Multi-agent simulation of partner selection behaviour based on matching degree in collaborative product development process

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Abstract

Collaborative Product Development (CPD) process is characterized by autonomous task control, dynamic task sequence, and frequent team collaboration, which endow the process with high flexibility and uncertainty. To make the process predictable and improve process efficiency, it is essential to model, simulate, and analyse the process by considering all these characteristics. Our work focuses on studying the human working behaviours in CPD process by agent-based simulation, which we think is the main source of process uncertainty and flexibility. In this paper, the partner selection behaviours are studied under the frame of agent-based simulation. In the simulation, the design agent selects his partner according to matching degree including ability and character. The simulation results indicate that the proposed utility strategy can effectively shorten the project total time of the case.

Keywords: collaborative product development, partner selection, multi-agent simulation

1 Introduction

Scholars usually describe, predict, evaluate, and optimize the design process CPD process by modelling and simulation. The typical modelling methods are: DSM (design structure matrix), Petri Nets and activity-on-node graphs et al. DSM can be applied to describe the complex relationship and dynamical dependencies among tasks implicitly by information flow, which can predict and evaluate the cost and duration [1-3]; Petri nets and activity-on-node graphs can be used to simulate workflow and to predict lead times of product development projects by formulating task networks [4-6]. In the above models, the process is described as a set of interactive tasks or activities, while the designers are considered as passive “design resources” assigned to activities. As a result, the designer’s autonomous and cooperative activities cannot be described and evaluated directly in the corresponding simulations, and it is difficult to anticipate the process and task execution time for the complex interaction relationship among designers in CPD process. To make the design process be able to quickly respond to the highly dynamic and distributed design environment, it is emphasized in CPD that team members are the most flexible and active elements. In this case, agent-based modelling and simulation (ABMS) has been recently considered as a valuable research approach as it supports active and collaborative process description of adaptive complex systems and reflects human’s autonomous as well as cooperative behaviours [7, 8]. In this paper, we concentrate on cooperation behaviour of members by agent-based modelling, including local partner selection behaviour of design agents, negotiation behaviour between design agents and arbitration behaviour of manager agent in partner selection conflict resolution.

In CPD project, an initial plan should be worked out before the real executing of the process. And then, during the executing process, the plan has to be adjusted according to the dynamic uncertainty of the design environment. One important reason of dynamic uncertainty is caused by ability limitation of designers. In this case, designers need partner to collaborate, which make the plan is adjusted by agents’ selection behaviours during the simulation. It is obvious that different selection behaviours of agents may play an important role to the efficiency of the process. Traditional partner selection often focuses on the macro fields such as supplier selection, enterprise alliance selection [9,10] and they provide efficient algorithm, systematic criterions et al. [11, 12], but the flexible human factors in the high dynamic environment are less motioned. In this paper, we emphasize the partner selection behaviours in relatively micro world and explore the behaviours how to influence the development efficiency.

To make the agents’ behaviours more flexible, we designed a partner selection behaviour process for the agents, in which the design agent selects his partner according to matching degree. To make the process more efficient, the strategies are proposed with consideration of task priority and matching degree simultaneously.

The rest of the paper is organized as follows. In Section 2, the agent model and partner selection process are introduced; Section 3 proposes matching degree algorithm. Then, simulation experiments of different scenarios are designed and carried out based on a real CPD project in Section 4.

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2 Simulation model and predicate definition of behaviours

In our approach, the simulation model is composed by agent model and environment model. The agent model maps organization members as intelligent agents and describes dynamic collaboration and iteration characteristics of agent's behaviour by defining a set of behaviour goals and knowledge (as shown in Figure 1). The environment model takes design tasks, product information, and design resource as environment objects, which can change their status by designers' behaviours. Components of the agent model include agent sensor, agent decision protocols, agent behaviours, and agent driver. The agent included 3 levels: react level, local programming level and group level. Agent will call different decision protocols under different environment change. The agent apperceives design environment objects, i.e. tasks, product information, and resource, by agent sensor. Then, the agent behaves according to the status of the environment and his decision protocols. Thereafter, the agent's behaviours act on the environment objects by agent driver. Based on this principle, the design process can be simulated as a continuous evolving process of the agents and the design environment objects. Hence, this simulation approach is expected to effectively support human behaviours analysis of the process.

