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Selection Algorithm of Virtual Enterprise Partner Based on Task-Resource Assignment Graph

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Abstract

The project deployment diagram, which is used to uniformly describe the process and resource of virtual enterprise is established aiming at how to choose virtual enterprise partner of time-cost tradeoff and set task-resource assignment graph as scheduling model, the iterative heuristic algorithm is adopted based on relative cost-effectiveness to solve. The production of virtual partner and transportation time and cost are taken into account in algorithm, which may ensure deadline constraint as well as effectively cut down overall cost. Such algorithm applying to resource distribution and a vast amount of simulative tests proved that this method is able to effectively cut down the operation time of obtaining prioritization scheme.

***Keywords**: Virtual enterprise; Partner selection; Project deployment diagram; Task-resource assignment graph; Relative cost-effectiveness*

1. Introduction

Virtual enterprise is the major mode of carrying through production operation and market competition for 21th century enterprise, more attention is being paid to it due to strengths such as lower cost, quick response to market opportunities and favorable adaptability etc. The key to success of virtual enterprise lies in how to select the most appropriate enterprise to product from heaps of potential collaborators whose are provided with diversified service quality (for example, cost factors, productive time, production quality, trust cooperation and risk factors etc). Aiming at the deficiency of partner optimization algorithm based on process model analysis and graph theory thought, this article put forward a kind of newly inspirational partner optimization algorithm based on the thought of graph theory and relative cost-effectiveness [11]. The project deployment diagram is at first established by algorithm to uniformly describe process model and resource model of enterprise and select a task-resource assignment graph [12] randomly from project configuration graph as a preliminary solution, adjust cooperative partners gradually within closing date, get the partners constantly with the maximum cost reduction inside and kick out those with maximum growth of time cost. Each adjustment of algorithm is from a global perspective with the consideration of process time and cost of cooperative partners and transportation time and cost of workpiece, which may reasonably optimize overall cost as well as avoid resource conflict of candidate partners. The simulate result proved performance and efficiency of algorithm.

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2. Problem Description

The project of virtual enterprise can be denoted with two-tuples $<DAG, R>$, of which DAG (Directed Acyclic Graph) is used to describe process model, $\mathrm{DAG} = <\mathrm{V}, \mathrm{L}>$, $\mathrm{V} = \{\mathrm{v}_i \,|\, 1 \le \mathrm{i} \le \mathrm{n}\}$ are subproject collection with mutual independence and some logical relation. $\mathrm{L} = \{\mathrm{l}_{\mathrm{ij}} \,|\, \mathrm{i} \ge 1, \mathrm{j} \le \mathrm{n}, \mathrm{i} \ne \mathrm{j}\}$ is the set of subproject correlation, $\mathrm{l}_{\mathrm{ij}} = (v_i, v_j)$ represents sequential relationship between v_i and v_j on execution, namely subproject v_j is not allowed to get it started until v_i have the execution completed, when v_i is precedence subproject to v_j, and v_j is successor subproject to v_i. $R = <E, D>$ is used to describe resource model, $\mathrm{E} = \bigcup_i^n \mathrm{E}_i = \bigcup_i^n \{\mathrm{e}_{iu} \,|\, 1 \le u \le \mathrm{m}_i\}$ is the set of candidate enterprise, $m = \left|\bigcup_i E_i\right|$ is the total number of virtual enterprise partners, " $|\ |$" is the potential operator of set; the candidate enterprise set of subproject v_i is E_i, m_i is the number of candidate enterprises for subproject v_i, $e_{iu} = (c_{iu}, t_{iu})$ represents QoS attribute description of candidate enterprise u of subproject v_i, this article primarily focuses on finished cost c_{ik} and time t_{ik}. $D = \{d_{iu,jv} \,|\, 1 \le i, j \le n, 1 \le u \le m_i, 1 \le v \le m_j, l_{ij} \in L\}$, $d_{iu,jv} = (c_{iu,jv}, t_{iu,jv})$ represents the cost and time of transportation for workpiece between two partners when v_i is being processed in partner enterprise u and when v_j is being processed in partner enterprise v. This article assumed that there has no constraints for processing capability of each virtual enterprise partner, however, there's only one subproject is able to process at random time, and there does exist transmission line between two random partners with no restraints of transmission capability, however, there's only one workpiece is able to transport at random time.

