A Study on the Tool Sharing Policy in FMS with Tool Center*

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In this paper we examine the issue of tool management in a Flexible Manufacturing System (FMS). A tool center storing all tools for jobs is introduced and all tools can be shared by the machining centers through tool change between the machining centers and the tool center. Two tool-change methods, "Augmented Magazine Method (AMM)" and "Magazine Carrier Method (MCM)", are proposed and evaluated using the methods for the allocation of tools and jobs proposed in this study. A job in this study is defined as a sequence of processing operations and is thus processed by a single machining center. We propose a two-stage method to integrate tool planning and the allocation of tools and jobs. The method in the second stage for the allocation of tools and jobs is proposed on the basis of an auction method including a dispatching rule. For the tool planning with AMM at the first stage, we propose a greedy search method to decide the total number of tools. By simulation, we investigate the characteristics and effectiveness of the proposed two-stage method and the tool-change methods together with the effectiveness of several dispatching rules.

Key Words: FMS, Tool Allocation, Schedule, Greedy Search, Auction

1. Introduction

In recent years, the diversified customer demands shorten the product-life-cycle in the market and drive the market to rapid and dynamic variation. Flexible Manufacturing System (FMS) is developed to cope with such a dynamic variation in the market. As the dynamism of variation becomes more drastic, the flexibility of FMS is required more to keep its effectiveness. In order to increase the flexibility of FMS, proper tool-and-job planning method is desired.

Machining centers in FMS usually perform only a limited number of operations, and then a job needs to be moved among machining centers until its completion. In most of the studies on this kind of system^{(1),(2)} the release times of jobs were not considered at the planning stage of the allocation of tools and jobs. As

a result, the effectiveness of tool allocation plan will not be assured in practical situation with dynamical arrival of job orders. This suggests the importance to take the release times or arrival times of jobs into consideration at the planning stage. In spite of the importance of the integration of tool management with system design, planning and scheduling, the integration of tool management has been paid little attention except in some studies^{(3),(4)}. Thus further study is necessary for an effective tool management method.

As far as necessary tools and programs are supplied to a machining center, the machining center can perform a variety of operations without moving the job until the cleaning and/or posture change of the job become unavoidable. In this study, we consider FMS with a tool center, where tools in the tool center can be allocated to a machining center on request. Our aim is to develop an efficient approach for tool planning and real-time control in this kind of FMS. We propose a two-stage method to solve this problem. The first stage is the planning stage for the decision of the proper duplications for each tool type, which should be prepared in the tool center to keep the system efficient. The second stage is for real-time control with the decided tools from the first stage. The logic of the allocation of jobs and tools is based

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on an auction method.

We define that a job in this study is an ordered set of operations which can be continuously processed on one machining center when necessary tools and programs are available. If a work must be moved between machining centers for the cleaning and/or posture change, the work is divided into several jobs. In order to simplify the tool handling operation, the tool change is limited between a machining center and the tool center only. In consideration of the tool magazine capacity, it is not realistic to arrange all the tools for assigned jobs in the tool magazine of the machining center. However among each time horizon only a part of tools are necessary to stay at the tool magazine. Other tools can wait at the tool center until it becomes necessary to transfer them to a machining center. Therefore, all the tools in the system can be shared by the machining center through tool change. We propose two kinds of tool change methods, Augmented Magazine Method (AMM) and Magazine Carrier Method (MCM) to change tools between machining centers and the tool center.

In this paper, we focus on analyzing the effects of the proposed tool change methods, tool planning method and several job dispatching rules so that an effective solution can be identified with high throughput rate. Their characteristics are investigated by simulation.

2. The Model of FMS with a Tool Center

The proposed FMS in this study consists of a job loading station, some machining centers, one tool center, sufficient number of automated guided vehicles to transfer tools and jobs. Each machining center has a tool magazine with a finite capacity, a loading buffer (LB) and an unloading buffer (ULB), each of which can store only one job at the most as shown in Fig. 1. Since the size of the loading buffer is one, only two jobs can be stored on one machining center and only the tools for these two jobs are necessary to be set into the tool magazine or wait to be set into.

