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Research on Modeling Method and Partner Selection for Collaborative Production of Virtual Enterprises

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Abstract: To describe and organize collaborative production process of Virtual Enterprises (VE) well, a flexible and extensible modeling method is very important for it. On the basis of analyzing the features of collaborate production process of VE, some meta-models are designed in the paper which contains the main aspects of collaborate production process such as organization mode, work-flow process, distribution of resource and permissions and so on. Each meta-model is formalized by some multi-tuple and can be self-defined and extended flexibly by users and at the same time, ensure the consistency of task execution for the overall enterprise chain in the dynamic environment. To select much appropriate collaborative partners, an evaluation method based on time, cost and consistency is proposed. It uses an approximation of ideal point method to create a objective function and adapts an ant colony algorithm to solve it. The feasibility and validity of the presented methods are verified by experiments.

Key words: Virtual enterprises, collaborative production, modeling, partner selection

INTRODUCTION

With development of modern enterprises as well as intensified market competition, more and more enterprises tend to megamerger so as to realize collaboration, network and agility, so the organization mode of virtual enterprise (VE for abbreviation) has been applied widely in various industry fields.

In the last few decades, a lots of theoretical researches and practices about VE have been done (Crispim and de Sousa, 2010; Wadhwa *et al*., 2009; Cho *et al*., 2007; Ying, 2010) and especially, there are some researching works on the collaborative production process of VE, for example, Guo and Huang (2002) have studied modeling and collaborative operation method for operation process, Li *et al.* (2009) have studied the virtual enterprise's collaborative mechanism with Agent-based technology, Cheng and Fan (2006) has presented a IDEF-based and UML-based collaborative production information model and some virtual enterprise's information model as well as information access mechanism with object-oriented technology and distributed work flow have also been studied (Song and Nagi, 1997; Bennett and Fellbaum, 2006; Li *et al*., 2010) and so on. Though these existed achievements provide virtual enterprise with certain theoretical approaches and practical references for effective collaboration production but they couldn't meet the flexible need of collaboration production process of virtual enterprise. So the study focuses on the flexible modeling and partner selecting methods for collaborative production process of VE.

ANALYSIS OF COLLABORATE PRODUCTION PROCESS OF VE

In the collaborate production process of VE, the core enterprise is to fulfill efficiently some works such as allocating resources, executing tasks and exchanging information among members by some advanced information technologies. For the characters of dynamic organization of VE and the variability of internal and external environment, collaborate production process of it has the following dynamic adjustment demands:

- VE should adjust the decomposing mode and execution order of overall tasks and resources allocating method when the external requirements of market or users changed
- To optimize the overall production plan, the core enterprise adjusts parts of workflow process and resource allocation scheme
- Member enterprises maybe adjust the goal and requirements of the sub-task when it encounters with an unexpected incidents from internal or external environment

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So it is better for VE to resolve its adjustment demands at different layer and different range among core enterprise and member enterprise which has been done well by a flexible model method presented in the study and it can ensure the consistency of task execution for the overall enterprise chain in the dynamic environment.

A modeling method for collaborative production of VE: The study proposed a modeling method for collaborative production process of VE based on the organization and business characteristic of it which includes some meta-models about organization, processes, activities, rights distribution and collaborative interaction.

Organization meta-model: The hierarchic organization model is as the Fig. 1 shown. It defines the relationships of core virtual enterprise, members of the enterprise and the related departments, staff and role of VE. A VE generally includes a number of member organizations such as a core enterprise and some collaborative enterprises and each member organization includes some collaborative departments. To reduce the degree of coupling of collaborative process, we take a department as a basic unit to divide collaborative tasks and assign staffs and roles for each task in the study. A role acts as one certain of task and a staff can be assigned one or more several roles, so the roles and staffs are in a form of one-to-many mapping mode. To describe the organization structure above more clearly, we give some definitions with multi-tuple format for the organizational meta-model of VE as follows:

Definition 1:

VE = {VE_Id, VE_Name, VE_Attribs, Member_Org}

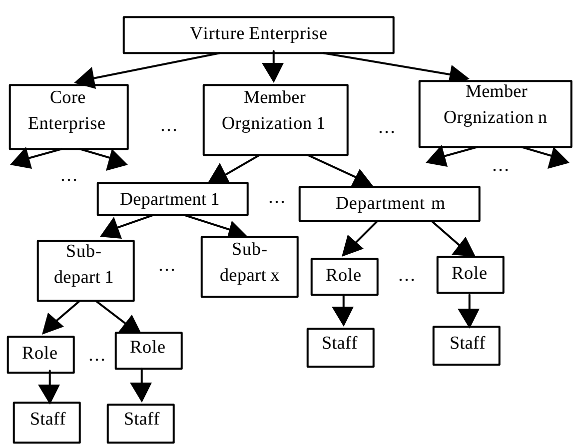

Fig. 1: Hierarchic organization meta-model

Definition 2:

Member_Org={MO_Id, MO_Name, MO_Deps, MO_Empls, MO_Roles, MO_MapofDS, MO_MapofSR }

In the definition 1 above, the set of VE uniquely identifies the unique identifier, name, attributes and members of a VE; and in the definition 2, the set of Member_Org represents, respectively the unique identifier, name, departments included, staffs, roles, the mapping relationship set of departments and staffs and the mapping relationship set of staffs and roles. Distribution of competences for the realization of the dynamic nature of the mapping between roles and personnel remain in the distribution of competences is defined in the model.

Process meta-model: The collaboration production process of VE is a distributed workflow control process, a process meta-model based on PetriNet is defined which includes processes, tasks, activities and other factors so as to support formalized description of the dynamic collaborative process.

According to the hierarchical organization model of the virtual enterprise, this study gives the definition of process and sub-processes, the former used by core enterprise for the definition of the overall process, the latter is used to all the members for their commitment task's definition in the local process which means the process of breaking down sub-tasks into several activities.

Definition 3:

Collabo_Process = {CP_Id, CP_Name, CP_Tasks, CP_Conditions, CP_MapofTC, CP_Paths}

CP_Tasks = {CT_Id, CT_Name, CT_Attribs, CT_Functs, CT_Author, CT_Operator, CT_Permi, CT_Time}

CT_Time = {CT_Start, CT_End, CT_exercute}

CP_Paths = {Sequence and_Split and_Joint, Or_ Joint, Or_Split, Synchronization, Merge, Loop, ...}

In the definition 3 above, the set of Collabo_Process defines the collaborative process of identifier, name, tasks, conditions, the mapping relationship set of tasks and conditions and the set of control paths. There, task is defined as a logical unit of the process and includes identifier, name, attributes, function, permissions, implementer of task, permissions and time requirements which includes the latest task start time, the latest completion time and execution time. The set of control paths includes sequential, parallel branch, parallel polymerization, selection branch, selection polymerization, synchronization, cycle and other control structures.

Definition 4:

Sub_Collabo_Process = { Sub_CP_Id, Sub_CP_Name, Sub_CP_Events, Sub_CP_Activs, Sub_CP_States, Sub_CP_MapofEAS, Sub_CP_Paths}

Sub_CP_Activs = {Sub_CP_A_Id, Sub_CP_A_Attris, Sub_CP_A_Functs, Sub_CP_A_PId, Sub_CP_A_TId, Sub_CP_A_RId, Sub_CP_A_PId, Sub_CP_A_Condits, Sub_CP_A_Events, Sub_CP_A_Rules, Sub_CP_A_States, Sub_CP_A_Time}

Sub_CP_A_Time = {CP_A_ Time_Start, CP_A_ Time_End, CP_A_ Time_Oper, CP_A_ Time_Dist}

In the definition 4, the set of Sub_Collabo_Process represent identifier, name, event collection, activities to the state of the ontology mapping of each sub collaborative process. There, collaborate activities are a series of basic operating units decomposed by member organization according to their sub-tasks and can be described as properties, functions, vested in the process, ownership of the task, performance of the role, the implementation of the application, a set of the conditions for triggering events, triggering events and transfer rules, actives and the execution time. There, the execution time is defined by multi-tuple such as scheduled start time, completion time, execution time and appointed time for the activities assigned to the work list.

Resources and permissions allocation meta-model: For the member organizations take part in the collaborative production process of VE in the way of undertaking tasks and the tasks are often decomposed to a list of activities by the different members. To ensure the autonomy of tasks execution for member organizations and at the same time, make it easy for core enterprise to adjust allocation of tasks and execution path, a resource and permissions model has been built in the study, as Fig. 2 has shown.