The target of partner selection is to select a candidate partner for each subproject so that the project can be completed at the lowest cost within closing time, the formal description of problem as follows:

$$\underset{u,v}{MIN}\ \left(\sum_i x_{iu} c_{iu} + \sum_i \sum_j x_{iu} x_{jv} c_{iu,jv}\right) \qquad 1 \le i, j \le n, 1 \le u \le m_i, 1 \le v \le m_j \tag{1}$$

$$s.t.\ \sum_{u=1}^{m_i} x_{iu} = 1 \qquad 1 \le \mathrm{i} \le n \tag{2}$$

$$f_{iu} + x_{iu}\mathrm{t}_{iu} + x_{iu} x_{jv} \mathrm{t}_{iu,jv} \le \mathrm{f}_{jv} \qquad \mathrm{l}_{ij} \in L,\ 1 \le i, j \le n, 1 \le u \le m_i, 1 \le v \le m_j \tag{3}$$

$$(f_{iu} - x_{iu} t_{iu} - x_{iu} x_{ju} \mathrm{t}_{iu,ju} - f_{ju}) * (f_{ju} - x_{ju} t_{ju} - x_{ju} x_{iu} \mathrm{t}_{ju,iu} - f_{iu}) \ge 0 \qquad 1 \le u \le m_i, 1 \le i, j \le n \tag{4}$$

$$f_{0u} = 0,\ f_{nu} = \mathrm{T} \qquad 1 \le u \le m \tag{5}$$

$$x_{iu} = \{0,1\}, \qquad 0 \le \mathrm{i} \le n, 1 \le u \le m_i \tag{6}$$

Where, the value of x_{iu} represents if subproject v_i is processed by partner u; f_{iu} represents completion time of subproject v_i in partner u. formula (1) is the cost to partner selection scheme and target to optimization problem; formula (2) represents each subproject can be only processed by one partner; formula (3) represents meeting the demands of subproject process for partial-order constraint and completion time for transportation; formula (4) is constraints of sharing resource, which means any partner is forbid to process multi-subprojects at any time; formula (5) is the date of completion for subproject and formula (6) explains that x_{iu} is Boolean variable.

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3. Selection Algorithm of Virtual Enterprise Partner

3.1. Related Definition

To intuitively reflect processing capability of virtual partner to different subprojects, transportation performance and possible conflict of sharing resource, for one thing, the process model and resource model of virtual enterprise project shall be transformed into project deployment diagram.

Definition 1. Figure $\mathrm{DAG} = < \mathrm{V}, \mathrm{L} >$ is given, the depth $BD(i)$ of subproject v_i is defined as the longest path length (the path length means the number of edge) from v_i to exit knot v_n.

$$BD(i) = \begin{cases} 1 & \text{i=1} \\ \max\limits_{j \in succ(i)} \{BD(j)+1\} & \text{otherwise} \end{cases} \tag{7}$$

Definition 2 The project deployment diagram $G = < V', L', E', D' >$ of virtual enterprise project $< DAG, \mathrm{R} >$ is a multilayer network diagram of $BD(n)$, the number of network node in k layer $n_k = \{\bigcup_j E_j \mid BD(j) = k\}$; if there exist identical node in adjacent layer back and forth, the transmission time and cost of workpiece between them both are 0; if $d_{iu,jv} \in D(l_{ij} \in L, DB(i) = k, DB(j) = k+1\}$, there does exist networking between u node of k layer and v node of $k+1$ layer, processing time of subproject i, j on u, v node are $c_{iu,} c_{jv}$ and $t_{iu,} t_{jv}$, respectively, transportation cost and time are $c_{iu,jv}$ and $t_{iu,jv}$ respectively.

The project employment diagram may uniformly describe the processing performance of candidate enterprise partner for virtual enterprise projects and subprojects and transportation performance of workpiece between candidate enterprise partners.

