Research on Task Planning Based on Activity Period in Manufacturing Grid

He Yu'an, Yu Tao, Hu Da chao

Abstract—**In manufacturing grid (MG), activities of the manufacturing task need to be planed after the task is decomposed, so that some activities can be executed concurrently with each other, manufacturing resources can be utilized optimally, and quality of service (QoS) can be raised. According to the requirements of the activity period, the paper proposes the task planning method, period-cost optimization method and algorithm based on activity period. The constraint degree of activities can be decreased and the period and cost of the whole task can be optimized. MG task planning goal that gets period from the critical path and gets resources from non-critical path is achieved.**

Index Terms— **Manufacturing grid (MG), task planning, task decomposition, activity period, Quality of Service (QoS).**

I. Introduction

In manufacturing grid (MG) [1], task managers or experts need to make a detailed task scheme or a progress schedule. The objective is to fulfill the quality of service (QoS) of task requirements within the prescriptive period under the lower cost as much as possible, and to optimize the task distribute beneficially. The scheme or schedule is the Manufacturing Grid Task Planning (MGTP).

MG task is composed of a series of activities under constraint relations. Activity periods determine the task period and the service time occupied, thus affect the constraint relations and the whole cost of the task.

The characteristics of MG task are that activities implement in concurrent or sequence under a certain constraint conditions. The constraint relations include sequence, parallel, concurrent and mutual exclusion [2]. The process of MGTP is to arrange the activities to an orderly aggregate after the task is decomposed into a series of activities [3]. MGTP is the important link to realize collaborative work, the basis of MG service discovery and matching, and the basis for implementing sequence of activities in work flow management [4].

The paper introduces the task planning method based on activity period in MG, the main content includes: drawing network diagrams according to the task decomposition structure, calculate related time parameters, ascertain key activities and paths, optimization of MGTP.

Manuscript received July 8, 2009. This work was supported by Innovation Program of Shanghai Municipal Education Commission (Project Number: 09YZ389) and supported by Shanghai Leading Academic Discipline Project, Project Number: J51501.

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II. Drawing Network Diagrams of Task Planning

The network diagrams of MGTP can represent the constraint relations among activities, is the basis for ascertaining and optimizing key paths. The related data needed in task planning includes: defining the service requirement information of activities, the periods and constraint relations of activities, which are the main basis for drawing network diagrams.

A. The Definition of Activity Periods

The activity periods are directly related to the working paths and the whole period of the task. If the estimation activity periods are too short, it will cause the situation of insufficient working periods; and vice versa, the whole period of the task will be prolonged. The main methods of defining activity periods are as follows:

1) The method of expert judgment: the experts define activity periods according to their historical experience and knowledge. Certainly, the results have some uncertainty and risk.

2) The method of analogic estimation: the method estimates the activity periods according to previous analogic MG task. When the information about MG task is limited, this is the common method which is a form of expert judgment method.

3) Estimation method of single period: the method can be used for estimating the most possible working period.

4) Estimation method of three periods: the method is applied to estimate three working periods: the optimistic period (shortest period), the pessimistic period (longest period), and the normal period.

B. The Definition of Activity Constraints

The constraint relations are defined commonly as below:

1) The relations of compulsory constraints: this constraint relation is the internal relation among activities, is the basis of activity sequence. This relationship is restricted by technical aspect, and determined by related technicians or managers.

2) The organizational relationship: for some nonrestraint activities, they are usually sequenced with some subjective casualness. The relationships depend commonly on the experiences and knowledge of task managers.

3) The relationship of external restriction: the conditions and influence of external activities must be considered when the MGTP is arranged, so that the task schedule will be

controlled.

4) The restrictions and hypotheses of the task: in order to constitute task planning well, all kinds of restrictions must be considered, at the same time, the conditions and hypotheses of task planning should be made.

For example, according to the decomposition structure of the task, the periods and constraint relations are shown in Table 1. Immediate predecessors refer to activities which have been completed before the activity starts and are directly related to the activity.

