A study on characterization of agile manufacturing system with square array layout of machining centres

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Abstract

To cope with the agility to respond the dynamic change in the market, we propose a manufacturing system with machining centres (MCs) in a square array layout. The machining processes of the target products are grouped into some processing groups, and any processing groups of any products can be processed by any MCs with proper tool arrangements. The selection of MCs is made by an auction mechanism. Noticing that each MC needs to be allocated sufficient number of tools, or tool sets to process all processing groups of all products, we propose a method to characterize MCs for processing specific processing group of specific product kinds by limiting the tool sets to be allocated to each MC and investigate the characteristics of the proposed method by numerical experiments.

Keywords

Agile manufacturing, square arrayed layout, auction method, tool allocation.

INTRODUCTION

Agility in manufacturing requires a quick response to the changes in the quantity of products without losing the productivity (Kidd, 1995) (Okino, 1993) (Kaihara, 1997, 1999). Flexible manufacturing system (FMS), e.g. (Raouf & Ben-Daya, 1995), has been introduced to improve the productivity in manufacturing many kinds of products with a small or medium volume, which can cope with frequent changes in the kinds and the volume of products in a short time. On the other hand, flexible transfer line (FTL) has been utilized for a mass production system by a series of numerically controlled machining cells arranged in a flow line. We have proposed high volume flexible manufacturing system (HV-FMS) as a new manufacturing system dissolving the limitations of FMS and FTL, which attains the high flexibility as well as the high volume production by a serial-parallel layout of machining cells as shown in Figure 1 (Fujii *et al.*, 1998a, 1998b, 1999a 2000a, 2002). In HV-FMS, machining processes of the target products are grouped into some processing groups (OPs). A specific OP of all products can be processed by MCs allocated to the OP.

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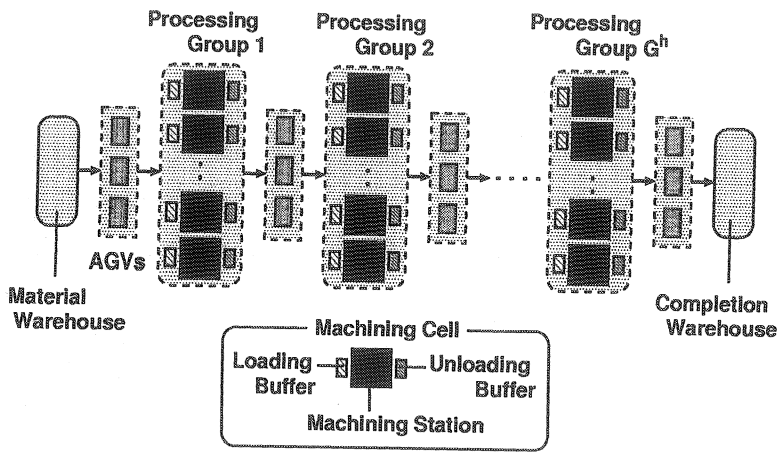

Figure 1 - System Configuration of HV-FMS

To generalize and extend the serial-parallel layout, we further proposed a square array layout of MCs (Fujii *et al.*, 2000b). In this layout, MCs are located at square grid points as shown in Figure 2, where each MC has all tool sets required to process all OPs of all products. The MCs are selected by the auction with five types of bids at the pallet change station (PCS). A basic study showed that MCs tend to process a specific OP and/or specific product by selecting an appropriate ordered set of bid types. It was also observed that a material flow from the entrance to the exit can be formed by some sets.

In this study, we investigate to find the possibility to characterize the MCs to specific OPs or specific products by allocating specific tool sets to MCs. The allocation of specific tool sets to MCs will result in the considerable reduction of the number of tool sets, since the total number of tool sets required to the basic system configuration will be (number of MCs) × (number of OPs) × (number of product kinds). In this study we count one tool set is required to process a specific OP of a specific product kind, even though many kinds of tools may be commonly used in specific OPs of different product kinds and only one tool of each common kind will be allocated to one MC in reality.

