'91 KACC 1991. 10. 22~24

INTERACTIVE MACHINE LOADING AND TOOL ASSIGNMENT APPROACH IN FLEXIBLE MANUFACTURING SYSTEMS

Kiyoshi Kato* , Fuminori Oba** , and Fumio Hashimoto*

* Dept. of Industrial Management, Osaka Institute of Tech.
** Div. of Machine Design Engeneering, Hiroshima Univ.

ABSTRACT

This paper discusses on the machine loading and tool allocation (MLTA) problem. Mathematical formulation of the problem is given first. Then a heuristic approach based on Group Technology (GT) is presented to deal with the MLTA problem effectively. By using this approach, part-tool group generation and their assignment to adequate machines can easily be obtained in consideration of the work load on each machine, the number of tool-set replacement, and the total number of cutting tools required through the interactive setting of the desired machine utilization rate.

1. INTRODUCTION

In recent years, various types of flexible manufacturing systems (FMS) have been developed to attain both productivity and flexibility in the mid-variety, mid-volume manufacturing area. To achieve the best utilization of the potential production capability in an FMS, careful system set-up should be done on the production planning problems.

This paper focuses on the problem of allocating operations and cutting tools to the tool magazine of limited capacity. Poor machine loading and tool allocation result in a low machine utilization and increase of the total tooling cost. Up to now, several studies have been done on this problem [1-3]. However, many of them seem to be impractical because of the calculation complexities or the lack of capabilities to treat multi-objective problems.

In this study, we propose an interactive tool allocation method to attain both high productivity and low tooling cost in FMSs. This method comprises of the following two phases. In the first phase, the parts to be produced and the cutting tools to be used in the manufacturing process are rearranged to form a part-tool structured matrix in such a way that the correlation among parts and cutting tools is maximized based on Group Technology (GT) concept. In the second phase, desired machine utilization rate for each machine is set interactively. Then, based on the part-tool structured matrix, construction of part-tool groups and their assignment to the adequate machine are automatically determined by the use of branch and bound method in consideration of the desired machine utilization rate, load balance among machines, total number of cutting tools required, and the total number of tool-set exchange. Numerical example is given to show the effectiveness of the proposed approach.

2. PROBLEM FORMULATION

Given the manufacturing information on the parts to be produced and the machines to be used in the planning horizon as shown in Table 1, the MLTA problem can be described as follows. Parts to be produced should be assigned to the appropriate machine within its available machining time. This forms the first constraint which can be expressed as eq.(1).

$$\sum_{u=1}^{Ns_j}\sum_{i=1}^{Np}\sum_{k=1}^{Nc} n_i\cdot t_{ik}\cdot x_{iju} + \sum_{u=1}^{Ns_j}(ts_j + \sum_{k\in R_{ju}} t_{Ejk}) \leq Lj \qquad (j=1,..,Nm) \quad \cdots\cdots (1)$$

Here, Ns_j is a number of the replacement of tool sets allocated to machine m_j, and R_{ju} is a set of cutting tools assigned at u-th stage of machine m_j (at u-th stage the u-th replaement of the tool set is done). Variable x_{iju} is a decision variable which takes the value 1 if the part p_i is processed at stage s_u on the machime m_j, and takes 0 otherwise. The second term in eq.(1) means the tool-set replacement time required on machine m_j.

Adding to the above constraint, each machine utilization rate should also be hold in a predetermined range defined by the desired utilization rate and its allowable deviation. This second constraint can be expressed as eq.(2) where Ej^* is a desired utilization rate of machine m_j and ΔEj is an allowable deviation from Ej^*.

$$Ej^*-\Delta Ej \leq (\sum_{u=1}^{Ns_j}\sum_{i=1}^{Np}\sum_{k=1}^{Nc} n_i\cdot t_{ik}\cdot x_{iju})/Lj \leq Ej^*+\Delta Ej \qquad (j=1,..,Nm) \quad \cdots\cdots (2)$$