Table 1. The periods and constraint relations

Activity name	Expecting periods of activities(days)	Immediate predecessors
A	2	--
B	2	--
C	3	--
D	2	A
E	1	B
F	4	C
G	2	C
H	2	A
I	2	D, E, F
J	2	H, I
K	3	G

C. Drawing network diagrams of MGTP

According to the constraint relationships of activities, the task planning network diagram is drawn. Fig. 1 is the example of the activity-on-arrow network (AOA) diagram. On the basis of activity periods and constraint relations in Table 1, the network diagram of MGTP using AOA is illustrated in Fig. 2.

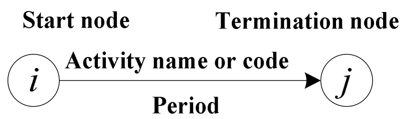

Fig. 1. Example of activity-on-arrow network diagram

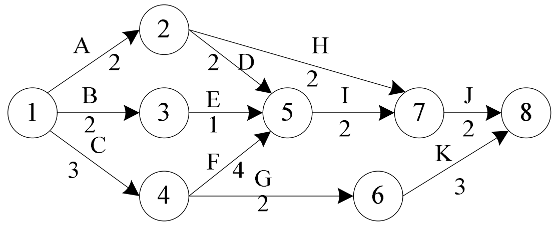

Fig. 2. Network diagram of task planning using AOA

D. The program realization

The network diagram is compiled by JAVA language. The base class named as *java.awt.graphics* provides graphic drawing, rendering and text output. All the windows classes named as *java.awt.component* provide a *paint*() method which has only one parameter being Graphics instance. The paper adopts the following Graphics methods: *drawLine*(), *drawOval*(), *drawString*(), etc. The program segments of task planning are shown in Table 2. The concrete steps are as below:

Step1: Arrange nodes. The coordinate position of initial point is (0, 0). Node position (*a*[*i*],*b*[*i*]) is determined according to preceding activities and succeeding activities.

Step2: Calculate the offset coordinate, angle of declination, length of bevel edge of position (*x, y*) from node *i* to node *j*.

Table 2. Program segments of drawing network diagram

```
public void paint(Graphics g) {
  Arrow   arrow=new   Arrow();
  ……
    String t = "1";
  for(int i=0;i<a.length;i++){
      int x=a[i],y=b[i];
       g.drawString(t,x-p,y+p);
       g.drawOval(x-r,y-r,2*r,2*r);
         char ver=t.charAt(0);// string to char
         int iver= (int) ver;//char to int
         iver=iver+1;
         ver= (char) iver;//int to char;
         t=String.valueOf (ver);
  }
int length=Math.abs(a[i]-a[j]);double len=length;//length
int height=Math.abs(b[i]-b[j]);double hei=height;//height
double jiao=Math.atan(hei/len);
double n=(d-2*r)/Math.cos(Math.PI/4);
double xpian=r*Math.cos(jiao);//offset
double ypian=r*Math.sin(jiao);
……
double
side=Math.sqrt(length*length+height*height)-2*r;//bevel
edge
……
arrow.drawArrow(g,a[i]+r,b[i],0,d-2*r,Arrow.SIDE_LEAD);
……double
side=Math.sqrt(length*length+height*height)-2*r;//      bevel
edge
……
arrow.drawArrow(g,a[i]+r,b[i],0,d-2*r,Arrow.SIDE_LEAD);
……
```

Step3: Calculate the coordinate position of the name of activity (*i, j*). It is in about half *x* and *y* offset from node *i* to node *j*.

Step4: Draw a circle of node j and a line form node i to node j, then write a name on the line.

Step5: If node j is not the terminate point, go to step2, else go to end, activities are listed, critical paths are confirmed.

III. Calculating Time Parameters of Task Planning

A. Time parameters of activity nodes

In task planning network based on activity periods, activity nodes (or called events) themselves do not occupy period, they are just time nodes representing the activity start or end. There are two time parameters [5]: one is the earliest start time (ES), another is the latest finish time (LF).