Usually this kind of manufacturing system is suitable for low-volume, high-variety manufacturing. In some cases, the volume can be one. It means the

Fig. 1 FMS model

entire work pieces are different. Although we know all jobs should be processed within certain period, the start time is not known beforehand. Because the work piece set on a pallet can be processed continuously on a machining center, we consider that a job consists of a continuous sequence of operations, each of which is processed by a single tool. In order to process the job continuously, the control program and tools for all operations of the job must exist in the machining center before the process starts. Since the capacity of the tool magazine of a machining center is limited, all of the tools are initially prepared in the tool center. When a job arrives at the system, it is necessary to decide a machining center to process the job together with the tools to be borrowed from the tool center. Other than at the event of a job arrival (Event 1), similar decisions, of which detail will be discussed later, are to be made at the event of the job completion (Event 2) and the receipt of tools at the tool center (Event 3). We propose an auction method for the selection of machining center and dispatching rules for the selection of job.

3. Tool Change Methods

Because the capability of a machining center is decided by the tools prepared in its magazine and the control programs installed, it is possible for machining centers to process various jobs by properly changing tools between the machining center and the tool center. In this research, we propose two methods, AMM and MCM for the tool-change procedure.

3.1 Augmented Magazine Method (AMM)

As for AMM, the tool magazine of a machining center, which can accommodate the tools of two optional jobs, is divided into two parts, a main magazine and an augmented magazine conceptually. The main magazine is used to store the tools for the job in process and the augmented magazine is used to store some tools for the job waiting in loading buffer.

When a job is assigned to a machining center, the tools that are not possessed at the machining center will be delivered to the machining center on request. If the assigned machining center is free, the tool change will be carried out as soon as the requested tools arrive at the machining center. However, if the assigned machining center is occupied and the job waits in the loading buffer, the tool change is processed only if the tool change does not interrupt the process of the job on the machining center. Otherwise the tool change cannot be carried out. On the other hand, when a job is finished in a machining center and the loading buffer is empty, all the tools will be returned to the tool center. However, if the loading buffer is not empty, the job in the loading buffer will be

transferred onto the machining center and the machining center requires a job to be assigned. After getting an assignment of a job if any, unnecessary tools job will be returned to the tool center.

3.2 Magazine Carrier Method (MCM)

As for MCM, tool magazines are prepared in the tool center. With the assignment of a job, all necessary tools will be installed into a tool magazine and then transferred to the machining center.

When the tool magazine arrives at the machining center, the tool magazine will be set up into the machining center if there is no job in process. If there is a job in process, the tool magazine will wait to be changed in the machining center. After the job is finished, the magazine in use is exchanged with the waiting tool magazine, and is returned to the tool center.

4. Tool and Job Allocation Methods

When a machining center can get the complete set of tools for a job, the job can be assigned to the machining center. If sufficiently large number of tools for each tool type are provided in the tool center, machining centers can request any tools necessary when a job is to be assigned. However, in most of the cases, the number of same tools is limited to reduce the tool cost. Thus in some cases a machining center cannot get the requested tools from the tool center and thus cannot get the job. This occurs because some types of the requested tools are all used by other machining centers and do not exist in the tool center. We call this a tool conflict. This suggests us the importance of considering the tool cost and the system efficiency to decide how many tools should be prepared. We call this a tool preparation problem and propose a greedy search algorithm to solve it at the first stage. The procedure to allocate jobs and tools in the greedy algorithm depends on the methods to allocate jobs and tools in the second stage; an auction method and a dispatching method in this study. These methods are explained firstly for the convenience of explanation assuming that the number of tools for each tool type is given.

4.1 Auction method

The auction⁽⁶⁾ is a deal between a coordinator and several potential bidders. In auctions, the coordinator wants to sell an item and get the highest possible payment for it while the bidders want to acquire the item at the lowest possible price.

