{inh}	1
γ	0.3
ζ	0.1

Table 2: Individual parameters

Team Member	Agent Knowledge
A1	[0.7,0.6,0.5]
A2	[0.5,0.7,0.6]
A3	[0.6,0.5,0.7]

Table 3: The knowledge (skill) of agents

Tasks in a Project	Task Knowledge
T1	[0.6,0,0]
T2	[0,0.6,0]
T3	[0,0,0.6]

Table 4: Project to be performed by the team

To observe the performance and development of the team, these three agents have to complete projects continuously. In our experimental design, the same project will be handled by the same team 40 times in succession, each time step in the experimentation represents a complete process of executing a project.

In addition to the setting of projects requirements and individual skills of the team, the critical variables aforementioned, the motivation threshold and the importance of three needs have the following values in all experiments (Table 5)

Parameter	Description	Value
T_{am}	Motivation Threshold	[0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1]
I_c	The importance of competence	[0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1]
I_a	The importance of autonomy	[0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1]
I_b	The importance of belonging	[0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1]

Table 5: The value of key variables

Input data

In the application of the model, further inputs from external sources such as data files are not required once the model is initialised.

Sub-models

The motivational need for the competence

Competence is the ability of an individual to do a job appropriately, competence is often considered to be contextual. If the task is too easy for a worker, the worker would be bored, if the task is too difficult, the worker would be anxious, an agent would be most motivated if the knowledge of itself close to the task requirement (Schiepe-Tiska 2013), this suggestion is consistent with the concept of flow, which describes when people are in a state of balance between one's skill and perceived difficulty (task demand), they will be in the zone and highly committed to the task. Hence, we need an inverted U-shape curve for explaining the relation between the need for competence and individual knowledge concerning task requirements. The satisfaction of the need for the competence of an agent a_i for a task t_j could be denoted as $MnCom(a_i, t_j) \in (0, 1]$ (Equation 1), when ak_i^l equals to tk_j^l, $MnCom(a_i, t_j) = 1$, where $\tau_i \in (0, 1]$, indicates to what extent agent a_i can tolerant or accept the difference in knowledge, the bigger τ_i is, the more discrepancy a_i can accept.

$$MnCom(a_i, t_j) = e^{-\pi \frac{(ak_i^l - tk_j^l)^2}{\tau_i}} \tag{1}$$

Where $\tau_i \in (0, 1]$, indicates to what extent agent a_i can tolerant or accept the difference in knowledge, the bigger τ_i is, the more discrepancy a_i can accept.

The motivational need for the autonomy

Autonomy is the capacity of an agent to act following its preference and willingness rather than under the influence of others. Agents want to be autonomous and have individual liking to use a certain skill, expertise, or knowledge, the more agents are capable of doing the tasks they like, the more perceived sense of choice ability, the more satisfied they are with the need for autonomy.

Generally, the sense of choice occurs when a certain activity is executed, which has a certain impact on the subsequent perception of autonomy. Therefore, the satisfaction of autonomy is influenced by both moment-to-moment and previous experience. Here we choose a simple solution, the satisfaction of autonomy is being increased if the initial choice of team members is consistent with the final allocation. If not, the satisfaction of autonomy would be decreased. This implies that for each task, the satisfaction of autonomy can be affected even when the agent does not want to perform it, nor performs it. Hence, we denote the need for autonomy of an agent for a particular task as $MnAut(a_i, t_j) \in (0, 1)$ (Equation 4).