1) Earliest start time (ES) of activity nodes $es(i)$: Earliest start time (ES) of activity nodes is referred to the possible earliest start time after immediate predecessors of the activity have been completed. Earliest start time of node i is denoted as $es(i)$.

Generally, the ES of original node equals to zero, namely $es(1)=0$, and the calculating method of ES of subsequent nodes: ES of node j equals to the sum of ES of arrow-tail node i and activity period $d(i, j)$. If there are more arrowheads into node j, the maximum value will be the ES of the node after every arrow's ES has been calculated, namely

$$es(j)=\max\{es(i)+d(i,j)\} \quad (1)$$

2) Latest finish time (LF) of activity nodes $lf(i)$: Latest finish time (LF) of activity nodes is referred to the latest finish time which all activities must have been completed. If one of activities does not complete, it certainly will affect the working schedule of the whole task. Latest finish time of node i is denoted as $lf(i)$.

Generally, the LF of terminal node equals to its ES, namely $lf(n)=es(n)$, and the calculating method of LF of anterior nodes: LF of node i equals to the difference value of LF of arrowhead node j and activity period $d(i,j)$. If node i has more arrow-tails, the minimum value will be the LF of the node after every arrow's LF has been calculated, namely

$$lf(i)=\min\{lf(j)-d(i,j)\} \quad (2)$$

B. Time parameters of activities

There are four time parameters in task planning network diagrams, they can be obtained from node parameter $es(i)$, $lf(i)$ and activity period $d(i, j)$. Let a activity is denoted as (i, j), then

1) The ES of activity (i, j) ($ES(i, j)$)equals to the ES of node i ($es(i)$), namely

$$ES(i, j)=es(i) \quad (3)$$

2) The earliest finish time (EF) of activity (i, j) ($EF(i, j)$) equals to the sum of ES of node i $es(i)$ and activity period $d(i, j)$, namely

$$EF(i, j)=es(i)+d(i, j) \quad (4)$$

3) The latest start time (LS) of activity (i, j) ($LS(i, j)$) is referred to the LF of the activity, so that the subsequent activities may start on schedule. It equals to the LF of arrowhead node $lf(j)$ subtracting the activity period $d(i, j)$, namely

$$LS(i, j)=lf(j) - d(i, j) \quad (5)$$

4) The LF of the activity equals to the LF of node i, namely

$$LF(i, j)=lf(i) \quad (6)$$

C. The total float periods of activities

The so called " the total float period" shows the maneuver period that can prolong and not affect the total period. It equals to difference value of LF subtracting EF, or LS subtracting ES of the activity, namely

$$\begin{aligned} TS(i, j) &= LS(i, j) - ES(i, j)=LF(i, j) - EF(i, j) \\ &= lf(j) - es(i) - d(i, j) \end{aligned} \quad (7)$$

The more the total float periods, the more the potential period has. The total float period or the maneuver period of the critical path is not the sum of the total float periods of all activities, but the maximum value of them. Thus, the total float period can share with all the activities.

IV. Critical Activities and Critical Paths

Critical activities and critical paths are the main contents of MGTP. The definitions of critical activities and paths are as below:

1) Critical activities are those which total float periods are zero in the activity network diagram. An activity's total float period represents no spare periods, namely, $ES(i, j)=LS(i, j)$, $EF(i,j)=LF(i, j)$.

2) Critical paths are those that the total periods are longest. There are two ways to define critical paths:

- If the period sum of all activities in a path equals to the period of the task, the path is a critical path.
- If the total float period of every activity in a path equals to zero, the path is a critical path.

According to Fig. 2, some related time parameters of task planning network diagram are shown in Table 3. According to Table 3, the critical path of the task is C-F-I-J.