In this paper we firstly describe the configuration of the manufacturing system with the square array layout of MCs and then the auction method as a dispatching method used for the selection of MCs. The characterization methods of MCs are proposed and their characteristics and effectiveness are investigated by simulation using a model manufacturing system.

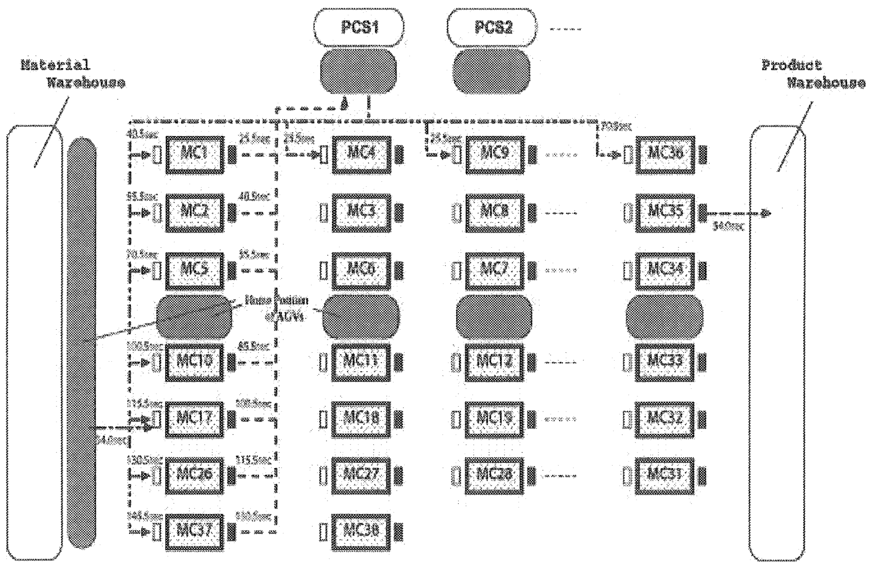

Figure 2 - Conceptual Configuration of Square Array Layout of MCs

CONFIGURATION OF SQUARE ARRAY MANUFACTURING SYSTEM

A manufacturing system with the square array layout of MCs shown in Figure 2 is named a square array manufacturing system in this study. Each MC located at a grid point is characterized by the tool sets allocated to it; in other words, the MC can process a specific processing group (OP) of a specific product only when the corresponding tool set to it is allocated to the MC. In this study, pallet changing stations (PCS) are located on the top in the Figure , while the home positions of automated guided vehicles (AGVs) are set at the middle of the system and at the PCSs.

A work piece fixed on a pallet for the first OP, OP1, is loaded at the entrance storage and is dispatched to an MC by a dispatching method, where the dispatching method used in this study is an auction method described in later section. The work piece is transported by an AGV to the assigned MC. After completing the processing of OP1, the work piece is transferred to the PCS that will change the pallet of the work piece from the one for OP1 to that for OP2. Then the work piece on the pallet for OP2 is dispatched to an MC by the dispatching method. This procedure will be repeated when the processing of OPi is completed. When the last OP is completed, the work piece is transported to the exit storage where the work piece is unloaded from the pallet.

AUCTION METHOD

An auction method is used as a dispatching method to select an MC to process a work piece. Among the five types of bids considered in the previous study (Fujii, *et al.*, 2000), we specifically consider following three types of bids as effective ones to characterize the MCs.

Type 1: Availability of MC
Bidding value: 2= Both the loading station and MC are empty
1= Only the loading station is empty
0= Fully occupied, i.e., not available

Type 2: Distance from PCS to MC
Bidding value: Higher value to closer MC

Type 3: Cumulative ratio of processing the product kind under consideration
Bidding value: Higher value to higher cumulative ratio

Basically, Type 1 is asked at first and the Type 2 or Type 3 is asked if more than one MCs are available with the same bidding value. If all MCs are not available, the work piece will stay at the PCS until an MC reports the completion of its processing. If more than one MCs make the bid for Type 2 or 3, one MC is selected randomly. The procedure is schematically shown in Figure 3.