Definition 3 TRAG (Task-Resource Assignment Graph) is a subgraph that meets with DAG and resource constraints on project deployment diagram, each TRAG is a solution to selection problem of virtual enterprise partner. If each task selects virtual partner with shortest processing time, and transportation time is assumed as 0, then the critical path of such scheme is MCP (Minimum Critical Path), and the path length of it is called as minimum fastest time.

Definition 4 Suppose u_1 and u_2 are optional two network nodes of j_1 subproject on j layer, respectively, precedence i_1 and successor k_1 are k_q of j_1 subproject in TRAG are undertaken by network node i_p on i layer and k_q on k layer, respectively, network node i_p on i layer and u_1 & u_2 on j layer both are provided with direct network connection, as well as u_1 & u_2 on j layer and k_q on k layer are also provided with network connection. The task-resource assignment graph transformed into TRAG' when moving j_1 subproject to u_2 node from u_1 node, then relative cost effectiveness $r(j_1,(u_1,u_2))$ is ration between overall cost and completion time transformation after TRAG is being varied, that is:

$$r(j_1,(u_1,u_2)) = \begin{cases} +\infty & c_{j_1,u_1} + \sum\limits_{i_1} c_{i_1 i_p, j_1 u_1} + \sum\limits_{k_1} c_{j_1 u_1, k_1 k_q} > c_{j_1,u_2} + \sum\limits_{i_1} c_{i_1 i_p, j_1 u_2} + \sum\limits_{k_1} c_{j_1 u_2, k_1 k_q} . CP(\underset{j_1 \to u_1}{\mathrm{TRAG}}) = CP(\underset{j_1 \to u_2}{\mathrm{TRAG'}}) \\ -\infty & c_{j_1,u_1} + \sum\limits_{i_1} c_{i_1 i_p, j_1 u_1} + \sum\limits_{k_1} c_{j_1 u_1, k_1 k_q} < c_{j_1,u_2} + \sum\limits_{i_1} c_{i_1 i_p, j_1 u_2} + \sum\limits_{k_1} c_{j_1 u_2, k_1 k_q} . CP(\underset{j_1 \to u_1}{\mathrm{TRAG}}) = CP(\underset{j_1 \to u_2}{\mathrm{TRAG'}}) \\ 0 & c_{j_1,u_1} + \sum\limits_{i_1} c_{i_1 i_p, j_1 u_1} + \sum\limits_{k_1} c_{j_1 u_1, k_1 k_q} = c_{j_1,u_2} + \sum\limits_{i_1} c_{i_1 i_p, j_1 u_2} + \sum\limits_{k_1} c_{j_1 u_2, k_1 k_q} \\ \dfrac{c_{j_1,u_1} + \sum\limits_{i_1} c_{i_1 i_p, j_1 u_1} + \sum\limits_{k_1} c_{j_1 u_1, k_1 k_q} - (c_{j_1,u_2} + \sum\limits_{i_1} c_{i_1 i_p, j_1 u_2} + \sum\limits_{k_1} c_{j_1 u_2, k_1 k_q})}{CP(\underset{j_1 \to u_2}{\mathrm{TRAG'}}) - CP(\underset{j_1 \to u_1}{\mathrm{TRAG}})} & \text{otherwise} \end{cases}$$

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Where, $CP(\underset{j \to u}{\text{TRAG}})$ represents critical path length of TRAG when submission j is being assigned to partner u.

Relative cost-effectiveness $r(j_1,(u_1,u_2))$ showed that the variation of cost time to scheduling plan when subproject j_1 is transforming from u_1 network node on j layer to u_2 node under the condition that any other subprojects in the whole project remain unchanged. $r(j_1,(u_1,u_2))<0$, overall time and overall cost variation, which generated from variation of processing node, are identical, with the selection of candidate partners with lead-time reduction may synchronously decrease overall cost. When $r(j_1,(u_1,u_2))=-\infty$, the change of candidate partner merely make overall cost increased but critical path length remains the same; $r(j_1,(u_1,u_2))>0$, the variation of critical path cost and overall cost, which generated from variation of processing node, are diversified, with the selection of candidate partner who will help increase critical path length may cut down the cost, yet with the selection of candidate partner with increased cost may reduce time, and with greater relative cost-effectiveness comes with an significant result. When $r(j_1,(u_1,u_2))=\infty$, the change of candidate partner will lead to a decrease of overall cost, but overall time remains unchanged.