The metal model above consists of two levels of resources and permissions allocation process. In the first level, it is up to the core enterprise to decompose overall task to some sub-tasks and allocate the available resources and permissions to each sub-task; in the second level, it is up to each member organization to transfer sub-tasks to the specific business activities and

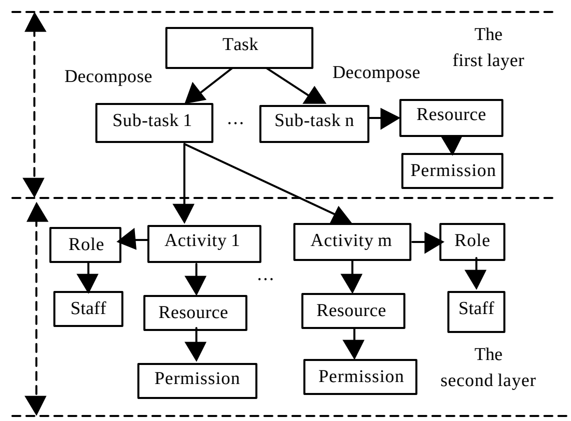

Fig. 2: Resources and permission allocation meta-model

decide the allocation of resources and permissions for each activity and also to assign roles and staff to each activity. According to this model, when the core business needs to adjust and modify the permissions of resources, it hasn't to consider the specific business activities and related to roles and staffs of member organizations which can meet better the needs of flexibility and dynamism of collaborative production's resources and permissions and ensure the independence of all members in the collaborative process. The definition of resources and permissions model is given as follows.

Definition 5:

FirstLevel_Permission = {FL_Tasks, FL_Permissions, FL_Resources, FL_Maps_RP}£»

SecondLevel_Permission={SL_Activities, SL_Permissons, SL_Resources, SL_Roles, SL_Staffs, SL_MapofAR, SL_MapofRP, SL_MapofRS}

In the definition 5, the first set of FirstLevel_ Permission includes some factors such as the collection of tasks, permissions of first level, available resources and the mapping relationship set of resources and permissions and the permissions of first level are defined by the core enterprise of VE. The second set of SecondLevel_Permission denotes the tasks corresponding collection of activities, permissions and resources of the second level, the role and executing staff of each activity and the mapping relationships set of activities and resources and permissions. The permissions of resources and their allocation in the second level are defined by the member organizations that undertake the sub-tasks.

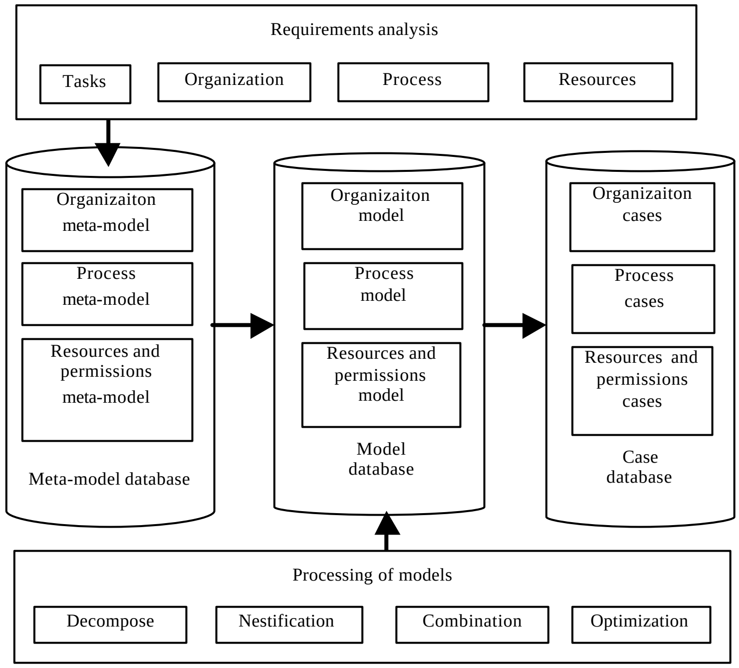

Fig. 3: Modeling process of collaborative production for VE

Modeling process based on meta-models: Based on the meta-models above, it is very convenient and flexible to model the collaborative production process which can be diagramed in detail as Fig. 3 shown.

Firstly, all members of VE make detailed requirement analysis about the overall tasks and local sub-tasks, the business process of tasks execution and available resources, etc.

Secondly, members design and extend all kinds of meta-model databases according to the requirement analysis and establish the model databases for themselves. In this process, some works can be done such as decomposing, overlapping, combining and optimizing, so as to meet the different needs of enterprises and make all of the models inherited and reusable.

Thirdly, during the collaborative production process, member enterprises and core enterprise select the appropriate models from the model databases, instantiate them and put the instants into the internal workflow engine for implementation. The instantiation process of models can be dynamic and user-defined according to the different execution conditions and environment. That is to say, users can do various instantiation definitions to meet different requirements, such as activity properties, activity functions, activity rigger conditions, activity transfer rules and so on.