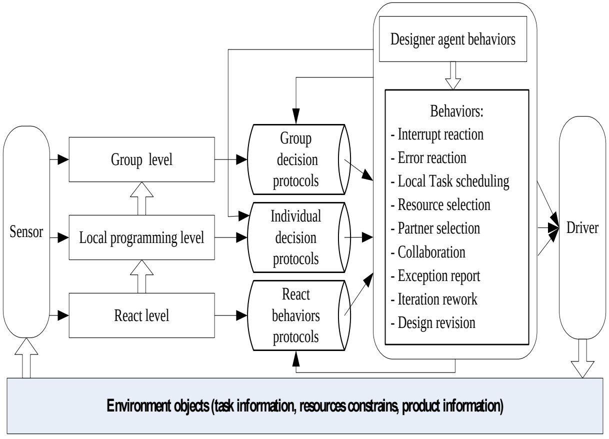

FIGURE 1 Agent-based simulation model of CPD

The detail definition and description of decision protocols of design agent can be found in our former researches [13, 14]. In this paper, the predicate and function definition are added shown as Table 1.

Based on the characteristics of CPD process, we have proposed the partner selection process shown as Figure 2. There are 3 phases in the process: 1) collaboration request, 2) collaboration response, 3) partner selection. Design agent firstly releases collaboration request to potential collaborative partners; potential agents respond to request according to their behaviour rules. Design agents who need partners select the best one from potential partners who accept request according to their status and matching degree between each other. The detailed steps are given as followings by using predicate and function definition.

TABLE 1 Predicate definition and function

Predicate definition	**Description**
DESIGNER(x)	Design agent x, domain of individuals is $A=\{x_1, x_2 \dots x_i\}$
TASK(y)	Design task y, domain of individuals is $B=\{y_1, y_2 \dots y_i\}$
EXECUTE(x,y)	Design agent x execute design task y, $x \in A$, $y \in B$
SEL_T(x,y_i)	Design agent x select task y_i, which belongs to his task box, $x \in A$, $y \in B$
SEL(x_1,x_c)	Design agent x_1 send collaboration request to x_c, $x_1 \in A$, $x_c \subset A$, $x_1 \notin x_c$
ACCEPT(x_1,x_2)	Design agent x_2 response collaboration request from x_1, $x_1,x_2 \in A$, $x_1 \neq x_2$
SEL_P(x_1,x_2)	Design agent x_1 select x_2 as the collaboration partner, $x_1,x_2 \in A$, $x_1 \neq x_2$
function definition	Description
Match(x)	Compute matching degree

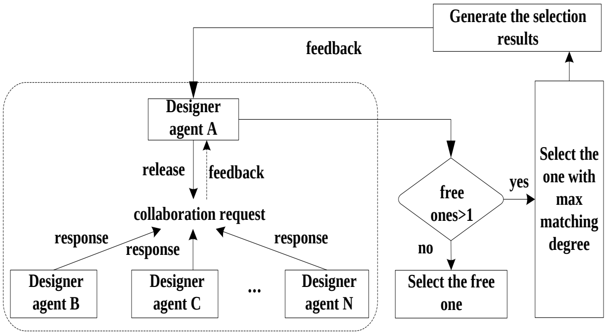

FIGURE 2 Partner selection process in CPD project

Step1.

$$(\forall x_1)(\forall x_2)(EXECUTE(x_1, y)) \wedge E(collabrate(x), \alpha) \rightarrow SEL(x_1, x_2),$$

from Figure 2, design agent A is x_1, B, C, D can be x_2, and x_1 release the collaboration request.

Step2.

$(\forall x_1)(\forall x_2)(ACCEPT(x_1, x_2))$, other design agents respond to the request.

Step3.

$$(\forall x_1)(\forall x_2)(SEL\_P(x_1, x_2)) \wedge E(match(x), \max) \wedge E(status(x), FREE),$$

design agent A selects the partner with "free" status and maximum matching degree.

3 Matching degree algorithm

Matching degree and task priority are 2 important indexes in partner selection process. Task priority algorithm is proposed in our paper [14], and matching degree algorithm will be introduced in the following. To compute matching degree between agents, we firstly studied the attributes of design agents in CPD process.