3.2. Algorithm Description

Algorithm 1 Conversion algorithm from DAG to project deployment diagram

Input: DAG, matrix E and D

Output: project deployment diagram

(1) Calculate the depth of each subproject in DAG according to formula (7);

Determine an overall layers of project deployment diagram according to $BD(n)$;

(2) Determine virtual enterprise partners on each layer of project deployment diagram according to matrix E;

(3) Add network connection to identical node of adjacent layers back and forth;

According to matrix D, if $d_{iu,jv} \in D(l_{ij} \in L, DB(i)=k, DB(j)=k+1\}$, network connection is created between u node on k layer and v node on $k+1$ layer;

(4) Output project deployment diagram;

Algorithm 2 Partner selection algorithm based on figure and relative cost-effectiveness

Input: project deployment diagram G and deadline T given by users

Output: selection scheme of virtual partner

(1) Compute relative cost-effectiveness of project deployment diagram G;

$k_0=0$; a task-resource assignment graph is generated randomly as an initiatory partner selection scheme and compute critical path time T_s of task-resource assignment graph;

Select subprojects of virtual enterprise whose relative cost-effectiveness is negative and critical path length is reduced, or relative cost-effectiveness is ∞ on task-resource distribution diagram, compute the critical path time T_s of task-resource assignment graph by adjusting scheduling plan;

(4) If $T_s>T$, there are subproject partners whose are provided with maximum relative cost-effectiveness with positive value and a decreased critical path length in adjustive task-resource assignment graph; if $T_s \le T$, there are subproject partners whose are provided with maximum relative cost-effectiveness with positive value and an increased critical path length in adjustive task-resource assignment graph. If there appears to be cyclic sequence in the sequence of relative cost-effectiveness with most-positive value in schedule, switch it to step (5) , otherwise switch it to step (3).

(5) Select task-resource assignment graph whose completion time is lower than and next to deadline as an optimal partner selection scheme and input.

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Property 1 The scheduling method of relative cost-effectiveness is convergent.

Prove: without loss of generality, suppose time cost of different scheduling schemes of some subproject on critical path of virtual enterprise as shown in figure 1.

Suppose that there has no virtual partners whose relative cost-effectiveness is positive and critical path is reduced, or its relative cost-effectiveness is ∞ in other subprojects of scheduling scheme, all of relative cost-effectiveness with positive value are less than r1, r2, r3 and r4, t1 is the process of j and time limit of workpiece transmission of subproject, partner 1 is the current selection of subproject j, the completion time of scheme exceeds deadline by this moment and the relative cost-effectiveness $r(j,(1,2))$, $r(j,(1,5))$ and $r(j,(1,4))$ under scheduling scheme are less than 0 and $r(j,(1,2))$ being the minimum, $r(j,(1,6))$, $r(j,(1,7))$ and $r(j,(1,8))$ are greater than 0.

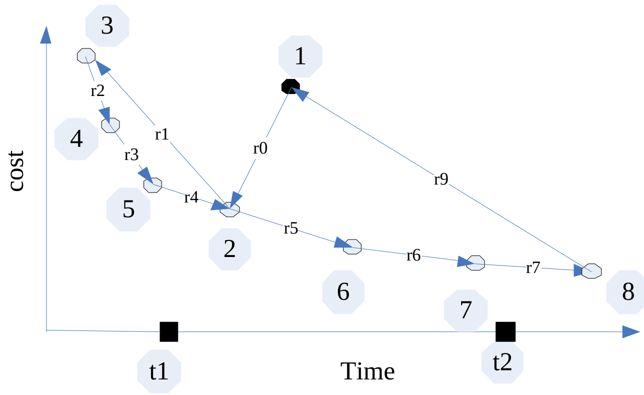

Figure 1. Time Cost of Different Scheduling Scheme of Some Subproject in Virtual Enterprise

3.3. Examples

Some virtual enterprise is composed of 6 subprojects whose sequential relationship is shown as in figure 2. Each subproject is bid by candidate enterprises of 3、2、3、3、3、2 in six candidate enterprises, respectively. Processability and transport properties of these candidate enterprises are described with table 1 and table 2, respectively. The deadline given by users is 18.