TABLE 1 Manufacuring Informations

Np=number of the kind of parts to be produced
Nm=number of machine tools
Nc=number of the kind of cutting tools
n_i=volume of the part type p_i to be produced (i=1,..,Np)
t_{ik}=processing time of part p_i with tool c_k (i=1,..,Np; k=1,..,Nc)
T_{ik}=tool life of c_k in the machining process of p_i (i=1,..,Np; k=1,..,Nc)
L_j=available machining time of machine m_j (j=1,..,Nm)
Q_j=capacity of the tool magazine attached to machine m_j (j=1,..,Nm)
ts_j=operation time for start/stop of machine m_j (j=1,..,Nm)
t_{Ejk}=replacement time of tool c_k on machine mj (j=1,..,Nm; k=1,..,Nc)

The third constraint is on the tool magazine capacity. In each stage of the machine, the number of tools used for machining parts loaded at the stage should not exceed the magazine capacity of the machine. Eq.(3) shows this constraint. Here, S_{ju} is a set of parts to be processed at s_u -th stage of machine m_j.

$$\sum_{k=1}^{Nc}\left[\sum_{i\in S_{ju}} n_i\cdot t_{ik}\cdot x_{iju}/T_{ik}\right]^+ \leq Qj \quad (j=1,..,Nm) \cdots (3)$$

The objective in this study is to minimize the total number of cutting tools required under the above three types of constrains. Thus the MLTA problem can be formulated as following by using the decision variables x_{iju}.

$$\text{Minimize} \quad V=\sum_{j=1}^{Nm}\sum_{u=1}^{Ns_j}\sum_{k=1}^{Nc}\left[\sum_{i\in S_{ju}}(n_i\cdot t_{ik}/T_{iki})\cdot x_{ju}\right]^+ \cdots (4)$$

subject to eq.(1) to eq.(3)

The MLTA problem defined above could be solved by the integer programming, but it would need very complicated computations especially for practical problems. Moreover, desired values of the machine utilization rate and their allowable variances have some ambiguities, so that the number of trials must be required for obtaining the feasible solutions.

From those view points, we propose the human-computer interactive approach based on GT concept.

3. GT-BASED HEURISTIC APPROACH

Our proposed method is comosed of the following two stages. In the first stage, parts to be produced and cutting tools to be used are rearranged to form structured part-tool matrix in such a way that the the correlation among parts and cutting tools is maximized based on group technology (GT) concept. In the second stage, generation of part-tool group and its assignment to the appropriate machine are sequentially determined under the constraints of eq.(1) to eq.(3) by using branch and bound method where the desirable machine utilization rates and their allowable diviation are set interactively by referring to the intermediate process of the branch and bound operation. Figure 1 shows the flow chart of this proposed approach.

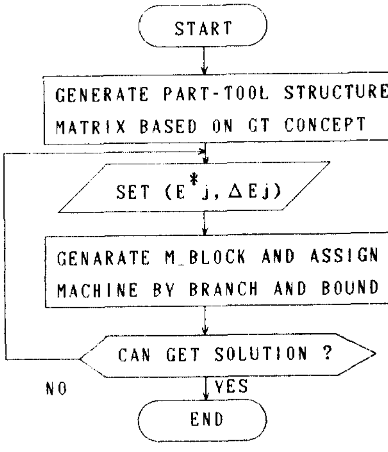

Figure 1 Flow chart of the proposed method

3.1 GENERATION OF PART-TOOL STRUCTURED MATRIX

Bsed on the manufacturing information described in 2, part-tool relation matrix can be constructed as shown in Figure 2 (a). In this figure, symbol "*" is used in place of the actual load rate of cutting tool defined by eq.(5).

$$LR_{i,k}=n_i\cdot t_{i,k}/T_{i,k} \quad (i=1,..,Np;\ k=1,..,Nc) \quad \cdots\cdots (5)$$

In order to rearrange the part-tool relation matrix so as to maximize the correlation among parts and cutting tools, the quantification theory III can be used. (The application of this theory to the manufacturing cell formation problem has been presented in [4].) By applying the quantification theory III to the part-tool relation matrix, the structured part-tool matrix can be obtained as shown in Figure 2(b).