The autonomy of the agent is being defined to what extent can an agent get what it wants. As the difference between the initial choice (what an agent wants) and the final allocation (what an agent gets) is larger, the need for autonomy is less fulfilled. We take the difference between the initial choice and the final allocation as the instantaneously perceived autonomy by agents. This instantaneous perception of autonomy of agent a_i for the task t_j can be denoted as Equation 2,

$$p_t Aut(a_i, t_j) = \sigma_i Diff_t(FinalAllocation, InitialChoice) \tag{2}$$

Where σ_i shows the reactivity of each agent's perceived autonomy of the difference between final choice and initial choice, $Diff_t(Finalallocation, Initialchoice) = 0 or 1$, when $Diff_t = 1$, it indicates the final allocation of a_i is equal to its initial choice when facing t_j at time t, thus a_i gets what it wants, which implies a_i perceived autonomy at time t, when $Diff_t = 0$, it shows the final allocation of a_i is distinguished from its initial choice, and a_i didn't perceive autonomy at this moment. The instantly perceived autonomy will gradually weaken over time, for a_i, after a while T, the $p_t Aut(a_i, t_j)$ will decay into (as Equation 3),

$$p_T Aut(a_i, t_j) = pAut(a_i, t_j)e^{-\mu_i T}, 0 < \mu_i \leq 1 \tag{3}$$

Where μ_i represents the decay rate, the value of μ_i for each member may be different, and the rate of decay is also different. The larger the μ_i, the faster the decay, and vice versa.

The satisfaction of autonomy is continuously accumulated, and the accumulation process goes through a process that grows from fast to slow, for this, the motivation of agent a_i for the task t_j driven by the need for autonomy at time t is expressed as,

$$M_t nAut(a_i, t_j) = \frac{1}{1 + (\frac{1}{M_{t_0} nAut(a_i, t_j)} - 1)e^{-\varrho_i t}} \times Inf(pAut(a_i, t_j)) \tag{4}$$

$$Inf(pAut(a_i, t_j)) = \begin{cases} \sum p^i_{t-i} Aut(a_i, t_j), & \text{if } 0 \leq \sum p^i_{t-i} Aut(a_i, t_j) \leq 1 \\ 1, & \text{if } \sum p^i_{t-i} Aut(a_i, t_j) > 1 \end{cases} \tag{5}$$

Where $M_{t_0} nAut(a_i, t_j)$ indicates the initial motivation of autonomy, $Inf(pAut(a_i, t_j)$ implies the influence of autonomy perceived in the past on the current motivation of autonomy, $p^i_{t-i} Aut(a_i, t_j)$ represents the perceived autonomy of a_i on t_j at the time i after time $(t-i)$. $Inf(pAut(a_i, t_j) \in [0, 1]$, generally, an agent will not be affected by the past unrestrictedly, the upper limit for this impact is 1 in this paper, indicating that when the past impact accumulates to 1, the agent will consider itself autonomous so far, and the cumulative equation for the satisfaction of autonomy at this moment is as Equation 4. Where ϱ_i shows to what extent the autonomy is influenced by the previous experience, the larger the ϱ_i, the more autonomy is affected by history. It is precisely because each agent has different reactivity, decay, and accumulation for autonomy, which reflects the heterogeneity of agents.

The motivational need for the belonging

The need for belonging refers to the need the agent has of being connected and as a part of a larger whole. In a setting in which a team performs a project, this logically implies that the agent wants to be a part of the team that performs the project. As we addressed that the sense of belonging of each individual depends on its feelings of connectedness. In this paper, we determined to adopt social connectivity as a proxy to represent members' belonging. Basically, this social connectivity refers to connectivity to the other agents, it is defined as an experience of belonging and relatedness, based on quantitative and qualitative social relationships (Walton et al. 2012). Social connectivity is intended to capture the social experience derived from a recent interaction. It is the connectivity between individuals and groups from the overall level that pertains to one's social network (Jose et al. 2012).

$Agent$	a_1	$\cdots$	a_j	$\cdots$	a_m
a_1	/	$\cdots$	$CS_t^{1\to j}(a_1)$	$\cdots$	$CS_t^{1\to m}(a_1)$
$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\ddots$	$\vdots$
a_i	$CS_t^{i\to 1}(a_i)$	$\cdots$	$CS_t^{i\to j}(a_i)$	$\cdots$	$CS_t^{i\to m}(a_i)$
$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\ddots$	$\vdots$
a_m	$CS_t^{m\to 1}(a_m)$	$\cdots$	$CS_t^{m\to j}(a_m)$	$\cdots$	/

Table 6: Representation of the connection strength between members within the team.

