TELKOMNIKA, Vol. 11, No. 2, February 2013, pp. 1024~1032
ISSN: 2302-4046

Evaluation on Decomposition Granularity of Manufacturing Task in Manufacturing Grid

Yong Yin*[1], Chaoyong Zhang[2], Jihong.Wang[3]
[1]Wuhan University of Technology, Wuhan, China
[2]Huazhong University of Science and Technology, Wuhan, China
[3]University of Warwick, Coventry, UK
*Corresponding author, email: Yiyng_hust@126.com, zcyhust@mail.hust.edu.cn,
Jihong.Wang@warwick.ac.uk

Abstract

Task decomposition is on of the most important activities for manufacturing task planning in Manufacturing Grid. Many achievements in the methods to decompose manufacturing tasks have been obtained. But as for the decomposition granularity, the study and research are rare. Referring to the principle of "strong cohesion and weak coupling" in the software engineering field, the decomposition model of manufacturing task is built up, in which a manufacturing task is decomposed into different subtasks, and each subtask is composed of various processing events. On the basis of the model, the constraint among processing events within the subtasks is analyzed. Then the evaluation index on decomposition granularity of manufacturing task is put forward based on several definitions and evaluation steps for the decomposition granularity of manufacturing task are listed. Finally, examples to illustrate the idea of the paper are given. We hope the work of the paper can promote the study and application for Manufacturing Grid further.

Keywords: manufacturing grid, manufacturing task decomposition, decomposition granularity

1. Introduction

Manufacturing Grid (MG) aims at realizing resource sharing, collaborative design and collaborative manufacturing, and achieving the purposes of reducing manufacturing cost, increasing resource utilization rate and speeding up the product development [1].

In Manufacturing Grid, the completion of a complex task often requires the dynamic and collaborative engagement of multiple resource nodes. Reasonable and effective planning of manufacturing task can shorten the cycle of product development, improve the task performance and upgrade the overall competitiveness of the enterprise. The decomposition of the manufacturing task is on of the basic activities for manufacturing task planning, in which a manufacturing task is decomposed into several different subtasks according to certain principles, and the relations among these subtasks are determined to facilitate the collaboration among multiple resource nodes [2].

In recent years, numerous studies on the decomposition of the manufacturing task have been conducted [3-7], and many exciting and innovative achievements have been obtained. Their works can be classified into the following categories, namely [8-12]: Similarity coefficient methods; Array-based methods; Graph theoretic methods; Mathematical programming methods and artificial intelligence-based methods.

Their achievements have explored the dependency relationship during the decomposition process of the manufacturing task, the methods to decompose and re-compose subtasks; the recognition and analysis of subtask coupling and decoupling, the conflict recognition and its resolution and so on [13-19], which can guide users to decompose manufacturing tasks into different subtasks effectively. However, their works only direct users how to decompose manufacturing tasks. As for the decomposition granularity of the manufacturing task, how to evaluate their decomposition, namely how to assess the performance of the decomposition results, rare works have been reported, so further explorations shall be made on relevant models, strategies and judging methods.

Received September 27, 2012; Revised January 6, 2012; Accepted January 17, 2013

In the decomposition of manufacturing task, the decomposition granularity plays an important role. For example, on one hand, too large decomposition granularity will increase the complexity of single subtask or activity, affecting the quality of service, and in turn influencing the execution of subsequent subtasks, weakening the flexibility of subtask execution. On the other hand, much small decomposition granularity will increase the number of subtasks, make subtask structure and task planning more complicated. Meanwhile, small decomposition granularity will increase the coupling degree among subtasks, increase the time for coordination among subtasks, or even trigger conflicts in the allocation among resource nodes. In order to ensure the completion of subtasks and avoid the delay in the completion of the manufacturing task caused by unbalanced allocation of subtasks, it is necessary to study relevant theories and methods concerning decomposition granularity of the manufacturing task.

This paper only focuses on how to evaluate the performance of the task decomposition, not the way to decompose. To begin with it, we give the decomposition model of the manufacturing tasks at first.

2. Decomposition Models

To begin the study on the decomposition granularity of the manufacturing task, this paper first decomposes a manufacturing task into different subtasks, and each subtask is composed of various processing events, as shown in Figure 1.

