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Improved ant Colony Optimization for Virtual Teams Building in Collaborative Process Planning

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Abstract: Virtual teams have been adopted by organizations to gain competitive advantages in this global economy. Virtual teams are a ubiquitous part of getting work done in almost every organization. For the purpose of building virtual teams in collaborative process planning, the method based on improved ant colony algorithm (IMACO) was proposed. The concept of virtual team was illustrated and the necessity of building virtual teams in collaborative process planning was analyzed. The sub tasks with certain timing relationship were described and the model of building virtual teams in collaborative process planning was established, which was solved by improved ant colony algorithm. In this paper applications of the IMACO and ACO are compared and demonstrate that the use of the IMACO algorithm performs better. An example was studied to illustrate the effectiveness of the strategy. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Virtual teams, Process planning, Computer supported cooperative work, Improved ant colony optimization

1. Introduction

Virtual teams are increasingly used to accomplish complex tasks, staffing them with the best people for the job irrespective for location. Virtual teams are a ubiquitous part of getting work done in almost every organization [1]. Generically, a team is a group of individuals who interact interdependently and who are brought together or come together voluntarily to accomplish particular tasks. Some research claims that the use of virtual teams increases capability, responsiveness, and flexibility within organization [2-3] partly because collaboration is created among team members who have different types of expertise, experience, or knowledge [4].

Globalization of international markets have created a high level of competition that requires high agility, rapid changes in the production styles and fast configuration of manufacturing systems. As the bridge between computer-aided design (CAD) and computer aided manufacturing (CAM), computer aided process planning (CAPP) plays an important role in the computer integrated manufacturing (CIM) environment [5]. There are a lot of collaboration tasks in collaborative process planning. In order to ensure the quality and efficiency of process planning, the optimal virtual team members with collaborative ability of process planning must be chosen to join in the virtual teams to complete process planning together.

2. What are Virtual Teams ?

Virtual teams can use computer-mediated communication technologies to work interdependently across space, time, and organizational boundaries [6]. Virtual team members may be located across the office, but almost as easily across the country or the world, and may rarely or perhaps never meet face to face. Townsend, DeMarie and Hendrickson [7] characterize virtual teams as groups of geographically and/or organizationally dispersed coworkers that are assembled using a combination of telecommunications and information technologies to accomplish an organizational task.

Virtual teams usually have a definable and limited membership, and the members may be geographically dispersed after the tasks finish. The members of the team depend on computer-mediated communication rather than face-to-face communication to accomplish their work.

An important advantage of virtual teams is that team members are able to collaborate and communication irrespective of time and location. Recent development of information and communication technology enables organizations to pull resources from all over the world via virtual teams. Virtual team members must communicate and collaborate to solve problems, to continue the work process, and to produce a product or service, just as any team does. Computer-mediated communication technologies also enable organizations or groups to use virtual or networked teams, which has profoundly changed how organizational members collect and distribute data and has also changed the dynamics and relationships between organizational members.

The members of the virtual teams function interdependently, usually with a shared sense of purpose that is either given to them or constructed by the team itself. The members of the virtual teams may be geographically dispersed and predominately rely on computer-mediated communication rather than face-to-face communication to accomplish their tasks. The highest degree of virtuality is when all members work apart from each other in distant locations and only communicate and interact through computer-mediated communication or other distance communication technologies.

3. Description of Virtual Teams Building in Collaborative Process Planning

The whole flow of virtual teams building in collaborative process planning includes ten steps and is shown by Fig. 1.

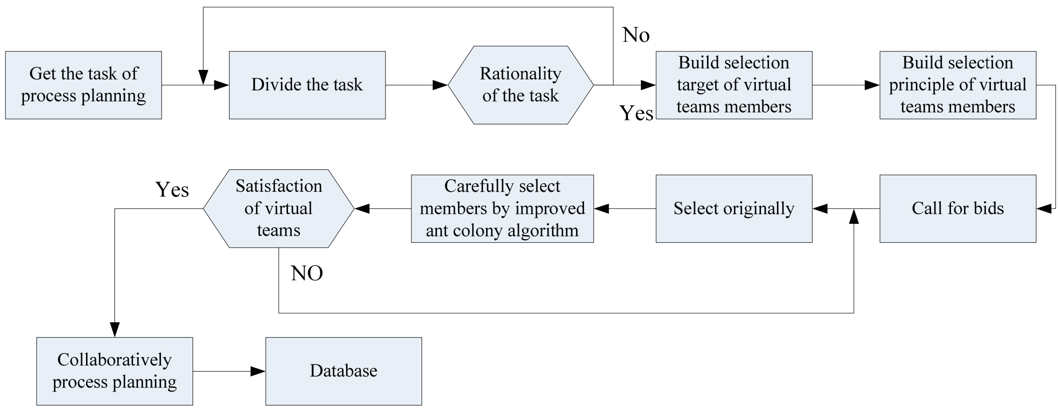

Fig. 1. Flow of virtual team building in collaborative process planning.