From the perspective of social connectivity, the need for belonging is related to connectivity between individuals. In this paper, we utilise connection strength to measure such connectivity, which is dynamic, depending on the collaboration and interaction between agents. The connection strength between a_i and other agents at time t, can be expressed as $CS_t^{i\to j}(a_i), i \neq j$, where, $j = 1, 2, \cdots, m$. The status of connection strength of the entire team is shown in Table 6.

$$CS_t^{i\to j}(a_i) \begin{cases} \alpha_i \log_2(1 + RoC_t^{i\to j}) + (1-\alpha_i)\log_2(1 + RoA_t^{i\to j}), & \text{if } 0 \leq RoA_t^{i\to j} \leq 1 \\ \alpha_i \log_2(1 + RoC_t^{i\to j}) - (1-\alpha_i)\log_2(1 - RoA_t^{i\to j}), & \text{if } -1 \leq RoA_t^{i\to j} < 0 \end{cases} \tag{6}$$

Where $CS_t^{i\to j}(a_i) \in [0,1], i \neq j$, $RoC_t^{i\to j} \in [0,1]$ indicated the ratio of the collaboration of a_i and a_j having been working on the same project at time t, $\alpha_i \in (0,1]$ indicates to what extent the collaboration rate affects connection strength, the collaboration status between agents can be expressed as the symmetric matrix MC (Equation 7), since the collaboration is mutual, so the mutual connections between agents are enhanced at the same time as the collaboration. In MC, $C_t^{i\to j}$ indicates whether or not a_i and a_j collaborate at time t, $C_t^{i\to j} = C_t^{j\to i} = 0, 1$, when $C_t^{i\to j} = 1$, it shows a_i and a_j collaborate, they work on the same project at time t, while $C_t^{i\to j} = 0$ shows they do not work on the same project. $RoC_t^{i\to j} = RoC_t^{j\to i} = \frac{\sum_t C_t^{i\to j}}{N(P)} = \frac{\sum_t C_t^{j\to i}}{N(P)}$, $N(P)$ represents the number of projects.

$RoA_t^{i\to j} \in [-1,1]$ refers to the ratio at which a_i should be accountable to a_j on the outcome of the interaction between them, $(1-\alpha_i) \in (0,1]$ implies that how much the accountability affects connection strength. The accountability between agents of the team can be expressed as the matrix MA (Equation 8), $A_t^{i\to j} = -1, 1$, when $A_t^{i\to j} = 1$, it indicates that a_i cause the final allocation of a_j to be inconsistent with its initial choice, for a_i, the connection between a_j would be strengthened due to the positive interaction outcome with a_j, however, for a_j, the connection would be weakened because of the negative interaction causing the inconsistency of a_j's choice occurs, accordingly, $A_t^{j\to i} = -1$. Since the accountability between any two agents is likely to be distinct, MA is an asymmetric matrix, when $I^{i\to j} \neq 0$,$RoA_t^{i\to j} = \frac{\sum_t A_t^{i\to j}}{I^{i\to j}}$, $I^{i\to j} = 0$,$RoA_t^{i\to j} = 0$, $I^{i\to j}$represents the number of interactions between a_i and a_j, the matrix MI represents the interaction among agents of the entire team (Equation 9).