3.1 DESIGNERS' ATTRIBUTES ANALYSIS

As the most active element in the CPD process, designers play a significant role in CPD for their autonomy, initiative and collaboration. Thus, designers' attributes are the most important basis to select partner. In this paper, we have summarized designers' attributes including ability attributes and character attributes according to the references. The specification is shown as Table 2.

TABLE 2 Designers' attributes

Category	**Attributes name**	**Attributes description**
Ability attributes	technique ability $T_d()$	The ability of designers to solve technical problems successfully in professional fields. It is the combination of theoretical knowledge gained by specific education with experience by practices. Thus, the technique ability can be measured by 2 aspects: theoretical knowledge level and level of solving the common technical problem successfully
	innovation ability $I_d()$	The ability of designers to solve creative problem based on their knowledge and experiences, introducing multi-industry and interdisciplinary knowledge, using innovation tools and approaches. There are 3 main parts: expertise, proficiency of innovation tools and approaches.
	collaboration ability $C_d()$	There are 2 kinds of collaboration in CPD: 1) based on task relationship; 2) collaboration autonomously. In the first situation, designers must do process and data collaboration for the task relationship; in the second one, designers collaborate for lack of ability, they should select partner to finish the task. Collaboration ability includes: collaboration experience level and communication ability.
Character attributes	decision character $D_p()$	There are 3 types: irresolute, conventional and resolute. Irresolute ones make decision speed slowly, and are easily affected by the rules; conventional ones are usually scholasticism; resolute ones have a quick wit and decisions are made quickly.
	cooperation character $C_p()$	There are 3 types: leading, obedient and cooperative. Leading ones get on well with others and emphasize the macroscopic; obedient ones emphasize the details and are weak in communication; cooperative ones also pay attention to details but are good at communication.

3.2 MATCHING DEGREE OF ABILITY ATTRIBUTES

Matching degrees between design agents are different for different ability requirements of tasks. In this case, algorithm of matching degree of ability is designed as follows while Agent *i* and Agent *i'* execute Task *j*.

$$PP_{ii'j}^{A}=\sum_{k}^{3}\omega_{k}^{j}\cdot PP_{ii'k}\ . \tag{1}$$

In the above algorithm, $PP_{ii'k}$ means the matching degree of Agent *i* and Agent *i'* in ability *k*, while ω_k^j ($\sum_k^3 \omega_k^j=1$) is weight of requirement for ability *k* of Task *j*.

The algorithm of $PP_{ii'k}$ is as follows.

$$PP_{ii'k}=1-\frac{|y-x|}{Y-X},x,y\in[X,Y] \tag{2}$$

x :value of Agent *i* in ability *k*, $x\in[a_1,b_1]$;

y : value of Agent *i'* in ability *k*, $y\in[a_2,b_2]$;

X : $X=\min(a_1,a_2)$;

Y : $Y=\max(b_1,b_2)$.

In above algorithms, *a* and *b* stand for values of upper and lower bounds of fuzzy interval respectively, which is corresponding to Table 3.

TABLE 3 Interval values corresponding to linguistic utility values of designers

Value		**[0, 0.2]**	**[0.2, 0.4]**	**[0.4, 0.6]**	**[0.6, 0.8]**	**[0.8, 1.0]**
Linguistic Utility Value	technique ability	Lower	Low	Normal	High	Higher
	innovation ability	Lower	Low	Normal	High	Higher
	collaboration ability	Lower	Low	Normal	High	Higher

3.3 MATCHING DEGREE OF CHARACTER ATTRIBUTES

Based on Chen's research [15], we summarize the character attributes of designer in Table 1. According to their accomplishment, the identification of character attributes are shown as Table 4, Table 5 is the symbol illustration, and the matching degree of various attributes are shown in Table 10. The final value of character attributes $PP_{ii'j}^{C}$ can be got after normalization.