- Get the task order.

An organization gets a task order and analyzes market opportunity to confirm collectivity goals of virtual teams building.

- Divide the task.

This step is determined by the organizator of virtual teams, who divides the whole task into several sub-tasks with certain timing relationship according to the complexity, experience and demand of manufacturing of the task in process planning.

- Analyze market demand.

Strategic partnership relationship is established based on trust, collaboration and open communication in the process of virtual teams building and the market environment must be analyzed.

The aim of analyzing market demand is find out overt or covert demand of virtual teams members.

- Build the selection target and principle of virtual teams members.

There are many factors of the influence to members selection of virtual teams. The substantive goals should be built according to the demand of manufacturing, for example, low cost, high efficiency and so on.

- Call for bids.

The decomposed sub tasks are put on the network, including the requirements of processing time, cost, quality and so on.

When the persons with the ability above mentioned find the bidding information and send out their information and corresponding ability evaluation.

- Select originally.

The persons who do not have the ability to complete the task are screened and this work was done by the organization of virtual teams.

- Carefully select members.

After the primaries, each sub task has several candidates and improved ant colony algorithm is chosen to select virtual team members to build the virtual teams.

- Collaboratively process planning.

After the establishment of virtual teams, members can work collaboratively to complete the task of process planning.

Take members selection of virtual teams for five sub tasks as an example. There are several candidates for each sub task, which is shown by fig. 2. Where $n_i (i \in [1,5])$ is the sub task, u_{ij} is the candidate, *i* is the number of sub tasks and *j* is corresponding number of the members for each sub task.

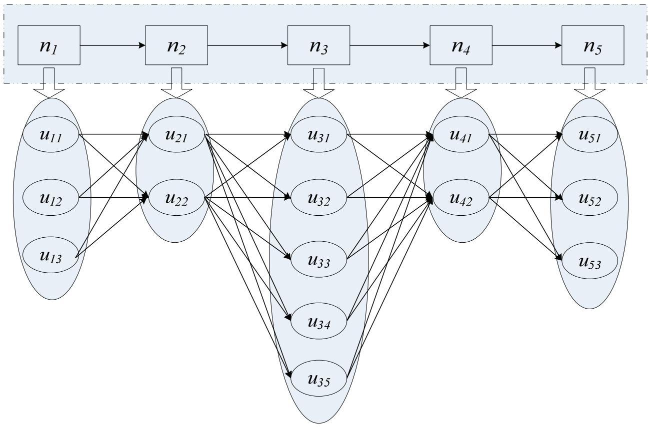

Fig. 2. Tasks and enterprises of members selection in collaborative process planning.

The total task of process planning is composed with several sub tasks, which are shown by a path. Each sub task is connected with the node to form a collaborative chain network. Each sub task is corresponding with several candidates. The most suitable members are selected for each sub task to constitute virtual teams and complete tasks of process planning.

Comprehensive abilities of process planning should be considered in the Selection of members of virtual teams. The time, cost, quality and Comprehensive abilities of process planning are chosen as the optimization objectives, in which the time and cost include process planning and manufacture of two parts.

The model of virtual teams building can be described as follows. The shortest path with the lowest cost, the shortest period, the best quality and the lowest production load rate is in search in the directed graph with sub tasks of process planning. The candidates in this path are members of virtual teams. Therefore, it is a multi-objective optimization problem. Improved ant colony algorithm is chosen to solve the problem of virtual teams building and select members of virtual teams.

4. Model Construction of Virtual Teams Building

Four important evaluation indexes are considered in virtual team building of collaborative process planning, which are the cost *Ctotal*, the time *Ttotal*, the quality *Q* and comprehensive ability *A* of process planning for members. Let C_{pr} and T_{pr} respectively represent the cost and time of process planning for candidate members. C_{tr}, T_{tr} respectively show transportation cost and transportation time. The optimization objective function according to four targets above-mentioned is shown by Eq. (1)-(4).