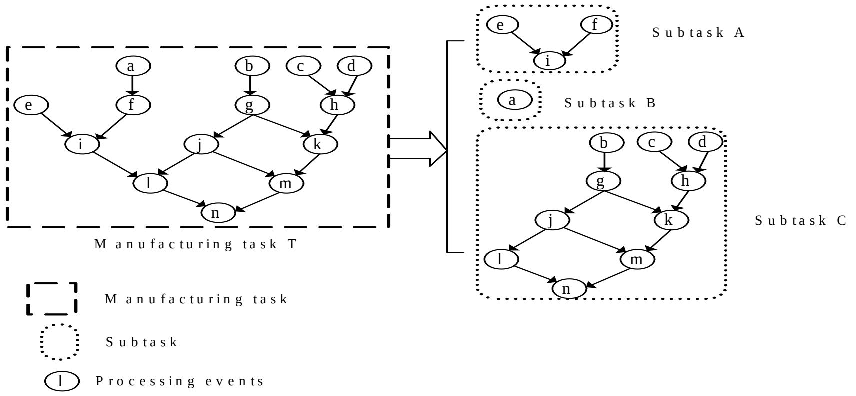


Figure 1. Manufacturing Task T Decomposed into 3 Different Subtasks

In Figure 1, manufacturing task T is decomposed into 3 subtasks, i.e. subtasks A, B and C. Generally one resource node in Manufacturing Grid can independently accomplish one subtask. The subtask is composed of a series of processing events. For instance, subtask A in Figure 1(b) contains 3 processing events e, f and i. Resource node R1 can independently accomplish this subtask (Take the subtask of nut manufacturing for example, the resource node that is capable of nut processing can accomplish 3 processing events, including Nut$^{\phi}$3, Nut$^{\phi}$5 and Nut$^{\phi}$8). Resource node with weak processing capacity may be allocated with only one processing event in a subtask, e.g. subtask B in Figure 1.

In the paper, the principle of “strong cohesion and weak coupling” in the software engineering field has been taken for reference [20]. To be specific, the internal processing events contained in each subtask should have strong cohesion coefficient, while the external coupling relationship among subtasks should be relatively loose. On such basis, this paper has adopted the activity constraint matrix to analyze the constraint relationship among subtasks. After that, the decomposition granularity of manufacturing task has been judged and evaluated by cohesion and coupling indicators. Finally, specific examples have been given on the decomposition granularity of manufacturing task, and the work of this study has been verified.

3. Constraint Analysis

According the decomposition model of manufacturing task in section 2, one manufacturing task is an ordered set of correlative subtasks, and each subtask contains several processing events. These processing events are executed under certain constraint conditions. The modification of one processing event will lead to the change in the entire status of the subtask, which may influence the execution of next subtask. This process keeps going on and on, until all the subtasks are completed. Therefore, the constraint relationship among processing events within a subtask needs to be analyzed. According to Reference [21], the constraint relationship among processing events can be divided into several types as shown in Figure 2.

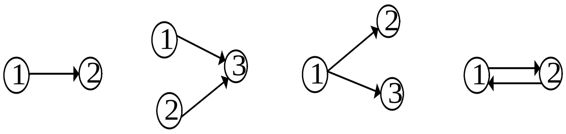


Figure 2. Different Constraint Relationship Among Processing Events

After the manufacturing task is decomposed into subtasks, there exists correlation constraint among processing events in each subtask. In Figure 2, the directions of the arrows represent input or output relationships among processing events. Suppose subtask T contains n processing events, i.e. e1, e2, e3, ……en. Then one n X n matrix can be constructed. The rows and columns of the matrix represent the correlation among processing events in the subtask. This correlation is expressed by eij, and it satisfies formula (1).

$$eij = \begin{cases} 1 & \text{i is input unit, j is output unit} \\ -1 & \text{i is output unit, j is input unit} \\ 1 & \text{No input or output relationship between i and j} \end{cases} \tag{1}$$

Since one processing event has no correlation constraint with itself possibly, all the diagonal elements of the matrix are “0”. See Figure 3 for the matrix E with n X n.

$$\begin{array}{c|cccccc|} & e_1 & e_2 & e_3 & \cdots & e_n \\ e_1 & 0 & e_{12} & e_{13} & \cdots & e_{1n} \\ e_2 & e_{21} & 0 & e_{23} & \cdots & e_{2n} \\ e_3 & e_{31} & e_{32} & 0 & \cdots & e_{3n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ e_n & e_{n1} & e_{n2} & e_{n3} & \cdots & 0 \end{array}$$

Figure 3. The Matrix E With n X n

4. Evaluation Index

Following sections 2 and 3, one manufacturing task is decomposed into a series of subtasks, and each subtask is composed of several processing events with correlations. The output of the previous processing event is the input of the subsequent one or several processing events. A group of input and output events constitutes an event control unit. The constraint structure of events has several activity control units. In here a formal definition of constraint structure among processing events has been specified, and the definition of cohesion coefficient and the measurement methods for its cohesion have been put forward as well [20, 21].