CHARACTERIZATION ALGORITHMS OF MCS

In this study we define that the characterization of an MC is to confine the capability to process OPs and/or product kinds by allocating specific tool sets necessary to process them. Since the basic configuration of the square array manufacturing system assumes that all MCs possess all tool sets necessary to process all OPs of all products, the characterization of MCs means to delete appropriate tool sets from the initially allocated tool sets. We propose following two algorithms to delete tool sets, which are named Characterization Algorithms a and b, or CA-a and CA-b in short.

1. Characterization Algorithm a: CA-a: After manufacturing a certain amount of products, we remove the ten least used tool sets from the system. If there are tool sets tying at the tenth rank from the least, all sets at that rank will be removed.
2. Characterization Algorithm b: CA-b: After manufacturing a certain amount of products, we remove the least used tool set from each MC. If there are more than one tool sets, one set is randomly chosen to remove.

The basic procedure to apply the algorithm is as follows:

[Step 1] The system is set at the initial conditions. All tool sets are allocated on each MC. The system is empty. Set the frequency counter of each tool set to zero.

[Step 2] The manufacturing of a prespecified amount of work pieces starts randomly and stop when all work pieces are processed completely.

[Step 3] If the make-span is less than the prespecified working hours, CA-a (or –

b) is applied and go to Step 4. If the make-span is over the prespecified hours, the procedure will be terminated.

[Step 4] Reset the frequency counter of each remaining tool set. A prespecified amount of work pieces are generated again and go to Step 2.

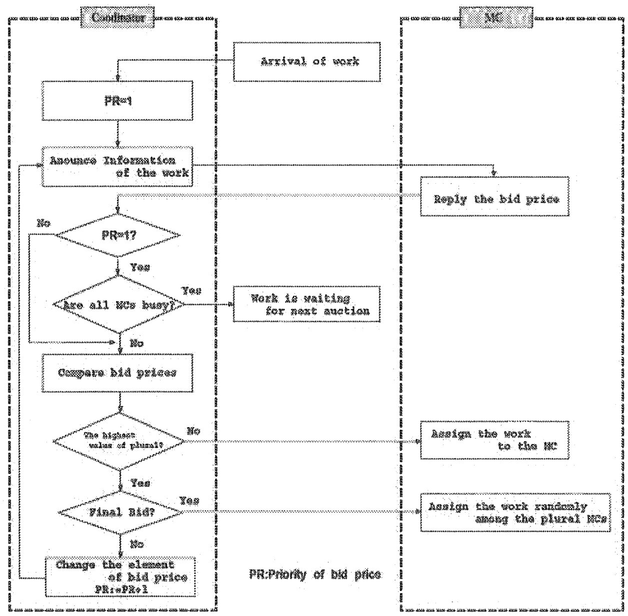

Figure 3 - Procedure to select an MC by the Auction

SIMULATION STUDY

We investigate the effectiveness of characterization algorithms and the types of bids used to select the MCs by simulation. Since the results obtained by two algorithms are similar, only the results by CA-a are reported here. We consider a manufacturing system producing 3 kinds of products, each of which consists of 5 OPs. The total production amount of products is 30,000 pieces per month, i.e., within 480 hours, and the basic product mix of three product kinds is set to 45: 20: 35. The processing times of all OPs of the products are given in Table 1. The total number of MCs becomes 38 assuming that the average utility is 80%. The number of MCs required to process each OP is estimated as listed in the table. The layout of 38 MCs is schematically shown in Figure 4 and Figure 5.

The number of AGVs is assumed to be sufficiently large. Pallets used for an OP are assumed to be commonly used for all product kinds and the total number of pallets is set to 100 which are allocated proportionally to the total processing time of each OP. The total number of tool sets becomes 570 sets (= 38 × 5 × 3). Each bid type of 2 and 3 is used after checking the availability of MCs by bid type 1 forming two ordered bid sets, BP[1,2] and BP[1,3] in this study. The prespecified parameters for the characterization algorithms are 30,000 work pieces and 480hours.