$$\min\ C_{total} = \min\left(C_{pr} + C_{tr}\right) = \min\left(\sum_{i=1}^{s}\sum_{j=1}^{m}\frac{C_i(j) + C_{j,j+1}}{C_{i\max}}\cdot matched_{ij}\right), \tag{1}$$

$$\min\ T_{total} = \min\left(T_{pr} + T_{tr}\right) = \min\left(\sum_{i=1}^{s}\sum_{j=1}^{m}\frac{T_i(j) + T_{j,j+1}}{T_{i\max}}\cdot matched_{ij}\right) \tag{2}$$

$$\min\ Q = \min\left(\sum_{i=1}^{s}\sum_{j=1}^{m}\left(1 - Q_i(j)\right)\cdot matched_{ij}\right), \tag{3}$$

$$\min\ A = \min\left(\sum_{i=1}^{s}\sum_{j=1}^{m}\left(1 - A_i(j)\right)\cdot matched_{ij}\right), \tag{4}$$

where *s* and *m* respectively represent the sub task and corresponding candidate enterprises. The cost and time of process planning and manufacture to candidate member u_{ij} for the sub task n_{i+1} is $C_i(j)$ and $T_i(j)$. $C_{j,j+1}$ and $T_{j,j+1}$ respectively express transportation cost and time for the members form the sub task n_i to n_{i+1}. The max cost and longest time for candidate members completing the sub task n_i are shown by C_{imax} and T_{imax}. The quality of process planning for u_{ij} completing n_i is represented by $Q_i(j)$ and $Q_i(j) \in [0, 1]$. $A_i(j)$ shows the comprehensive ability of process planning for candidate member u_{ij} and $A_i(j) \in [0, 1]$. The meanings of $matched_{ij}$ is shown by Eq. (5).

$$matched_{ij} = \begin{cases} 1 & \text{candidate member } u_{ij} \text{ is selected} \\ 0 & \text{otherwise} \end{cases}, \quad (5)$$

Finally the multi-objective problem is transformed into single objective problem. The model of member selection of virtual team in process planning is shown by Eq. (6).

$$\begin{aligned} &\min \ F=\omega_1 \cdot C_{total} + \omega_2 \cdot T_{total} + \omega_3 \cdot Q + \omega_4 \cdot A, \\ &\text{s.t. } T_{i+1\_start} \geq T_{i\_start} + T_i(j), \\ &\max \sum_{i=1}^{n} \sum_{j=1}^{m} T_i(j) \leq T_{ctotal} \\ &\max \sum_{i=1}^{n} \sum_{j=1}^{m} C_i(j) \leq C_{ctotal} \end{aligned} \quad (6)$$

The weight is represented by ω_k and $\sum_{k=1}^{3}\omega_k = 1$. The first constraint shows start time T_{i+1_start} of n_{i+1} is bigger than the sum of start time $T_{i\_start}(j)$ of n_i and machining time. The second and third constraint respectively represent the total time constraint T_{ctotal} and cost constraint C_{ctotal}.

5. Model Solving of Virtual Teams Building by Improved Ant Colony Optimization

Virtual starting point *vStart* is added in front of the initial sub-task and the execution time is zero. The execution of the sub task starts from *vStart.* Place the *M* ants in the *vStart* node at the initial time. Then the *M* ants start routing and select a member in each task. When all the ants finish all the tasks, the set formed by members of sub tasks is built [8].

All candidate members u_{ij} of sub-task n_i constitute solution space of team members selection. The candidate members for each sub-task are continuous subset. The ants can move toward a fixed target in each iteration of ant colony algorithm.

5.1. Rules of Virtual Team Building

The ant, for example h (h=1, 2, …, M), transfers the direction according to the edge of the pheromone quantity in the optimization process. The ants pass the candidate members which are then selected to team members of completing corresponding tasks. $\tau_{jk}(t)$ is residual pheromone on directed line (j, k) of candidate member u_{ij} for the sub task n_i to the next $u_{i+1,k}$ for n_{i+1}. $P_{jk}^h(t)$ is the probability of selecting members $u_{i+1,k}$ for the ant in the T traversal. The formula of state transition probability is shown by Eq. (7).

$$P_{jk}^h(t) = \begin{cases} \dfrac{\left[\tau_{jk}(t)\right]^{\alpha} \bullet \left[1/F_{jk}\right]^{\beta}}{\sum_{s \in allowed_h} \left[\tau_{js}(t)\right]^{\alpha} \bullet \left[1/F_{js}\right]^{\beta}}, & k \in allowed_h \\ 0, & \text{otherwise} \end{cases}, \quad (7)$$

where $allowed_h$ is the candidate members set to the sub task n_{i+1} for the ant h in the iterative process. $1/F_{jk}$ is the heuristic function and F_{jk} is the defined as the objective function value from the sub task u_{ij} to $u_{i+1,k}$. α and β are adjustable parameters.