Definition 1: Activity constraint structure among processing events within a subtask.

The activity constraint structure among processing events within a subtask is defined as two-element (T, C), and it satisfies the following conditions:

(1) T represents a finite number of processing events in constraint structure of subtasks;

(2) C={(os, is) T x D(T)} is a constraint control set composed of a series of processing events. It represents the input and output relationship among all the processing events in the constraint structure. “os” represents the output event set, and “is” represents the input event set. The constraint control set (os, is) belongs to the constraint structure space composed of processing events. As one example shown in Figure 4, the input processing events a, b and c have a

common output processing event d. This activity control relationship can be expressed as d {a, b, c} by control units. For another example in Figure 4, the input processing events e and f have a common output processing event h, and the output of g is also h. So this activity control unit can be expressed as {(h {e, f}), (h {g})}.

Figure 4. Examples of Activity Control Unit

Definition 2: Effective subtask. Supposing there exists an activity constraint structure (T, C) of a subtask, any constraint subset t C is called an effective subtask of this constraint structure.

Definition 3: Effective subtask sequence. Provided that an activity constraint structure (T, C) of a subtask exists, one two-element (Q, F) is the effective subtask sequence of this constraint structure, and it meets the following conditions:

(1) For any c∈C, when c∈t, then t∈Q always exists. Q is a collection of effective subtasks, and Q⊆P(C);

(2) For any t,u∈Q, when ps∈is, (os,is) ∈t, (ps, qs) ∈u, (u, t) ∈F. F⊆Q X Q is a constraint structure based on Q;

Definition 3 has provided a collection composed of several input events. “c” is the basic control unit; is and qs are the input event sets; os and ps are the output event sets. Both “t” and “u” are effective subtasks. Condition (1) indicates that all the control units in the activity constraint structure should appear at least once in subtasks, while Condition (2) stresses the correlation among subtasks. In another words, the input event of a control unit in the subsequent subtask is the output event of control unit in the previous subtask. This condition has ensured the correctness of subtask sequence.

In Manufacturing Grid, each subtask is completed based on certain constraint structure according to corresponding working flow. The output of a processing event may be the input of the next one. During the interacting process between the input and the output, many reused activity units will be produced. Those units may appear twice or move in constraint control. The reused cohesion coefficient of processing event is defined as follows [21].

Definition 4: Reused cohesion coefficient of processing events. With respect to the effective constraint task “t” based on activity constraint structure (T, C), the reused cohesion coefficient of its processing events is [20]:

$$\alpha(t)=\begin{cases}\dfrac{\left\|\{u\in T\mid \exists(os,is)\in t,(ps,qs)\in t,u\in(\{os\}\cup is)\cap(\{ps\}\cup qs),(os,is)\neq(ps,qs)\}\right\|}{\left\|\{u\in T\mid \exists(os,is)\in t,u\in(\{os\}\cup is)\}\right\|} & |t|\geq 0\\ \\ 0 \quad |t|=0\end{cases} \tag{2}$$

Reused cohesion coefficient of a processing event is the ratio between the number of reused processing events and total processing events. It can reflect the proportion of reused processing events in total processing events in the constraint structure.

Definition 5: Correlated cohesion coefficient among processing events. For the effective constraint subset “t” in the unit constraint structure, the correlated cohesion coefficient $\beta(t)$ among processing events is defined as follows [20]:

$$\beta(t)=\begin{cases}\sum_{(os,is)\in t}\{(ps,qs)\in t\mid(\{os\}\cup is)\cap(\{ps\}\cup qs)\neq\phi,\ os\neq ps\} & |t|>1\\ \\ 0 \quad |t|\leq 1\end{cases} \tag{3}$$

In the above formula, “$\sum$” is the sum of non-empty intersections among one control unit and others. The correlated cohesion coefficient among processing events is a coefficient measuring the relationship among control units in the constraint structure. It has reflected the general level of correlation among adjacent control units. According to the definitions, the cohesion coefficient inside a subtask is thereby defined as follows.