PARTNER SELECTION METHOD FOR COLLABORATIVE PRODUCTION

Partner selection is also important for the collaborative production of VE. Assuming the core enterprise decomposes the task into J different subtasks based on the decomposition of business processes and the candidate enterprises set $E^{I\times J}$ that need to optimize, where J represents the task number, I is the number of candidate enterprises for each task. u_{ij} is task j which select its candidate partners in the corporate collection of the i-th enterprise as the final members to implement the task, i = 1, 2..., I, j = 1, 2..., J.

For generally, the time, cost and risk are three key basic factors to be considered in the partner selection process of VE (Huang *et al*., 2013), so this study also take these factors into consider as the key parameters for core enterprise to select partners.

According to the characteristics of the virtual enterprise partner selection, set the time T, the cost of C and the risk R to be three objective functions as follows:

$$\min T = \min\left[\sum_{j=1}^{J}\sum_{i=1}^{I}(T_{ij}H_{ij})\right] \quad (1)$$

$$\min C = \min\left[\sum_{j=1}^{J}\sum_{i=1}^{I}(C_{ij}H_{ij})\right] \quad (2)$$

$$\min R = \min\left[\sum_{j=1}^{J}\sum_{i=1}^{I}(R_{ij}H_{ij})\right] \quad (3)$$

$$H_{ij} = \begin{cases}1, \text{The candidate partner } u_{ij} \text{ is selected} \\ 0, \text{The candidate partner } u_{ij} \text{ is not selected}\end{cases} \quad (4)$$

Wherein, T_{ij} indicates the required time when the task j is the i-th candidate corporate executive, C_{ij} represents required costs when task j is the i-th candidate corporate executive, R_{ij} is the risk that choosing the i-th candidate enterprises to execute task j. J represents the total number of tasks; I is the number of candidate enterprises for the j-th task. Ultimate goal is a minimum time, cost and risk.

Partner selection method: For multi-objective decision-making problems, it is very difficult for the decision makers to give the specific means and consider the polarity inconsistent of goal. Ideal point method (TOPSIS) is a good method of solving multi-objective decision problems and the relative merits of existing object evaluation ideal point method is also known as pros and cons of solutions of distance method. Define a measure in space to measure the degree of a program close to the ideal solution and away from negative ideal solution, pros and cons of sort of candidate programs based on the value provide a basis for decision-making.

This study uses ideal point method to construct the fitness function of the multi-objective decision problems, in which decision-makers need to give positive ideal value (positive ideal point) of each goal and negative ideal value (negative ideal point). The positive ideal point of the time, cost and risk in this article is (T^+, C^+, R^+), negative ideal point is (T^-, C^-, R^-) and the objective function is f (t):

$$f(t) = \frac{d^-}{d^- + d^+} \quad (5)$$

$$d^-(t) = \left\| \frac{(T(t)-T^-)}{T^+}, \frac{(C(t)-C^-)}{C^+}, \frac{(R(t)-R^-)}{R^+} \right\| \quad (6)$$

$$d^+(t) = \left\| \frac{(T(t)-T^+)}{T^+}, \frac{(C(t)-C^+)}{C^+}, \frac{(R(t)-R^+)}{R^+} \right\| \quad (7)$$

where, || || means to take norm, *t* is the number of ants, d^+ is the positive ideal distance measure and d^- point is the negative ideal distance measure. They can make use of Euclidean norm to solve, the value d^+ and d^- can be calculated using Eq. 8-9:

$$d^+(t) = \sqrt{(T(t)-T^+)^2 + (C(t)-C^+)^2 + (R(t)-R^+)^2} \quad (8)$$

$$d^-(t) = \sqrt{(T(t)-T^-)^2 + (C(t)-C^-)^2 + (R(t)-R^-)^2} \quad (9)$$

An example of partner selection algorithm: It is assumed that the core enterprise divides the total product plan of a new project into task 1-8 and each task can be assigned several candidate enterprises to finish in the optimum combination stage after the first phase and the second phase of the selecting, for example, the candidate enterprises named P11, P12, P13 and P14 can undertake the task 1 and the candidate enterprises named P21 and P22 can undertake the task 2 and so on. The time, cost and risk of each candidate enterprise to finish the task are shown in the Table 1.

According to the information provided in Table 1, each candidate set can be calculated by using TOPSIS. For example, positive ideal points of the candidate set {P11, P12, P13, P14} is (90, 5.5, 0.35), the negative ideal point is (110, 7.5, 0.45). And the directed graph of ants' path finding can be gotten by calculating all the candidate sets which is shown as Fig 4.