$$MC_t = \begin{pmatrix} C_t^{1\to 1} & \ldots & C_t^{1\to j} & \ldots & C_t^{1\to m} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ C_t^{i\to 1} & \ldots & C_t^{i\to j} & \ldots & C_t^{i\to m} \end{pmatrix}. \tag{7}$$

$$MA_t = \begin{pmatrix} A_t^{1\to 1} & \ldots & A_t^{1\to j} & \ldots & A_t^{1\to m} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ A_t^{i\to 1} & \ldots & A_t^{i\to j} & \ldots & A_t^{i\to m} \end{pmatrix}. \tag{8}$$

$$MI = \begin{pmatrix} I^{1\to 1} & \ldots & I^{1\to j} & \ldots & I^{1\to m} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ I^{i\to 1} & \ldots & I^{i\to j} & \ldots & I^{i\to m} \end{pmatrix}. \tag{9}$$

Based on the above description, the belonging of an agent is related to its overall connectivity, which is denoted by Equation 10,

$$MnBel_a(a_i) = \beta_i \log_2(1 + CS(a_i)) \tag{10}$$

$$CS(a_i) = \frac{1}{m-1} \sum_{j=1, i \neq j}^{m} CS^{i \to j}(a_i) \tag{11}$$

Where $CS(a_i)$ (Equation 11)shows the average connection strength between a_i and other agents, $\beta_i \in (0, 1]$, which indicates to what extent the need for belonging of a_i affected by its overall connectivity.

The **overall expected motivation** of agent a_i $(MK(a_i))$. In the workplace, it is feasible for workers to make choices based on a combination of three motivations. In this paper, this combination is called overall expected motivation, which is a weighted average related to the different importance of three needs, as Equation 12.

$$MK(a_i) = \frac{I_c(a_i)}{W(a_i)} MnCom(a_i) + \frac{I_a(a_i)}{W(a_i)} MnAut(a_i) + \frac{I_a(a_i)}{W(a_i)} MnAut(a_i) \tag{12}$$

Where,$W(a_i) = I_c(a_i) + I_a(a_i) + I_b(a_i)$,$I_c(a_i)$,$I_a(a_i)$,$I_b(a_i)$ respectively represent the importance of motivation for competence, autonomy, belonging of individuals, they may be distinguished, which implies that agents believe that the three needs of the overall motivation are of different importance.

The initial choice of an agent

Specifically, when every agent decides whether or not to perform a task is determined by the value of two conceptual nodes, an I-node and a Y-node, which respectively means 'I will do it' and 'I will not do it, I want you to do it. Both I-node and Y-node have values varying from 0 to 1, indicating the extent to which the agent wants and does not want to do a particular task, and the values are related to four elements: agent knowledge, knowledge requirement of tasks, agent motivation, and motivation threshold. The values of I-node (V_{I-node}) and Y-node (V_{Y-node}) represent different extents. The former indicates to what extent I want to do a certain task, and the latter indicates to what extent I do not want to do a certain task. If the value of I-node is not lower than Y-node ($V_{I-node} \geq V_{Y-node}$), then I do, and vice versa. Based on the relationship between the four elements aforementioned, the following four zones can be divided, shown in Figure 2.

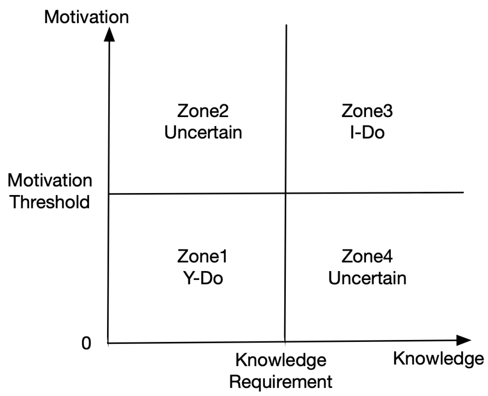


Figure 2: Four zones for making an initial choice.