We apply an auction method for the allocation of tools and jobs. The central computer of the FMS serves as a coordinator to organize the auction and machining centers are regarded as bidders.

4.2 Tools and jobs allocation algorithm

The following algorithms are used for three events explained previously. Different bidding terms are specified in the procedure for each event.

4.2.1 Procedure for event 1

When a new job arrives, the job can only be assigned to a machining center which can get the complete set of tools for the job. If the job can be assigned, its completion time in the machining center can be predicted. We employ this predicted completion time as the first bidding term where the earlier time is preferable. If the job cannot be assigned, there are two cases. One is that all of the machining centers and their loading buffers are full. The other is that some of the necessary tools are not in the machining center and the tool center. If the machining center cannot accept the job, it returns a sufficiently large completion time as its bidding price. When AMM is employed for tool change, the total number of tools to be changed for each machining center could be different. Therefore if AMM is employed, the total number of tools to be changed is introduced as the second bidding term where the smaller number is preferable. If MCM is employed there is no such kind of difference because MCM changes the tool magazine holding all necessary tools.

When a new job arrives, the allocation of the job is decided by the following steps:

Step 1 The coordinator broadcasts the job to each machining center and requests them to bid the first bidding term.

Step 2 Each machining center returns its bidding price for the term.

Step 3 The coordinator judges the conflict among machining centers returning a same bidding price.

- If there is no conflict, the coordinator assigns the job to the machining center returning the most preferable bidding price and go to Step 5.

- Otherwise go to step 4.

Step 4 If the present bidding term is the last one, the coordinator selects a machining center at random to assign the job. Otherwise the coordinator starts a new round of auction among conflicting machining centers with the next bidding term and go to Step 2.

Step 5 If the job is assigned, the necessary tools are prepared to be delivered at the same time in the tool center. If it cannot be assigned, the job is added to a queue and waits for another opportunity of assignment.

4.2.2 Procedure for event 2

When a machining center completes a job and its loading buffer is empty, all tools are returned to the tool center. Otherwise the machining center starts to process the job in its loading buffer and at the same time it starts

to select a job from jobs waiting for the assignment by the following steps:

Step 1 The machining center investigates the queue of jobs waiting for assignment according to an order of a dispatching rule which will be explained later. If there is an available job when the necessary tools exist either in the machining center or in the tool center, the job is assigned to the machining center.

Step 2 If there is a job to be assigned, remove the job from the queue and the necessary tools are allocated to the machining center. When the machining center received the information of assigned job, the machining center decides the unnecessary tools to be returned to the tool center in case of AMM and these tools will be transferred after all the unnecessary tools are set onto the tool transfer device. In case of MCM, after the machining center completes the job in process, the tool magazine taken off will be returned to the tool center. If there is no job to be assigned, there is no tool to be allocated. All the tools will be returned to the tool center if there is no job to be processed.

4.2.3 Procedure for event 3 When the tool center receives the returned tools, the coordinator will check if the job loading station is empty. If there are jobs waiting in the job loading station, the coordinator will choose a machining center at first. Then the machining center will select a job from the waiting jobs. By similar procedures to the subsections 4.2.1 and 4.2.2, the coordinator will attempt to assign jobs to some machining centers. It is decided by the following steps:

Step 1 The coordinator asks each machining center to answer its operational state (busy/idle).

Step 2 Each machining center returns its operational state to the coordinator.

Step 3 The coordinator judges if there is an idle machining center or not.

- If there is only one idle machining center, it becomes the candidate. If there are more than one, the coordinator chooses one at random.

- Otherwise the coordinator asks the busy machining centers to answer its buffer state (full/empty).

- If there is only one machining center with empty loading buffer, it is the candidate. If there are more than one, the coordinator chooses one machining center with the shortest remained time to the job completion.

- If there is no machining center with empty loading buffer, stop.

Step 4 If there is a machining center selected, the machining center searches jobs which can be processed by the tools in this machining center and the tool center.