It must be point out that the critical path is not an invariable. In MGTP, if the contents and sequences of activities are changed, or some of activities are completed in advance or delayed, the critical path changes correspondingly. The manager of task planning must recalculated according to actual changes.

Table 3 Time parameters of task planning network diagram

Activities	Start node	$es(i)$	$EF(i, j)$	$lf(j)$	$LS(i, j)$	Total float period (TS)	Critical activities
A	(1, 2)	0	2	5	3	3	
B	(1, 3)	0	2	6	4	4	
C	(1, 4)	0	3	3	0	0	C
D	(2, 5)	2	4	7	5	3	
E	(3, 5)	2	3	7	6	4	
F	(4, 5)	3	7	7	3	0	F
G	(4, 6)	3	5	8	6	3	
H	(2, 7)	2	4	9	7	5	
I	(5, 7)	7	9	9	7	0	I
J	(7, 8)	9	11	11	9	0	J
K	(6, 8)	5	8	11	8	3	

V. Period-cost optimization algorithm of MGTP based on activity periods

A. The way for period-cost optimization

In MG, period-cost optimization includes two aspects: one is to plan the minimum cost based on the task planning period, the other is to find the optimum period of the task under the conditions of meeting minimum cost.

Generally speaking, the task's cost can be divided into direct cost and indirect cost. The direct cost includes the workers' wage, equipment depreciation, energy, tools, and material consumption. In order to short activity periods, some technical organizations are needed, accordingly some direct cost are increased, such as increasing equipment or energy consumption. Therefore, the shorter the activity period, the more the direct cost increases. Indirect cost usually comprises managers' wages, office expenses and so on. Indirect cost can be allocated according to activity periods. In a certain production scale, the shorter the activity period, the less the indirect cost is allocated.

In MGTP, in order to realize period-cost optimization, one should make rational use of the MG resources and shorten work periods. Some concrete methods include:

1) In MG resource discovery and task scheduling, manufacturing resources should be allocated preferentially to critical activities, namely "to reduce duration time by way of critical path (activities)".

2) In MGTP, using the total float periods of non-critical activities, the start time of activities are staggered, the peak in resource demands is equilibrated, namely "to save resources by way of non-critical path (activities)".

B. Formal description and period model

Network graphs are the foundation of task planning. In such a way of network diagram, the ES, EF, LS, LF and float period are calculated conveniently.

The network N of MGTP may be represented as below:

$$N = (V, A, D, s, t,) \tag{8}$$

Where, V is the set of network nodes $\{v_i \mid i = 1, 2, \cdots, n\}$; A is the set of activities $\{a_{ij} \mid 1 \le i \le j \le n\}$, a_{ij} is the only edge connecting node v_i and node v_j; D is the set of activity periods, d_{ij} is the fuzzy period of activity a_{ij}; s and t are the source and sink of the network respectively.

Period mathematical model: x_j denotes the happening time of node j, $j \in v$, node s is 1, and node t is n, then the period T of N is represented by $\min Z = x_n - x_1$. In order to ensure enough work period of activity (i,j), the model must satisfy $x_j - x_i \ge d_{ij}$. So the period mathematical model is as below:

$$\min Z = x_n - x_1$$
$$\text{s. t.} \begin{cases} x_j - x_i \ge d_{ij}, \ \forall (i,j) \in A \\ x_j \ge 0, \ \forall j \in V \end{cases} \tag{9}$$

C. Rational period optimization model

When the activity period is normal, the period of N is T. If the task must be completed in advance, the period is shortened from T to T_S, $\Delta T = T - T_S (\Delta T > 0)$.

Let $t_N(i, j)$ denotes the normal expected time, $t_S(i, j)$ is the time which is the completion ahead of time; $C(i, j; t_N)$ is the direct cost in normal periods, $C(i, j; t_S)$ is the direct cost which activity (i,j) is completed in advance in work period t_S, then $C'(i, j; t)$ is the marginal cost of the activity, namely

$$C'(i, j; t) = \frac{\mathrm{d}C(i, j; t)}{\mathrm{d}t}, t \in [t_S, t_N]$$

When $C(i, j; t)$ is a linear relationship, then

$$C'(i, j; t) = \frac{C(i, j; t_S) - C(i, j; t_N)}{t_N(i, j) - t_S(i, j)} = K(i, j)$$

Where $K(i, j)$ is the slope of cost [6].