	c1	c2	c3	c4	c5	c6
p1	A	A	A	A	.	A
p2	A	.	A	.	.	A
p3	A	.	A	.	.	A
p4	.	A	.	A	A	.
p5	.	.	.	A	A	.
p6	A	.	A	.	.	A
p7	A	A	A	.	.	A
p8	.	A	A	A	A	.
p9	.	A	.	A	A	.
p10	A	.	.	.	.	A
p11	A	.	A	.	.	A
p12	A	A	A	A	A	.
p13	.	A	.	A	A	.
p14	.	.	.	A	A	.
p15	.	A	A	A	A	.
p16	A	.	.	.	.	a

(a) Relation matrix

	c5	c4	c2	c3	c2	c6
p14	A	A	.	.	.	.
p5	A	A	.	.	.	.
p4	A	A	A	.	.	.
p9	A	A	A	.	.	.
p13	A	A	A	.	.	.
p15	A	A	A	A	.	.
p8	A	A	A	A	.	.
p12	A	A	A	A	A	.
p1	.	A	A	A	A	A
p7	.	.	A	A	A	A
p11	.	.	.	A	A	A
p6	.	.	.	A	A	A
p3	.	.	.	.	A	A
p10	.	.	.	.	A	A
p2	.	.	.	.	A	A
p16	.	.	.	.	A	A

(b) Structured matrix

Figure 2 Generation of the structured part-tool matrix

3.2 GENERATION OF PART-TOOL GROUPS AND DETERMINATION OF THEIR APPROPIATE ASSIGNMENT TO MACHINES

In the second phase, generation of part-tool groups and their adequate assignment to machines are performed for the presetted values of desirable machine utilization by using branch and bound method.

3.2.1 GENERATION OF PART-TOOL GROUP

Throughout this study, each part is assumed to be processed wholly on a single machine. Hence, part group and the corresponding cutting tool group can be easily generated by applying horizontal cut to the structured part-tool matrix as shown in Figure 3. In this figure, two kinds of horizontal cut are used, i.e., S_cut and E_cut.

At the beginning of the procedure, S_cut and E_cut are set at the first row of the structured part-tool matrix to form a temporal block including only a kind of part. Then the machining time of that block is checked for each un-

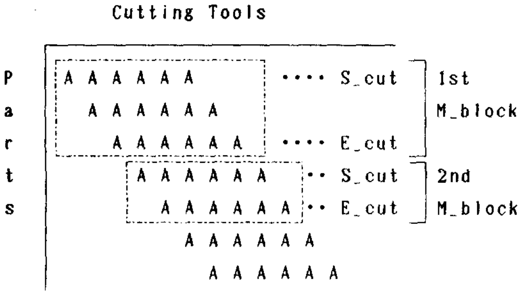

Figure 3 Generation of M_block

assigned machine whether the constraint of eq.(2) is satisfied. If there is no machine to satisfy the constraint of eq.(2) for the temporal block, the construction of this temporal block should be canceled. Then E_cut is sifted downward by one row and the same procedure is repeated untill the machine satisfied eq.(2) can be found.

If there exist some machines which satisfy eq.(2), the temporal block becomes a candidate block to form a part-tool group. In this paper, this candidate block is called M_block. There is also a possibility to form a number of different M_blocks having the same S_cut.

Once the M_block is formed, S_cut is reset at E_cut+1. Then the same procedure is repeted untill E_cut is set at the last row of the structured part-tool matrix. In this way, the generation of M_block and its assignment to the appropriate machine can sequentially be determined by partitioning the structured part-tool matrix in consideration of machine utilization rate.

3.2.2 CALCULATION OF THE TOOL SET REPLACEMENT TIME AND OF THE MINIMUM NUMBER OF CUTTING TOOLS

After the M_block is generated and assigned to the candidate machine, the minimum number of replacement of the tool set can be determined by the following way.