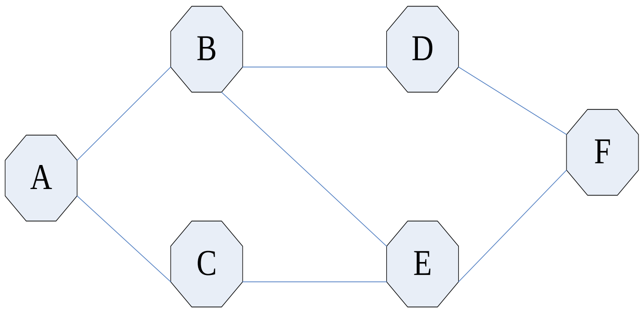

Figure 2. DAG Graph of Virtual Enterprise Project

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Table 1. E Matrix of Virtual Enterprise Project

$$\begin{bmatrix} 1 & 2 & 3 & 4 & 5 & 6 \\ (10,5) & - & - & (8,4) & - & (9,4) \\ - & (4,2) & (8,2) & - & - & - \\ - & - & (18,4) & - & (4,2) & (5,2) \\ (25,5) & - & (20,6) & - & - & (33,6) \\ (11,3) & - & - & - & (12,3) & (9,3) \\ - & (10,3) & (13,3) & - & - & - \end{bmatrix}$$

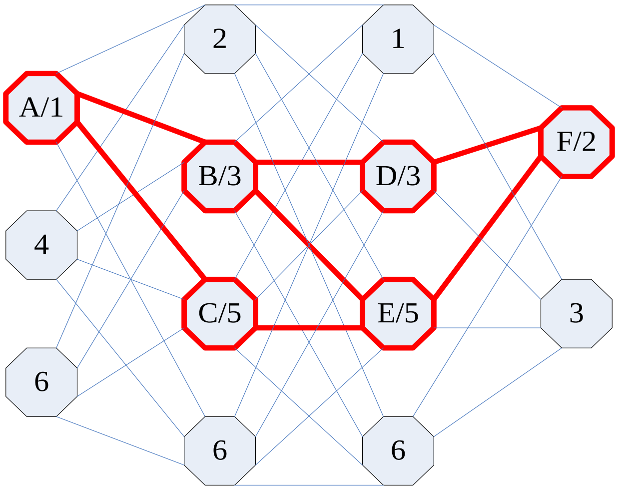

Figure 3. Project Deployment Diagram of Virtual Enterprise and Initial Task-Resource Assignment Graph

Suppose that initial task-resource assignment graph of virtual enterprise, as shown in figure 3, then overall cost and time are 76 and 20, respectively, the relative cost-effectiveness of subproject A $r(A,(1,4)) = -4$, $r(A,(1,6)) = -\infty$, owing to the existing time of this subproject and candidate partner 4 of relative cost-effectiveness with negative value, select the partner of subproject A as 4. An overall cost and time of task-resource assignment graph are 72 and 19, respectively, as shown in figure 4(a).

The relative cost-effectiveness of subproject C is $r(C,(5,3)) = -6$, however, but the time for partner 3 is increased; $r(C,(5,6)) = -2.5$, but the time for partner 6 is increased, hence making no adjustments to partner of subproject C; the relative cost-effectiveness of B is $r(B,(3,2)) = 2$, where has no candidate partners of relative cost-effectiveness with negative value, the partner of subproject B remains unchanged; the relative cost-effectiveness of subproject D is $r(D,(3,1)) = r(D,(3,6)) = -\infty$, on account of an increased cost, hence the partner of subproject D remains unchanged as well; the relative cost-effective of subproject F is $r(F,(2,3)) = 0.5$, where has no candidate partners of relative cost-effectiveness with negative value and decreased critical path length or of infinity positive value, the partner of subproject F still remains unchanged.