Let $w(i, j)$ denotes the curtate period, then $K(i, j) \cdot w(i, j)$ represents the increased direct cost, $\sum_{(i,j) \in A} K(i, j) \cdot w(i, j)$ represents the total cost completing the task in advance.

In order to guarantee enough work period of activity (i,j), the model must satisfy

$x_j - x_i \geq d_{ij} - w(i,j), \forall(i,j) \in A$, and the activity's period must satisfy $0 \leq w(i,j) \leq t_N(i,j) - t_S(i,j)$, the target is $x_n = T^*, T^* \in [T_S, T_N]$, T_S is the limit period of N [7].

The cost of task N can be divided into direct and indirect cost. Generally speaking, when the period is shortened, the direct cost is increased, and the indirect cost is decreased. The total cost is the sum of direct cost and indirect cost. The rational period should choose the period based on minimum cost. If indirect cost is proportional to the period x_n, namely $p \cdot x_n$ (p is the indirect cost that per unit period allocates), the rational period is shown in equation (10).

$$\min Z = p \cdot x_n + \sum_{(i,j)\in A} K(i,j) \cdot w(i,j)$$
$$\text{s. t.} \begin{cases} x_j - x_i \geq t_N(i,j) - w(i,j), \forall(i,j) \in A \\ 0 \leq w(i,j) \leq t_N(i,j) - t_S(i,j), \ \forall(i,j) \in A \\ T_S \leq x_n \leq T_N \\ x_j \geq 0, \ \forall j \in V \\ x_1 = 0 \end{cases} \quad (10)$$

VI. CONCLUSIONS

The MGTP must be detailed described, reasonable and have a good operability. Only when the scheme and schedule of the MG task are determined, the task can be carried on orderly, unnecessary losses caused by work period delay can be avoided. According to the characteristics of the task, the paper puts forward the method and algorithm of task planning based on period-cost optimization. The constraint degree of activities has been decreased during task implementation. The finishing period and cost of the task have been optimized. The goal that raises the quality of service (QoS) has been achieved. The future work will focus on further studying task planning based on service constraints.

REFERENCES

[1] L. L. Liu, Y. Tao, Z. B. Shi, "Self-organized manufacturing grid and its task scheduling", *Computer Integrated Manufacturing System (CIMS)*, vol. 9, Jun. 2003, pp. 449-455.

[2] Y. H. Li, J. Z. Hua, Y. Jin, "Research on the relationship between process of parallel development and evolution of product model", *Mechanical Science and Technology*, vol. 19, Jun. 2000, pp. 893-895.

[3] Y. A. He, T. Yu, L. L. Liu, et al, "A QoS-based Task Decomposing Middleware Research for Manufacturing Grid", *Proc. of 1st International Conference on Semantics, Knowledge and Grid (SKG 2005)*, Beijing, China, Nov. 2005, 513-519.

[4] Y. A. He, T. Yu, D. C. Hu, "An Algorithm for Matching Resource Based on Semantics and QoS in Manufacturing Grid", *11th IASTED International Conference on Internet and Multimedia Systems and Applications*, Aug. 2007.

[5] DuPont, "CPM-Critical Path Method", *http://www.netmba.com/operations/project/cpm/*.

[6] H. Q. Wu, L. Tang, X. J. Sun, "Research on period optimization of related joint construction network", *Journal of Systems engineering*, Apr. 2001, pp. 43-46.

[7] Q. M. Wu, "The algorithm for PERT time parameters and period-cost optimization", *Journal of Shaoxing University*, vol. 4, 2001, pp. 4-8.