Based on the magazine capacity of the assigned machine, similar horizontal cut approach to the structured matrix described above is performed again to the M_block, but in this case, the constraint of the block division is not eq.(2) but eq.(3). The subdivided block is referred to as C_block. Here, the cutting tools involved in the C_block can be considered to form a tool set. Thus the minimum number of replacement of the tool set can be determined in such a way that E_cut is set to process as much parts as possible within a single stage of the assigned machine. Here, stage means a period from one setup of the tool set to the next tool set setup. S_cut and E_cut used for determining the minimum number of replacement of the tool set are called S_0_cut and E_0_cut respectively.

For example, given a constructed M_block shown in Fig. 4, three C_blocks can be generated for the machine with magazine capacity of 18. The contents of these C_blocks are shown in Table 2. In this case, the minimum number of replacement of the tool set is three.

The next problem is to determine the minimum number of cutting tools required. The number of cutting tools required at stage s_u of machine m_j can be given by eq.(6).

	c1	c2	c3	c4	c5	c6	c7	c8	c9	c10
p1	0.5	0.5	0.4	0.5	0.3	*	*	*	*	*
p2	0.6	0.7	0.6	0.4	0.4	*	*	*	*	*
p3	0.7	0.8	0.5	0.7	0.5	0.3	*	*	*	*
p4	0.5	1.2	0.7	0.9	0.5	0.4	0.5	*	*	*
p5	0.4	0.6	0.7	0.5	0.5	0.8	0.5	*	*	*
p6	*	*	0.4	0.6	0.3	0.5	0.7	0.6	0.5	0.3
p7	*	*	*	0.5	0.6	0.3	0.5	0.7	0.8	0.5
p8	*	*	*	0.5	0.4	0.5	0.5	0.4	0.8	0.7
p9	*	*	*	*	0.3	0.6	0.6	0.6	0.5	0.6
p10	*	*	*	*	*	0.4	0.4	0.4	0.6	0.5

Figure 4 Generated M_block

Table 2 Content of the C_block generated from Fig.4

C_block No.	S_0_cut	E_0_cut	Number of tools
No.1	1st row	4th row	17
No.2	5th row	7th row	17
No.3	8th row	10th row	12

* magazine capacity =18

$$NT_{j,u}=\sum_{k=1}^{Nc}\left[\sum_{i\in S_{ju}} R_{i,k}\right]^{+} \quad (j=1,\ldots,Nm;\ u=1,\ldots,N_{sj}) \quad \cdots(6)$$

In eq.(6), N_{sj} is the minimum number of replacement of the tool set just determined at the preceding step.

Both a number of cutting tools required and a number of replacement of the tool set depend on how to construct the tool set. In this approach, the number of replacement of the tool set is fixed at N_{sj} so as to minimize the machine stop time.

C_blocks defined by S_0_cuts and E_0_cuts are not necessarily optimal from the view point of minimum number of cutting tools, hence there is a need to reconstruct the C_blocks. Reconstruction of the C_blocks under the constraint of N_{sj} can be performed by using branch and backtrack method.

Figure 5 shows a branch and backtrack tree generated for the M_block in Figure 4. In this figure, a notation (i,j) in each node means that the E_0_cut of i-th C_block is shifted upward by j rows in the M_block which causes a shift of the S_0_cut of the (i+1)-th C_block upward by j rows.

At each node of the tree, the number of cutting tools required is calculated by eq.(6) then checked whether the constraint of magazine capacity is satisfied or not. If such constraint cannot be satisfied at the node, backtrack to the parent node is provoked. Backtrack is also provoked if the node to be considered is a leaf node of the tree, i.e., node (N_{sj},k).