- If there is only one job, it will be assigned to the machining center. If there are more than one jobs, machining center selects a job from these jobs by a dispatching rule and remove the job from the queue. The necessary tools will be allocated. Go to Step 1.

- If there is no job, the machining center loses the qualification of auction because necessary tools for each job are not all available at this moment and the jobs in job loading station cannot be assigned. Go to Step 1 to try other machining centers if any one untested machining center remains. Otherwise stop.

5. Tool Preparation Problem

Assuming that the number of tools for each tool type is given, we proposed the auction method for the allocation of tools and jobs. Another important issue is how to determine the number of tools for each tool type, i.e., the tool preparation problem. The following greedy search method is proposed to solve this problem for AMM. As for MCM, different method to decide the total number of tools should be developed. It is the extension of this study and under investigation.

We define that the makespan is the last completion time of jobs put into the FMS. Suppose that the makespan is not longer than M^* . The number of tools for each tool type is determined by three steps:

Step 1: A large number of tools for each tool type is set and the arrival times of jobs are set at random.

Step 1.1 Array T is used to save the number of tools for each tool type. Perform a simulation and save the resulting makespan to a variable M .

Step 1.2 Calculate the conflicts occurred for each tool type.

Step 1.3 Decrease the number by 1 for the tool types that do not cause any tool conflicts and renew T . The number for the tool types that caused tool conflicts is not changed.

Step 1.4 If there is a tool type whose number of tools is 1, go to Step 2.1. Otherwise go to Step 1.1.

Step 2: The number of tools for each tool type is determined to keep the makespan less than M^* .

Step 2.1 Let a variable D be the number of tool types to be increased to reduce tool conflicts. Set $D = W * 0.15$ at the beginning, while W is the total number of tool types.

Step 2.2 Perform a simulation with T and save the simulation result of makespan to M .

Step 2.3 Calculate the tool conflicts. Sort the tool types in descending order of the conflicts.

Step 2.4 If $M > M^*$, increase the number of tools by 1 for the tool types that caused tool conflicts until the number of increased tools becomes D . Renew T and go to Step 2.2. If $M \leq M^*$, go to Step 2.5.

Step 2.5 If $D=1$, go to Step 3.1. Otherwise, T in the last round of simulation is retrieved. Set $D=D*0.15$, and go to Step 2.2. (If resulting D is not an integer, the smallest integer larger than D is the new D .)

Step 3: Perform simulations with different sets of job release data and revise the result from the second step.

Step 3.1 Generate a set of job arrival data at random.

Step 3.2 Perform a simulation with T and save the simulation result of makespan to M .

Step 3.3 If the number of simulation runs exceeds prespecified value, save T to T^* as the solution and stop. Otherwise go to Step 3.4.

Step 3.4 If $M \leq M^*$, go to Step 3.1. Otherwise, go to Step 2.1.

6. Simulation Experiment

In order to investigate the characteristics of the proposed tool change methods, different values for tool-change time, tool-transfer time and job-transfer time are used in simulation experiments. The performance of the proposed greedy search method and several dispatching rules are investigated when AMM is applied.

6.1 Simulation conditions

In the simulation, the FMS model has 4 machining centers. 100 jobs arrive dynamically and the intervals between job arrivals follow an exponential distribution with a mean of 95. Supposing the due date of a job is d , job release time is r and job processing time is p , the due date is decided by $d=r+p*f$, where f is an integer generated with a uniform distribution from 3 to 5. In this study, all jobs are different as a result of job generation procedure below. Jobs are grouped into 5 according to the number of operations, namely, 10, 15, 20, 25 and 30, and 20 jobs in each group are generated. The processing time of each operation is decided by the tool used. The number of tool types is set to 120. 36 tool types are used most frequently (between 22 and 50 times) and their processing times are generated with a uniform distribution from 1 to 50. 36 tool types are not used frequently (less than 9 times), whose processing times are generated with a uniform distribution from 1 to 10. Other 48 tool types are used moderately (between 9 and 21 times), whose processing times are generated with a uniform distribution from 1 to 30. By the abovementioned procedure, one set of job processing data, J , is generated. Two groups of job release data, Initial- R used for Step 1 of the tool preparation problem and R for Step 3 are generated for J ; 6 sets for Initial- R , IR 1~IR 6 and 1 000 sets for R , R 1~R 1 000.