Zone 1: when there is insufficient knowledge and motivation, $AK < T_ak$ and $AM < T_am$, which will consequently result in a Y-Do choice. The value of I-node and Y-node can be simply described as Equation 13 and Equation 14:

$$V_{I-node} = 0 \tag{13}$$

$$V_{Y-node} = \lambda \frac{T_{ak} - AK}{T_{ak}} + (1-\lambda) \frac{T_{am} - AM}{T_{am}} \tag{14}$$

Zone 2: where the motivation is sufficient, and the knowledge is insufficient, $AK < T_{ak}$ and $AM >= T_{am}$ (as Equation 15 and Equation 16).

$$V_{I-node} = (1-\lambda) \frac{AM - T_{am}}{1 - T_{am}} \tag{15}$$

$$V_{Y-node} = \lambda \frac{T_{ak} - AK}{T_{ak}} \tag{16}$$

Zone 3: where the knowledge and motivation of an agent are both exceeding their threshold, $AK >= T_{ak}$ and $AM >= T_{am}$ which leads to an I-Do choice. In this situation, the value of the I-node is a function of the knowledge (AK), motivation (AM), and their threshold (T_{ak}, T_{am}), and a parameter $\lambda \in [0,1]$ which implies the balance between knowledge and motivation (ad Equation 17 and Equation 18).

$$V_{I-node} = \lambda \frac{AK - T_{ak}}{1 - T_{ak}} + (1-\lambda) \frac{MK - T_{am}}{1 - T_{am}} \tag{17}$$

$$V_{Y-node} = 0 \tag{18}$$

Zone 4: In this situation, where the knowledge is sufficient, but motivation is insufficient,$AK >= T_{ak}$ and $AM < T_{am}$. We define the value of the I-node as a function of its knowledge, and the Y-node as a function of its motivation (as Equation 19 and Equation 20).

$$V_{I-node} = \lambda \frac{AK - T_{ak}}{1 - T_{ak}} \tag{19}$$

$$V_{Y-node} = (1-\lambda) \frac{T_{am} - AM}{T_{am}} \tag{20}$$

The individual learning and forgetting

The learning phenomenon has proved applicable in various organisations, people can benefit from previous experience and therefore they would "learn" to improve productivity. Learning is an important method of adapting and responding to the organisational environment and an important process for adapting and developing team capabilities. The learning process stems from individuals repeating the same task and gaining skill or efficiency from their own experience and practice (Jarkas & Horner 2011). The process of handling tasks and using knowledge is also a process of the learning experience for individuals, this acquired experience could be attributable to increased knowledge about the task being performed (Jarkas & Horner 2011). The more frequently someone performs a task, the better they get at it.

The knowledge of the agent will improve after the task has been executed because an agent will learn the particular knowledge by doing tasks, the learning amount relates to the times of uses of certain knowledge. The learning speed will change from slow to fast, then to slow. The learning curve is asymptotic, and the idealized general form of learning curve follows the Sigmoid function (Leibowitz et al. 2010; Murre 2014)(as Equation 21).

$$AK_t(a_{i,l}) = \frac{1}{1 + (\frac{1}{AK_{t_0}} - 1)e^{-\gamma_i T_p(ak_i^l)}} \tag{21}$$

Where $T_p(ak_i^l)$ represents the period of a_i continuously performing a particular knowledge, $AK_t(a_{i,l})$ shows the lth knowledge of a_i at time t. Besides, $\gamma_i \in (0,1]$ illustrates a learning ability of a_i, the larger the γ_i, the higher the learning ability.

Besides, there is enough empirical evidence that knowledge depreciation (forgetting) occurs in organisations (Argote 1993). All of the knowledge not being used will be gradually forgotten with time. The behaviour of knowledge forgetting is usually assumed to have the same form as knowledge learning, except that the forgetting rate is negative and the learning rate is positive (Jaber 2013). This widely recognised assumption is consistent with the suggestion that the learning and forgetting effects are considered as mirror images of each other (Globerson et al. 1989). As we elaborated on the learning curve, forgetting curves also comply with an asymptotic curve, see the following equation 22.

$$AK_t(a_{i,l}) = \frac{1}{1 + (\frac{1}{AK_{t_0}} - 1)e^{-\zeta_i T_{np}(ak_i^l)}} \tag{22}$$

Where ζ_i implies the forgetting rate, $T_{np}(ak_i^l)$ represents how long has it passed since a_i not performing a particular knowledge. The dynamic of the agent knowledge over time with learning and forgetting is shown in Figure 3.