5.2. Rules of Pheromone Updating

Pheromone updating is an important process of ant algorithm. When an ant completes a tour, the solution may be not the best. When the solution is not the best solution, the passed path of the ant is added into little pheromone amount. If the solution is the best, more pheromone amount is added [8]. If the solution is not the best, $\Delta\tau_{jk}(t)$ is computed as Eq.(8). If the solution is the best, $\Delta\tau_{jk}(t)$ is computed as Eq. (9).

$$\Delta\tau_{jk}(t) = \Delta\tau_{jk}(t) + A\tau, \quad (8)$$

$$\Delta\tau_{jk}(t) = \Delta\tau_{jk}(t) + \frac{Q}{L_h}, \quad (9)$$

Q is a constant representing pheromone density. L_h denotes objective function value of all selected enterprises when an ant h completes a tour.

$$\tau_{jk}(t+1) = (1-\rho)\tau_{jk}(t) + \Delta\tau_{jk}(t), \quad (10)$$

where ρ represents the evaporation of pheromone in each tour completion time and $\rho \in [0,1]$.

The strategy of adaptive control is taken to ρ to prevent local optimum of ant colony algorithm. When the paths of successive generations for optimal ant search are same, the algorithm is trapped into a local convergence and adaptive adjustment to ρ is in accordance with Eq. (11).

$$\rho(t+1) = \begin{cases} 0.9 \cdot \rho(t), & 0.9 \cdot \rho(t) > \rho_{\min} \\ \rho_{\min}, & \text{otherwise} \end{cases}, \quad (11)$$

where $\rho_{\min}$ is the minimum of ρ and 0.9 in the equation represents volatile restraint parameters.

5.3. Pheromone Range Restriction

Pheromone τ_{jk} in optimizing path from u_{ij} to $u_{i+1,k}$ is restricted from the minimum to the maximum to avoid stagnation problem of ant colony algorithm, that is $\tau_{min} \le \tau_{jk} \le \tau_{max}$. Above all, pheromone update strategy is shown by Eq. (12).

$$\tau_{jk}(t+1) = \begin{cases} \tau_{min}, & \tau_{jk}(t) \le \tau_{min} \\ \text{Eq.}(14), & \tau_{min} \le \tau_{jk}(t) \le \tau_{max} \\ \tau_{max}, & \tau_{jk}(t) \ge \tau_{max} \end{cases} \quad (12)$$

The Flow chart of improved ant colony algorithm for members selection of virtual teams in collaborative process planning is shown in fig. 3 according to the rules above, which takes sub task as the basic optimizing unit and chooses virtual teams members for each sub task.

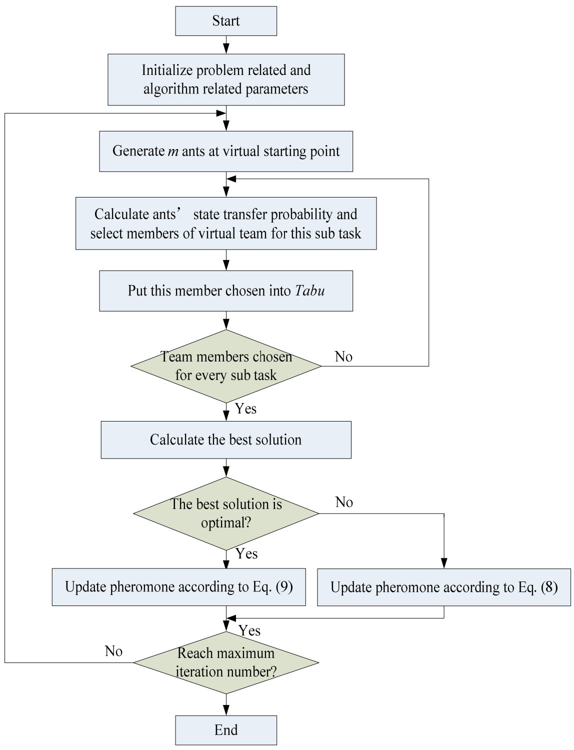

Fig. 3. Flow chart of improved ant colony algorithm.

6. The Example

Shenyang Blower Group Co., Ltd. is the main enterprise in general machinery industry of Shenyang. The leading products are centrifugal compressor, centrifugal blower and large-scale ventilator. This enterprise gets an urgent order of centrifugal compressor production, which is composed of design and manufacture of spindle, ternary vane wheel and diaphragm coupling. There are not enough persons to complete this task and some tasks are very complex, therefore, the members with excellent process planning ability should be recruited to build the virtual team and collaboratively complete the task. The enterprise bids on Web, constructs the system for the information collection of virtual teams members in B/S construction and adopts improved ant colony algorithm to solve the members selection of virtual teams.