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4. Experimental Result and Analysis

Simulation test is adopted to virtual enterprise applications of diversified DAG to assess the performance of estimate method and make it compare with performance and efficiency of branch and bound method. The experimental simulation environment is PIV 2.6GH, 512MB with Windows2000 operating system. DAG auto-creator of document-similar [11] is introduced in process model of virtual enterprise, and the number of node will be inputted by users. Fixed value 5 is applied to the number of virtual partner. Finished cost c_{ik} and time t_{ik} of subproject v_i in candidate enterprises are random number of 20 and 10 for seed, respectively; transportation cost $c_{iu,jv}$ and time $t_{iu,jv}$ of workpiece between two partners are random number of 10 and 5, respectively, for seed when subproject v_i is being processed in partner enterprise u and v_j in partner enterprise v. Take 2*MCP as completion time given. DAG (10, 15, 20, 25 and 30, respectively) of each node number runs 10 times, respectively, that is, make a comparison of average cost and operation time.

The expense cost and operation time of ultimate scheduling scheme for two algorithm on different nodes are described in figure 4. The dot line is results from proposed algorithm, an optimal cost and operation time of DAG node, from high to low is: 10, 15, 20, 25 and 30; the border line results from branch and bound method, an optimal cost and operation time of DAG node, from high to low is: 10, 15, 20, 25 and 30.

Comparative effectiveness of two algorithms is shown in figure: (1) as an increase of the number of DAG node, computing time of proposed algorithm has a linear increasing trend, however, the computing method of branch and bound method has an index increasing trend. This is because proposed algorithm all the time selects virtual partners whose processing time is being the lowest when completion time is in excess of deadline, the other way around, and original partner of corresponding task will be replaced. (2) For DAG with identical number of node, final cost obtained from brand and bound method is superior to proposed algorithm, however, the difference between them will get smaller and smaller as the number of node increases. This is because there exist a time fragment between completion time of final scheme and given deadline in proposed algorithm under different DAG and it fails to remedy with cost, as an increase of the number of DAG node, this unoccupied time fragment will become small and the effect results from cost remedy will be lower and lower.

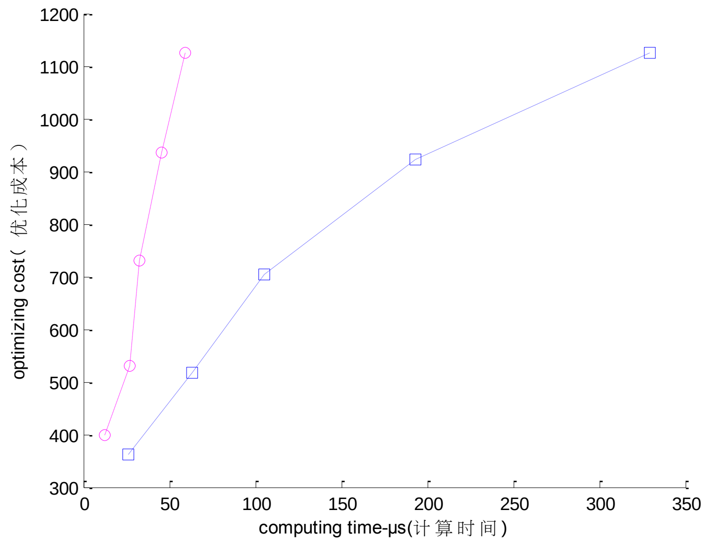

Figure 4. Computing Time and Cost Expenses of Final Scheme Obtained from Two Algorithms

5. Conclusion

Virtual enterprise partner selection with transportation time and cost of workpiece is a typical NP-Hard problem. This article established project deployment diagram model from optimal selection of virtual enterprise partner and set task-resource assignment graph as solution scheme, heuristic algorithm, which is used to gradually adjust task-resource assignment graph within given deadline in the process of partner optimization to realize optimization solution, based on relative cost-effectiveness is given. Effectiveness of model and its solution algorithm are certified using examples.

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