Table 1: Time, cost and risk of candidate enterprises

Candi-partner	Costs (10000$)	Time (month)	Risk
Task 1			
P11	100	6.5	0.41
P12	99	7.1	0.40
P13	110	5.5	0.35
P14	90	7.5	0.45
Task 2			
P21	56	2.7	0.22
P22	77	3.3	0.33
Task 3			
P31	59	5.3	0.50
P32	67	5.5	0.45
P33	50	4.5	0.35
Task 4			
P41	80	5.0	0.33
P42	88	3.2	0.51
P43	79	3.4	0.52
Task 5			
P51	130	5.2	0.22
P52	139	4.0	0.33
P53	122	6.2	0.25
P54	140	4.0	0.20
Task 6			
P61	80	5.0	0.33
P62	79	3.4	0.52
P63	88	3.2	0.51
Task 7			
P71	56	2.7	0.22
P72	77	3.3	0.22
P73	103	4.1	0.25
Task 8			
P81	59	5.3	0.50
P82	67	5.5	0.45
P83	50	4.5	0.35
P84	66	4.0	0.25

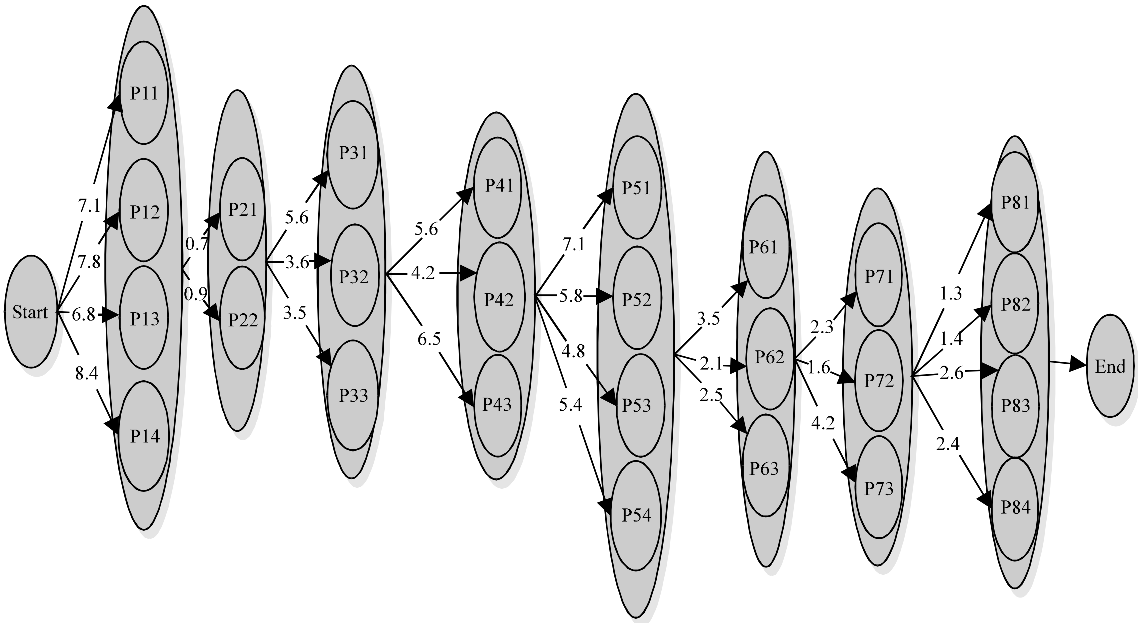

Fig. 4: Graph for ants' path finding

The initial number of ants of the algorithm is 30, constant Q = 20, C = 0.1 and weight coefficient, respectively 0.7 and 0.9. When all of the ants finished the whole path, there are 27 ants converged to the path of (P14, P22, P31, P43, P51, P61, P73, P83), so the candidate enterprises included in the path set can be selected as final cooperative partners.

CONCLUSION

The organization form of VE has developed rapidly in many kinds of industries. This study proposes a flexible modeling method for the collaborative production process of VE which includes organization mode, work flow process, resources and permissions allocation and so on. The meta-models can be extended easilly and meanwhile ensure the consistency of total task execution of VE in the dynamic environment. In the other hand, a partner selection algorithm based on ideal point method and ant colony algorithm for the collaborative production process is proposed in the study and the methods above are verified by the experiments. And establishing the optimized production plan model for collaborative production process of VE by using genetic algorithm and simulated annealing algorithm will be our future works.

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