The sub tasks of collaborative process planning in virtual teams building are shown by Table 1. The sums of candidates are 3, 4, 2, 3 and 4 respectively for each sub task. Four aspects are the quality, cost, time and Comprehensive abilities of process planning, which are described by *Q*, *Ctotal*, *Ttotal* and *A*. The parameters of each weight are calculated by Analytic Hierarchy Process, which are 0.42, 0.31, 0.16 and 0.11 respectively. The parameters of each candidate are shown by Table 2.

The programme of improved ant colony algorithm is compiled by Matlab. The number of ants and iterations are respectively set 50 and 200. Other parameters are set as follows. α =3, β =1, ρ =0.9, Q=0.2, τ_{min} =0.1, τ_{max} =10, ρ_{min} =0.1 and $A\tau$ =0.1. the targets are constrained and set T_{ctotal} =16 and C_{ctotal} =6500.

The optimization calculation is implemented and the optimum members are got, which are [u_{12}, u_{21}, u_{32}, u_{41}, u_{54}]. The object value changes according to the integrations, which is shown in Fig. 4. ACO (ant colony algorithm) is optimizing curve of the basic ant colony algorithm, and IM-ACO (improved ant colony algorithm) is improved algorithm. The optimal solution can be drawn by the two methods, which is 2.4090. However, ACO requires about 130 generation convergence and IM-ACO only needs about 30 generation. The efficiency is improved obviously.

Table 1. Collaborative sub-tasks.

Sub tasks	Detail
n_1	Exploitation of ternary vane wheel with mass flow
n_2	Exploitation of diaphragm coupling
n_3	Exploitation of spindle with high speed and energy conservation
n_4	Exploitation of weld enclosure series in centrifugal blower
n_5	Exploitation of enclosure in gear booster engine

Table 2. Relative parameters of candidates.

Sub tasks	Candidates	*Ctotal*	*Ttotal*	*Q*	*A*
N_1	u_{11}	1800	3.6	0.96	0.85
	u_{12}	1600	3.8	0.92	0.84
	u_{13}	1900	3.5	0.95	0.87
N_2	u_{21}	90	2	0.91	0.68
	u_{22}	95	2.5	0.90	0.75
	u_{23}	87	1.5	0.92	0.72
	u_{24}	93	2	0.93	0.78
N_3	u_{31}	4500	7.5	0.88	0.73
	u_{32}	4450	7.2	0.85	0.75
N_4	u_{41}	70	1.5	0.90	0.86
	u_{42}	75	2	0.92	0.83
	u_{43}	78	1.8	0.89	0.87
N_5	u_{51}	120	0.5	0.93	0.65
	u_{52}	115	1.6	0.91	0.67
	u_{53}	110	1.2	0.94	0.54
	u_{54}	105	1	0.92	0.73

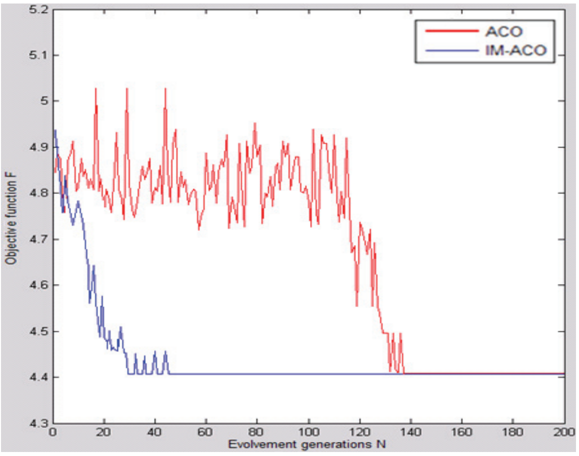

Fig. 4. The optimal value curves of ant colony algorithm.

7. Conclusions

Virtual teams are increasingly common in most organizations, and business communication is increasingly intercultural, horizontal, and change focused as well. The solution based on improved ant colony algorithm is proposed to solve members' selection of virtual teams in collaborative process planning. The sub tasks with certain timing relationship were described on the basis of virtual teams' concept. The model of virtual teams building is established and solved by improved ant colony algorithm. Ant colony algorithm is a good solution to the members selection of virtual teams by the example. Through the improvement of the basic ant colony algorithm, which are pheromone updating rules and the scope of pheromone restriction, the algorithm premature convergence in local optimal solution is effectively avoided and the quality and efficiency can be significantly improved.

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