TABLE 4 Character attributes of designers and identifications

attributes	**decision character**			**cooperation character**		
	irresolute	conventional	resolute	leading	obedient	cooperative
identification	P+T	J+T	J+F	N+E	S+I	S+E

TABLE 5 Combination of character attributes and symbol illustration

	P+T	J+T	J+F		
P+T	+&o	-&o	-&+		
J+T	-&o	+&o	+&+		
J+F	-&+	+&+	+&o		
	N+E	S+I	S+E	symbol	value
N+E	o&+	+&o	+&+	+	9
S+I	+&o	o&-	o&o	-	-3
S+E	+&+	+&o	+&+	o	3

3.4 MATCHING DEGREE ALGORITHM

Based on ability and character attributes, matching degree algorithm of Agent *i* and Agent *i'* is shown as follows while executing Task *j*.

$$PP_{ii'j} = \lambda_1 PP^A_{ii'j} + \lambda_2 PP^C_{ii'j}\,. \tag{3}$$

In above algorithm, λ_1 and λ_2 are the weights of ability and character attributes, $\lambda_1 + \lambda_2 = 1$.

4 Case study

4.1 SIMULATION RUNNING AND EXPERIMENTS DESIGN

In order to demonstrate the partner selection method, we design 2-group contrastive experiments as shown in Table:

TABLE 6 Experiment design

Item	Partner selection	Simulation times
Experiment 1	Select partner randomly	100
Experiment 2	Select partner based on higher matching degree	100
Aim	prove the importance of matching degree	

4.2 ORIGINAL DATA AND INPUT PARAMETERS

There is some collaborative product development project with 15 tasks and 9 designers. The process chart with normal execution time of every task and the designer-task allocation is shown as Figure 3.

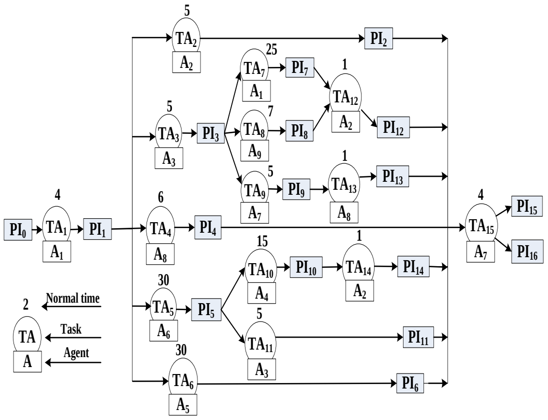

FIGURE 3 The process chart of some collaborative product development process with normal execution time of every task and the designer-task allocation

Table 7 and 8 are attributes of designers and input parameters respectively.

TABLE 7 Attributes of designers

Designer	Ability attributes			Character attributes		
	Technique	*Innovation*	*Collaboration*	*Decision*	*Cooperation*	*Identification*
A_1	0.8	0.6	0.7	conventional	cooperative	JTSE
A_2	0.7	0.8	0.7	resolute	leading	JFNE
A_3	0.7	0.6	0.6	conventional	obedient	JTSI
A_4	0.6	0.5	0.8	resolute	cooperative	JFSE
A_5	0.8	0.7	0.7	irresolute	obedient	PTSI
A_6	0.6	0.9	0.8	resolute	cooperative	JFSE
A_7	0.5	0.6	0.8	irresolute	obedient	PTSI
A_8	0.9	0.7	0.6	resolute	leading	JFNE
A_9	0.8	0.8	0.8	conventional	cooperative	JTSE

TABLE 8 Parameters

Initial status of product information *PI()*	PI_0= Known; PI_j= Unknown (*j*=1,2,3…16);
Learning effect factor *decrease*	redo_decrease=0.8, except_decrease=0.8
Collaboration rate: α	α=2%
Exception rate: β	β=2%
Error rate: γ	γ=2%
Rework rate: λ	$\lambda(TA_1)$=2%，$\lambda(TA_5)$=2%，$\lambda(TA_7)$=2%，$\lambda(TA_{10})$=2%，$\lambda(TA_{11})$=2%
Rejection rate: τ	$\tau(1)$=5%,$\tau(2)$=2%,$\tau(3)$=1%,
Response for selection partner:	Global response

4.3 MATCHING DEGREE RESULTS

Based on former matching degree algorithm, matching degrees of character attributes and ability attributes are calculated in detail respectively. Table 9 shows matching degrees of character attributes between each agent, and Table 10 contains matching degrees of ability attributes of A1 with other agents while executing TA_{18}, TA_{20}, TA_{23}, TA_{25} and TA_{27} which are temporary tasks generated in the process in some simulation.