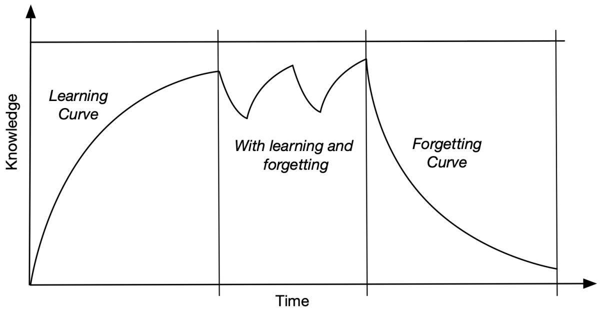


Figure 3: Four zones for making an initial choice.

Metrics and indicators

In this paper, we measure how fast projects are performed by the team and their satisfaction after handling the projects. Simply, indicators are designed from two aspects: performance time and Group satisfaction. **Performance Time**(T_{perf}) consists of two parts: allocation time and completion time (as Equation 23). The former refers to the time used during the allocation process, also known as coordination time, denoted as T_{coor} (as Equation 24), $T_{coor}(a_i, a_j)$ shows the coordination time spent on the task t_j between the agent a_i and a_j, the latter part demonstrates the time used to execute the whole project, equalling to the time spent by the person who completed the task last.

$$T_{perf} = T_{coor} + Max(t_{exec}(a_i)) \tag{23}$$

$$T_{coor} = \sum Max(T_{coor}(a_i, a_j)) \tag{24}$$

Where $t_{exec}(a_i)$ represents the time of a_i spending on executing the tasks which are allocated to it, as Equation 25.

$$t_{exec}(a_i) = \sum \frac{TD(t_j)}{\lambda \times AK(a_i) + (1-\lambda) \times AM(a_i} \tag{25}$$

Group Overall Satisfaction shows the overall satisfaction of the team as a whole, here, we adopt the average satisfaction of all members as the group overall satisfaction, which is denoted as Equation 26,

$$GS = \frac{1}{m}\sum_{i=1}^{m}\left(\frac{I_c(a_i)}{W(a_i)}SnCom(a_i) + \frac{I_a(a_i)}{W(a_i)}SnAut(a_i) + \frac{I_b(a_i)}{W(a_i)}SnBel(a_i)\right) \tag{26}$$

Where m represents the number of team members. The implications of $W(a_i)$,$I_c(a_i)$,$I_a(a_i)$,$I_b(a_i)$ are consistent with their implications in individual motivation. For every agent, they have three types of motivational needs, for a particular need, its satisfaction level shows to what extent it has been fulfilled, we define individual need satisfaction as the average of agent's satisfaction for every task, denoted as $SnCom(a_i)$, $SnAut(a_i)$, $SnBel(a_i)$) (Equation (27-29)), they respectively represent the satisfaction of need for competence, autonomy, and belonging.

$$SnCom(a_i) = \frac{1}{n}\sum_{j=1}^{n} MnCom(a_i, t_j) \tag{27}$$

$$SnAut(a_i) = \frac{1}{n}\sum_{j=1}^{n} MnAut(a_i, t_j) \tag{28}$$

$$SnBel(a_i) = \frac{1}{n}\sum_{j=1}^{n} MnBel(a_i, t_j) \tag{29}$$

Discussion

There are several variables and parameters in the model, which are not directly relevant to achieving our purpose, may influence the results. Such variables include the team size, project size, types of knowledge, and other individual parameters. Hence, we fixed those parameters, make the team processes projects in the context created by the experimental settings.

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