Table 1 - Processing Times of Processing Groups of All Product Kinds

	OP-1	OP-2	OP-3	OP-4	OP-5
WORK-1	5.731	5.476	8.583	4.000	8.000
WORK-2	4.601	5.020	5.850	3.230	6.000
WORK-3	7.241	3.537	6.067	4.000	8.000
Assigned MCs (38)	7.814 ≅ (8)	6.094 ≅ (6)	9.268 ≅ (9)	4.981 ≅ (5)	9.843 ≅ (10)

BP[1,2] and CA-a

Figure 6 shows the change in the make-span when the tool sets are reduced from 570 by CA-a using BP [1,2]. As shown in the Figure, the make-span to manufacture 30,000 pieces does not exceed the prespecified 480 working hours until the tool sets are reduced to 79 in this case. The make-span remains 400 hours until the tool sets are reduced to 109 and jumps to 461 hours at 99 sets remaining at the same make-span to 79 sets. We adopt 109 sets for the investigation below considering the safety margin for the make-span. The increase in the make-span from 109 sets to 99 sets is explained by the fact that only one tool set is assigned to process OP1 of Product 2 among 99 sets resulting in the bottle neck of the material flow and increasing the make-span, while 6 sets are assigned to the same OP among 109 sets.

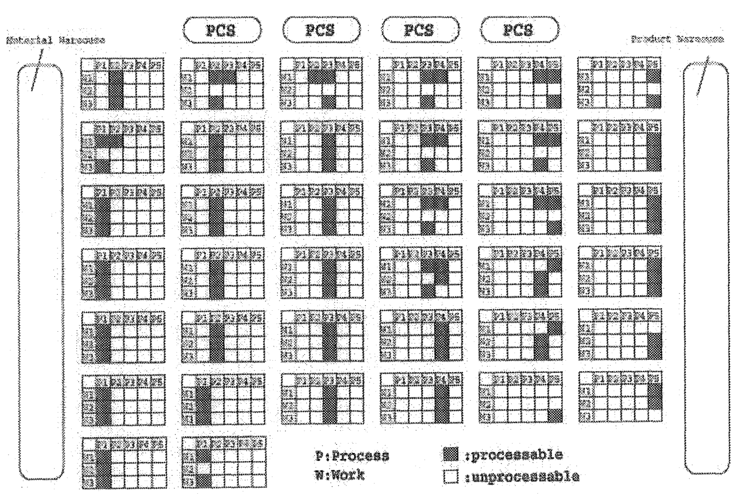

Figure 4 - Allocation of 109 Tool Sets: BP[1,2] and CA-a

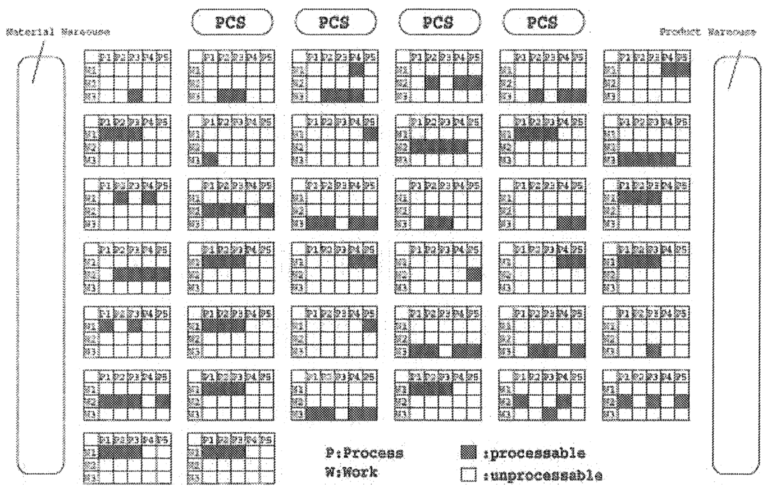

Figure 5 - Allocation of 103 Tool Sets: BP[1,3] and CA-a

Figure 4 shows the allocation of 109 tool sets at MCs. Each black section of each MC indicates that the tool set remains at the MC to process the OP of the product corresponding to the black section. Each MC tends to possess the tool sets to process a specific OP; for example, the MC at the top left in the Figure can process the OP2 of any products. MCs at the left side of the Figure, i.e., the entrance side, possess the sets with the smaller number of OPs and those at the right side, i.e., the exit side, with the larger OP number. This means that a material flow is formed from the left to the right and the similar layout is autonomously formed as that in HV-FMS in Figure 1. It is also noted that 7 MCs for OP1, 5 for OP2, 5 for OP3, 2 for OP4, 7for OP5 and 1 for OPs 1 and 2, 2 for OPs 2 and 3, 4 for OPs 3 and 4 and 5 for OPs 4 and 5. If MCs for two OPs are counted in half, the number of MCs for each OP becomes 7.5, 6.5, 8, 6.5, and 9.5, showing a good agreement with the number of the assigned MCs in Table 1.