TABLE 9 Matching degree of character attributes

	A_1 (JTSE)	**A_2 (JFNE)**	**A_3 (JTSI)**	**A_4 (JFSE)**	**A_5 (PTSI)**	**A_6 (JFSE)**	**A_7 (PTSI)**	**A_8 (JFNE)**	**A_9 (JTSE)**
A_1 (JTSE)	-								
A_2(JFNE)	24	-							
A_3(JTSI)	30	36	-						
A_4(JFSE)	30	18	36	-					
A_5(PTSI)	6	18	0	18	-				
A_6(JFSE)	30	18	36	30	18	-			
A_7(PTSI)	6	18	0	18	12	18	-		
A_8(JFNE)	24	24	36	18	18	18	18	-	
A_9(JTSE)	36	24	30	30	6	30	6	24	-

TABLE 10 Matching degree of ability attributes of A_1

	TA_{18}	**TA_{20}**	**TA_{23}**	**TA_{25}**	**TA_{27}**
A_2	0.701065	0.67282	0.714565	0.709795	0.71809
A_3	0.798395	0.82718	0.787235	0.790205	0.78191
A_4	0.719345	0.73031	0.735845	0.720005	0.7343
A_5	0.5653267	0.5255767	0.5626867	0.5728567	0.5668567
A_6	0.618005	0.58922	0.630665	0.626195	0.63449
A_7	0.43976	0.481565	0.47378	0.437315	0.468905
A_8	0.5668	0.5668	0.5668	0.5668	0.5668
A_9	0.863185	0.832345	0.846565	0.86629	0.848995

4.4 PARTNER SELECTION EXPERIMENT

Null hypothesis: *The project total time has no significant difference with that of the random selection, when designers select partner based on matching degree, i.e.* $PTT_1 = PTT_2$. Results of z test are shown in Table 11.

TABLE 11 z test results

Item	**Sample 1**	**Sample 2**
Mean	85.2	71.03
Covariance	121.5152	163.3223
N	100	100
Hypothesis of mean deviation	0	
z	8.395977529	
P(Z<=z) One-tailed	0	
z One-tailed	1.644853627	
P(Z<=z) Two-tailed	0	
z Two-tailed	1.959963985	

In addition, utility strategy is adopted in the 2 experiments to resolve conflict. After 100 runs respectively, $PTT_1=85.2$, $PTT_2=71.03$, Significance level $\alpha=0.05$.This value exceeds the critical value and the null hypothesis $PTT_1= PTT_2$ is rejected. This means the value of *PTT* in experiment 2 is significantly shorter than PPT in experiment 1.

Managerial insight from partner selection experiment: in collaborative product development process, matching degree influences the duration significantly. Random selection method lacks rigor without consideration of designer's attributes. In this case, simulation can help to find out the most suitable partner for designer who needs collaboration.

5 Conclusions

In this paper, firstly, designer attributes including ability attributes and character attributes are described as the basis to evaluate the matching degree between designers; secondly, partner selection behaviour of design agents are studied under the framework of agent-based simulation. To make the agents' behaviours more flexible, a selection process is developed for the agents by using prediction definition and function definition; lastly, According to the comparative simulation study, the proposed selection method is approved to be effective in shortening lead time of the project. The simulation results also show high accordance with the typical management rules in CPD projects.

Compared with existing references, the proposed approach is developed especially for CPD projects and has the following highlights: 1) designers' ability and character are considered simultaneously; 2) Besides task priority, matching degrees between agents are also integrated into the partner selection strategy, so that the designers can select suitable collaborative partner in time; 3) considering the partner selection behaviours impact on the efficiency of the implementation of the whole process is our main work.

However, the current case study is carried out only in single project environment. It should be extended to the multi-project environment by adding project priority into the partner selection strategy when agents come from different projects and distributed organizations. In addition, to reflect the CPD process explicitly, the resource and cost restraints should be added. Based on the current work, more experiments can be carried out in the near future with the consideration of project priority, resources and costs.

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