Definition 6: cohesion coefficient inside subtask. Given an effective constraint subset of subtask activity constraint structure (T, C), its cohesion coefficient is the product of correlated cohesion coefficient and reusable cohesion coefficient of processing events [20]:

$$c(t) = \alpha(t) * \beta(t) \tag{4}$$

Definition 1~6 have described the cohesion relationship among processing events within each subtask that is decomposed from the manufacturing task.

However, with respect to the relationship among subtasks, the fundamental principle to decompose a manufacturing task is to ensure certain independence of each subtask, namely weak coupling among subtasks. The coupling coefficient between subtasks is defined as follows.

Definition 7: Coupling coefficient among subtasks. Suppose there are n kinds of coupling relationship among subtasks, in which the influence coefficient of the kth in n is λ_k, so the coupling coefficient between subtask Si and Sj is defined as follows:

$$r_{ij} = \sum_{k=1}^{n} \lambda_k r_{i,j}^{k} \qquad 1 \ge r_{ij} \ge 0 \tag{5}$$

In formula (5), we have:

$$r_{i,j}^{k} = \begin{cases} 1 & \text{Subtasks Si and Sj meet the kth coupling relation} \\ 0 & \text{Subtasks Si and Sj don't meet the kth coupling relation} \end{cases} \tag{6}$$

$$\sum_{k=1}^{n} \lambda_k = 1 \tag{7}$$

In further step, as one subtask is of autocorrelation by itself, its coupling coefficient is:

$$r_{ij} = \sum_{k=1}^{n} \lambda_k c_{i,j}^{k} = 1 \qquad i = j, \;\; 1 \ge r_{ij} \ge 0 \tag{8}$$

Combing the definition 6 and 7, the evaluation index, namely the decomposition granularity coefficient, can be deduced:

$$\rho = \frac{r}{c(t)} \tag{9}$$

5. Evaluation Steps

On the basis of the evaluation index in section 4, according to the principle of “strong cohesion and weak coupling” for decomposition of manufacturing task, the steps for the evaluation of decomposition granularity of one manufacturing task is listed as follows [22].

1) When decomposing the manufacturing task, the task to be decomposed is regarded as one subtask (i.e. this manufacturing task is accomplished by one resource node). First of all, the processing events of the manufacturing task before decomposition are determined according to definition 1;
2) According to section 2 and 3 of the paper, the activity correlation matrix E of this manufacturing task is derived;

3) Constraint structure (T, C) of this manufacturing task is obtained according to the activity correlation matrix;
4) The decomposition coefficient ρ of the manufacturing task is calculated according to definition 4~7 in section 4;
5) Then the manufacturing task is decomposed into 2 subtasks. Return to steps (2), (3) and (4), and calculate the decomposition coefficient ρ of each subtask again;
6) The following rules can be used to evaluate the decomposition granularity of manufacturing task:

Rule No.1: If the decomposition coefficient ρ of manufacturing task before decomposition is larger than that of the effective subtasks after decomposition, that is, the manufacturing task is in tight constraint structure, the decomposition granularity of the manufacturing task is appropriate, and the initial constraint structure of manufacturing task should be maintained.

Rule No.2: If the decomposition coefficient ρ of the manufacturing task before decomposition is smaller than that of the effective subtasks after decomposition, it indicates a weak cohesion exists among the internal activity units of the initial task, and the manufacturing task has loose constraint structure. It is strongly recommend decomposing the task further.

7) If the manufacturing task needs to be decomposed with different granularities, return to steps (2), (3) and (4), decompose the task once again, and calculate the decomposition coefficient ρ of subtasks after decomposition. The granularity with the minimum value of ρ is the optimal choice of manufacturing task decomposition.

In the following part of the paper, examples to demonstrate the decomposition process of a manufacturing task with proper granularity are given.

6. Examples

Providing that a manufacturing task T is to be decomposed, which contains 14 processing events, i.e. a,b,c,d,e,f,g,h,i,j,k,l,m and n, as shown in Figure 5.