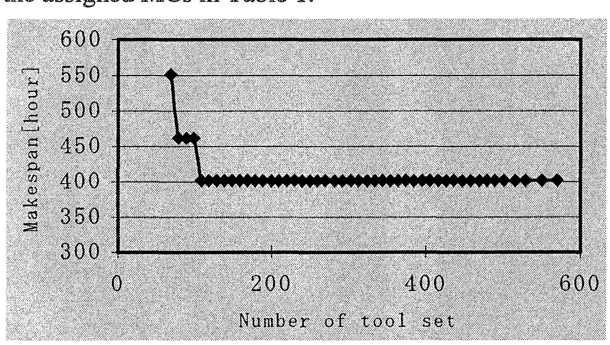

Figure 6 - Effect of Reduction of Tool Sets on the Make-span: BP[1,2] and CA-a

BP[1,3] and CA-a

In the simulation with BP[1,3] and CA-a, the least number of tool sets is 103 sets as shown in Figure 7. The tool allocation of 103 sets is shown in Figure 5. In this case, each MC tends to possess tool sets required to process a specific kind of product; for example, the second top MC at the left possesses tool sets to process OPs 1,2 and 3 of Product 1. This suggests that the MCs for a specific product can be grouped, i.e., 17 MCs for Product 1, 7 for Product 2, 12 for Product 3, one for Products 1 and 3 and one for Products 2 and 3, although it is not clear in the Figure how to group MCs yet. It is noted that the ratio of MCs assigned to the products shows a good agreement with the product mix, i.e., 45: 20: 35.

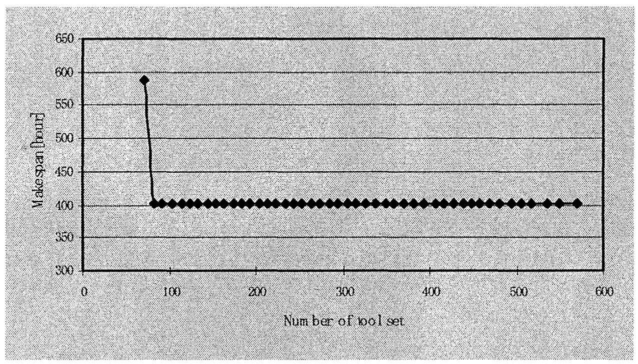

Figure 7 - Effect of Reduction of Tool Sets on the Make-span: BP[1,3] and CA-a

CONCLUSIONS

We proposed two characterization algorithms to reduce the number of tool sets in the square array manufacturing system. Both algorithms can effectively reduce the tool sets to less than one fifth of original sets without increasing the make-span to manufacture the pre-specified work pieces. The bid types used for the auction to select the MC have the significant influence to the resulting tool set allocation. The auction bid set BP[1,2], based on the distance from the pallet changing station to the MC, can characterize each MC to process a specific OP forming a material flow from left to right. The auction bid set BP[1,3], based on the ratio of frequency of processed product kinds at an MC, can characterize each MC to process a specific product kind enabling MCs to be grouped by the product kind.

We plan to investigate the effectiveness of the proposed algorithms with different product mixes and other manufacturing environment in further studies.

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