In Figure 5, node 3 represents the initial C_blocks constructed by S_0_cuts and E_0_cuts. Backtrack from node 3 is then carried out by shifting both E_0_cut of the 2nd C_block and S_0_cut of the 3rd C_block upward by 1 row respectively. Node 4 shows this status. At node 7, mark X

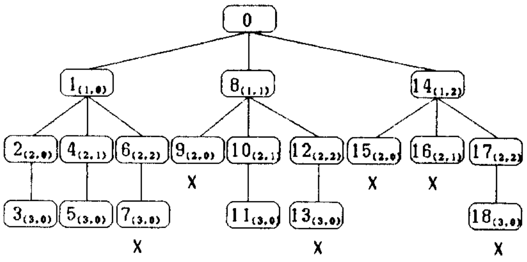

Figure 5 Branch and backtrack tree for M_block shown in Fig.4

denotes that the constraint of the magazine capacity is violated at the 3rd C_block. When no more child node of satisfying magazine capacity constraint can be generated from a node at level, i.e., the first C_block, the branch and backtrack is terminated. In this way, all the possible patterns of C_block generation can be obtained.

3.2.3 BRANCH AND BOUND METHOD

Branch and bound method used here can briefly be described as follows. (1) Branching operation; Select a node having the least value of Vw defined by eq.(7). At this node, try to make M_block for the remaining part of part-tool structured matrix. Each M_block constructed for the same S_cut generates a new node which has the same parent node. (2) Bounding operation; Bound all nodes having greater value of Vw than a minimum value of the feasible solutions. Node can also be boundedif the total machining load of the unassigned parts cannot be expected to satisfy the constraint of eq.(2).

The lower bound of the total number of cutting tools (Vw) can be obtained by the following equation.

$$Vw = \sum_{j=1}^{Nm} \sum_{u=1}^{N_{mj}} Rq_{j,u} + \sum_{k=1}^{Nc} [\sum_{i \in Rm} LR_{i,k}]^{+} \qquad \cdots\cdots (7)$$

Here, $Rq_{j,u}$ is a total number of tools to be replaced at stage s_u of machine m_j, and Rm is a set of unassigned parts. $Rq_{j,u}$ is the same as the left side of eq.(3) when the cutting tools are replaced by the tool set. But the $Rq_{j,u}$ can be reduced by the common use of cutting tools among a series of stages. The latter idea is taken in the next numerical example.

4. NUMERICAL EXAMPLE

As a example, the MLTA problem for the manufacturing information given in Table 3 is considered. The expected values of machine utilization rate and its allowable variance which are determined through a number of interactions are also shown in the table. There are 32 types of parts to be machined with 45 types of cutting tools. Table 4 shows a result obtained by the proposed method. The number of nodes generated in the branch and bound tree is 17 for the settings of the desired machine utilization rates and allowable diviations given in Table 3.

Table 3 Sample data for MLTA problem

Part	W.Load	Part	W.Load	Part	W.Load	Part	W.Load
p1	10.29	p9	14.97	p17	17.41	p25	23.86
p2	12.63	p10	10.76	p18	16.17	p26	21.35
p3	16.37	p11	10.82	p19	15.28	p27	18.23
p4	21.99	p12	16.00	p20	17.52	p28	18.75
p5	18.71	p13	19.77	p21	21.12	p29	17.19
p6	18.24	p14	15.53	p22	22.42	p30	20.31
p7	18.24	p15	16.00	p23	26.24	p31	14.06
p8	17.78	p16	16.47	p24	23.38	p32	15.10

Machine	A.M.T	Magazine C.	D.U.R	Deviation
M1	180	18	90 %	±2 %
M2	150	20	80 %	±3 %
M3	140	14	80 %	±3 %
M4	100	14	70 %	±5 %
M5	120	16	80 %	±7 %

A.M.T=available machining time
D.U.R=desirable utilization rate

Table 4 Results for sample data

Machine	Utilization	Num. of Tools	T.S.R
M1	88.8 %	38	3
M2	79.2 %	33	3
M3	80.0 %	31	3
M4	68.6 %	18	3
M5	86.4 %	26	3

T.S.R=number of replacement of tool set

5. CONCLUSION

In this paper, we propose an interactive approach for machine loading and tool allocation problem based on GT concept. The advantages of this approach can be considered as follows: (1) expected value of the machine utilization rate can be set independently for each machine, (2) feasible solution can easily be obtained in consideration of machine utilization rates, machine load rates, magazine capacities, number of replacement of the tool set, and the total number of cutting tools required.

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