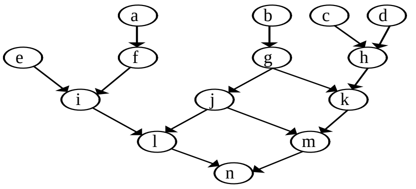
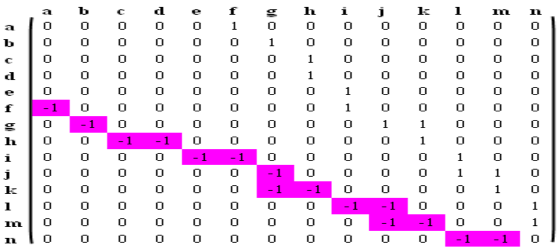


Figure 5. Manufacturing Task T to be Decomposed

Following step (1), T is treated as one subtask. According to section 3, the correlation constraint matrix of processing events in manufacturing task T is obtained as in Figure 6.



$$\begin{array}{c|cccccccccccccc|}
 & a & b & c & d & e & f & g & h & i & j & k & l & m & n \\
a & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
b & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
c & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
d & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
e & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
f & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
g & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\
h & 0 & 0 & -1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
i & 0 & 0 & 0 & 0 & -1 & -1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
j & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 1 & 1 & 0 \\
k & 0 & 0 & 0 & 0 & 0 & 0 & -1 & -1 & 0 & 0 & 0 & 0 & 1 & 0 \\
l & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & -1 & 0 & 0 & 0 & 1 \\
m & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & -1 & 0 & 0 & 1 \\
n & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & -1 & 0
\end{array}$$

Figure 6. Correlation Constraint Matrix of T

The set of the processing events in manufacturing task T is as follows:

$$T=\{a,b,c,d,e,f,g,h,i,j,k,l,m,n\} \tag{10}$$

In terms of formula (10), we get the constraint control set of manufacturing task T in Figure 6:

$$C=\{f(a), g(b), h(c, d), i(e, f), j(g), k(g, h), l(i, j), m(j, k), n(l, m)\} \tag{11}$$

According to formula (2), the reused cohesion coefficient of processing events in manufacturing task T can be achieved:

$$\alpha(t)=\frac{8}{14}=\frac{4}{7} \tag{12}$$

Next by formula (3), the cohesion coefficient of all the processing events in task T is:

$$\beta(t)=\frac{1+2+1+1+3+3+3+3+2}{9*8}=\frac{19}{72} \tag{13}$$

Then in the light of formula (4), the cohesion coefficient inside the subtask of manufacturing task T (In here, T is decomposed into only one subtask) can be acquired:

$$c(t)=\alpha(t)*\beta(t)=\frac{19}{72}*\frac{4}{7}=0.15 \tag{14}$$

As T is only decomposed into one subtask, its coupling coefficient r=1. So the decomposition granularity coefficient for manufacturing task T can be derived out.

$$\rho=\frac{r}{c(t)}=\frac{1}{0.15}=6.67 \tag{15}$$

It can be seen that, if manufacturing task T is decomposed into only one subtask, the decomposition granularity coefficient is very large, so the task needs to be further decomposed. Suppose the manufacturing task T is decomposed into two subtasks T1 and T2 as shown in Figure 7.

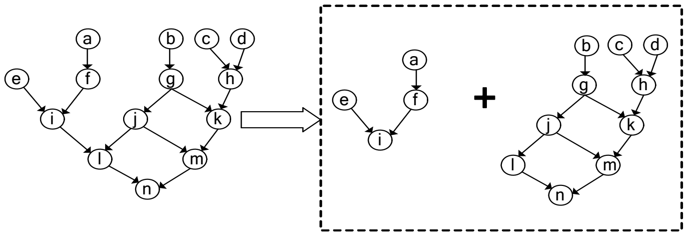
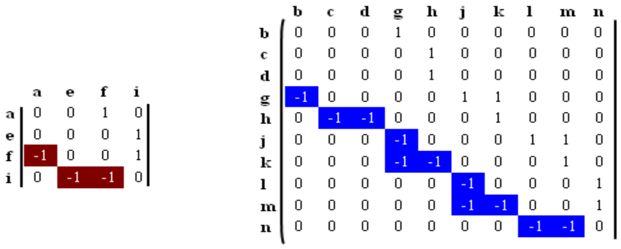


Figure 7. T is Decomposed into Two T1 and T2



$$\begin{array}{c|cccc|}
 & \mathbf{a} & \mathbf{e} & \mathbf{f} & \mathbf{i} \\
\mathbf{a} & 0 & 0 & 1 & 0 \\
\mathbf{e} & 0 & 0 & 0 & 1 \\
\mathbf{f} & -1 & 0 & 0 & 1 \\
\mathbf{i} & 0 & -1 & -1 & 0
\end{array}
\qquad
\begin{array}{c|cccccccccc|}
 & \mathbf{b} & \mathbf{c} & \mathbf{d} & \mathbf{g} & \mathbf{h} & \mathbf{j} & \mathbf{k} & \mathbf{l} & \mathbf{m} & \mathbf{n} \\
\mathbf{b} & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
\mathbf{c} & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
\mathbf{d} & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
\mathbf{g} & -1 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\
\mathbf{h} & 0 & -1 & -1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
\mathbf{j} & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 1 & 1 & 0 \\
\mathbf{k} & 0 & 0 & 0 & -1 & -1 & 0 & 0 & 0 & 1 & 0 \\
\mathbf{l} & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 1 \\
\mathbf{m} & 0 & 0 & 0 & 0 & 0 & -1 & -1 & 0 & 0 & 1 \\
\mathbf{n} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & -1 & 0
\end{array}$$

Figure 8. Correlation Constraint Matrix Inside Subtask T1 and Subtask T2

Subtask T1 contains 4 processing events, i.e. a,e,f,i; subtask T2 contains 10 processing events, i.e. b, c, d, g, h, j, k, l, m, n. See Fig. 8 for correlation constraint matrix of these processing events inside subtask T1 and subtask T2.

According to the correlation constraint matrix of processing events in subtasks T1 and T2, their constraint control set are as follows:

C1={f(a), i(e, f)} C2= { g(b), h(c, d),, j(g), k(g, h), l(j), m(j, k), n(l, m)} (16)

The reused cohesion coefficients of processing events in subtasks T1 and T2 can be achieved individually according to formula (2):

$$\alpha_1(t)=\frac{2}{4}=\frac{1}{2} \qquad \alpha_2(t)=\frac{6}{10}=\frac{3}{5} \tag{17}$$

The cohesion coefficients of all the processing events in subtasks T1 and T2 can be acquired by formula (3):

$$\beta_1(t)=\frac{1+1}{2*1}=\frac{2}{2}=1 \qquad \beta_2(t)=\frac{2+1+3+3+2+3+2}{7*6}=\frac{16}{42}=\frac{8}{21} \tag{18}$$

Then in the light of formula (4), we get the cohesion coefficient inside subtasks T1 and T2:

$$c_1(t)=\alpha_1(t)*\beta_1(t)=\frac{1}{2}*1=0.5 \qquad c_2(t)=\alpha_2(t)*\beta_2(t)=\frac{3}{5}*\frac{8}{21}=0.23 \tag{19}$$

As shown in Figure 7, subtask T1 and T2 is only coupled by node i and l, and their coupling coefficients r1 and r2 are 0.5. So the decomposition granularity coefficients ρ_1 and ρ_2 of subtask T1 and T2 are as follows:

$$\rho_1=\frac{r_1}{c_1(t)}=\frac{0.5}{0.5}=1 \quad \rho_2=\frac{r_2}{c_2(t)}=\frac{0.5}{0.23}=2.17 \tag{20}$$

It can be seen that, after the manufacturing task T is decomposed into subtask T1 and T2, the decomposition granularity coefficients of both T1 and T2 have decreased. Therefore, it is appropriate to decompose manufacturing task T into subtasks T1 and T2.

Of course, manufacturing task T can also be decomposed into different kinds of subtasks in different ways. After decomposing manufacturing task T into different subtasks each time, we calculate the decomposition granularity coefficient ρ of subtasks according to the steps in section 5, and the decomposition with the minimum granularity value of ρ is the optimal decomposition of the manufacturing task.

7. Conclusion

Manufacturing grid has provided manufacturing enterprises with a global platform for sharing manufacturing resources, and it is a key step to decompose the manufacturing task into subtasks with proper granularity. Referring to the principle of “strong cohesion and weak coupling” in software engineering field, this paper has established the model for evaluating the decomposition granularity of the manufacturing task, explored the design steps for the decomposition granularity, and put forward examples to illustrate the idea of the paper. This study is based on the assumption that each resource node on manufacturing grid is capable of executing the subtasks decomposed according with appropriate granularity. Meanwhile, this paper has evaluated the decomposition granularity only through the subtasks after decomposition, i.e. to passively compare and evaluate the appropriateness of different decomposition granularity through subtasks after decomposition. Since a manufacturing task can be decomposed in various kinds of approaches, it will be a very meaningful research to actively guide the decomposition of manufacturing task by combining this evaluation method and certain optimization algorithms while taking the constraint of resource node into account as well.

References

[1] Yong Yin, Zude Zhou, Youping Chen, Yihong Long. Information service of the resource node in a manufacturing grid environment. *Int J Adv Manuf Technol*. 2008; 39: 409-413.

[2] Robin G Qiu. *Manufacturing Grid: A Next Generation Manufacturing Model*. Proceeding of IEEE International Conference on Systems, Man and Cybernetics (SMC2004), Netherlands. 2004; 20-22: 4667-4672.

[3] Kusiak A, Wang J. Decomposition of the Design Process, ASME Transactions. *Journal of Mechanical Design*. 1993; 115(4): 687-694.

[4] Anussornnitisarn Pornthep, Nof Shimon Y, Etzion Opher. Decentralized control of cooperative and autonomous agents for solving the distributed resource allocation problem. *International Journal of Production Economics.* 2005; 98(2): 114-128.

[5] Tang D, Zhen GL, Li Z, et. al. Reengineering of the design process for concurrent engineering. *Computers &Industrial Engineering.* 2000; 38(4): 479-491.

[6] Su Caimao, Ke Yinglin. Task planning and decoupling strategy for collaborative design. *Computer Integrated Manufacturing System*. 2006; 12(1): 22-26.

[7] Zhou Rui, Yu Dingwen, Zhang Yufeng. A Strategy for Automatically Distributing Tasks Based on BOM. *Mechanical Science and Technology*. 2003; 22(2): 315-317.

[8] Brewer A, Sloan N, Landers T. Intelligent tracking in manufacturing. *Journal of Intelligent Manufacturing.* 1999; 10(3-4): 245-250.

[9] Nof SY. Collaborative e-work and e-manufacturing: Challenges for production and logistics managers. *Journal of Intelligent Manufacturing.* 2003; 17(6): 689-701.

[10] Restrepo IM, Balakrishnan S. Fuzzy-based methodology for multi-objective scheduling in a robot-centered flexible manufacturing cell. *Journal of Intelligent Manufacturing.* 2008; 19(4): 421-432.

[11] AI Kokkinaki, KP Valavanis. A distributed task planning system for computer-integrated manufacturing systems. *Journal of Intelligent Manufacturing*. 1996; 7(4): 293-309.

[12] Shaw C Feng. Preliminary design and manufacturing planning integration using web-based intelligent agents. *Journal of Intelligent Manufacturing.* 2005; 16(4-5): 423-437.

[13] Hisup Park, Mark R Cutkosky. Framework for modeling dependencies in collaborative engineering processes. *Research in Engineering Design*. 1999; 11: 84-102.

[14] Raposo AB, Fuks H. Defining task interdependencies and coordination mechanisms for collaborative systems. *Frontiers in Artificial Intelligence and Applications.* 2002; (34): 88-103.

[15] Zhao Jinmin, Liu Jihong, Zhong Yifang, et al. A new tearing method of coupled task set within concurrent design process. *Computer Integrated Manufacturing Systems.* 2001; 7(4): 36-39.

[16] Su JC, Chen S, Lin L. A structured approach to measuring functional dependency and sequencing of coupled tasks in engineering design. *Computers & Industrial Engineering*. 2003; 45(1): 195-214.

[17] Zhou Xionghui, Li Xiang, Ruan Xuyu. Study on task plan algorithm for injection product and mold collaborative design. *Chinese Journal of Mechanical Engineering*. 2003; 39(2): 113-117.

[18] Dong Ming, Chen Fuan, Zha Jianzhong, et al. A matrix scheduling method in concurrent design process. *Journal of Tianjin University.* 1997; 30(4): 408-415.

[19] Browning TR. Applying the design structure matrix to system decomposition and integration problems: a review and new directions. *IEEE Transactions on Engineering Management.* 2001; 48(3): 292-306.

[20] He Yuan, Yu Tao, Zhang Qiling. Granularity Control and Cohesion Measurement in Manufacturing Grid Task Decomposition. *Journal of Convergence Information Technology*. 2011; 6(7).

[21] Chen Hongna. The research on task-based product design process management. Dalian: Dalian University of Technology. 2005.

[22] Pang Hui, Fang Zongde. Task decomposition strategy and granularity design in networked collaborative environment. *Computer Integrated Manufacturing Systems.* 2008; 14(3): 425-430.