6.2 Investigation of tool change methods

The number of tools for each tool type is set to the same to the number of machining centers in the system. It is supposed that the number of tools is enough to prevent the tool conflict in most of the cases. However, the tool conflict could occur when the tools are on the way back from a machining center to the tool center. We investigate the proposed tool change methods by different values of tool-change time, which is the time for the setup of a single tool, job-transfer time and tool-transfer time. The EDD rule explained later is employed for job dispatching. In the following, a same job release data set, IR-1, is used for all simulations in section 6.2.

6.2.1 Tool change time Both of the transfer-times of job and tool are set to 200. The setup time of jobs is set to 5 and is employed through the following sections. The simulation results with different tool-change time are shown in Fig. 2. Each bar in the figures shows the makespan of a machining center which processed the last job determining the makespan. The makespan is composed of idle time of the machining center for waiting tools, idle time of the machining center for waiting jobs, setup time of jobs, and busy time of the machining center orderly. The same order is adopted in other figures shown later.

(a) AMM

(b) MCM

Fig. 2 Effect of tool-change time on makespan

Comparing Fig. 2(a) with Fig. 2(b), it is concluded that MCM is more efficient for tool change if the tool-change time is long and there are sufficient tools prepared. However, if the tool-change time is short, there is no great difference between the makespans of the two methods. For example, when the tool-change time is shorter than 3, the main reason of idling is that the machining center waits for jobs to process. It can be caused when there is no job to be assigned to the machining center.

6.2.2 Job transfer time The tool-transfer time is set to 200 and tool-change time is set to 5. The simulation results with job-transfer time from 40 to 800 are shown in Fig. 3.

With the increase of job-transfer time, the makespan increases in both tool change methods because the idling of machining centers occurs for waiting the job to be transferred. There is no prominent difference between two methods. The makespan is short and stable when the job-transfer time is less than 320 while the idle time for no tool becomes not negligible in this range. This means that the machining center is forced to be idle until it receives the necessary tools even when the job-transfer time is set shorter. Therefore both of the tool-change time and the tool transfer time must be properly determined to improve the makespan.

6.2.3 Tool transfer time The job-transfer time is set to 200 and tool-change time is set to 5. The

simulation results with tool-transfer time from 40 to 800 are shown in Fig. 4.

Comparing Fig. 4(a) and Fig. 4(b) there is no prominent difference between two tool change methods. With the increase of tool-transfer time, the makespan increases in both cases because the idling occurs for waiting the transferring tools to process the job in machining center. Therefore, the tool center should be located as close as possible to machining centers to reduce the tool transfer time.

From the above-mentioned results, it is observed that although short tool-change time, job-transfer time and tool-transfer time are preferable to shorten the makespan, the effectiveness of the local improvement regarding to one factor is limited for the improvement of makespan because other factors can become a bottleneck for the further improvement.

6.3 The method for tool preparation problem

Both tool-transfer time and job-transfer time are set to 200. Tool-change time is set to 5. The same simulation conditions as before are used for the tool preparation problem for AMM. The makespan M^* is set to 13 000. The simulation result of the first two steps of greedy search is shown in Table 1 using a set of job release data IR-1. According to the greedy search algorithm, initial value of D in Step 2 is 18 and it will adjusted to 3 and 1 for a finer search ($D = W \cdot 0.15$, $D = D \cdot 0.15$, $W = 120$).

At the beginning of the first step, the number of

(a) AMM

(b) MCM

Fig. 3 Effect of Job-transfer time on makespan

(a) AMM

(b) MCM

Fig. 4 Effect of tool-transfer time on makespan

Table 1 Results of greedy search by step 1 and Step 2 for IR-1

Step1		Step2(18)		Step2(3)		Step2(1)	
T	M	T	M	T	M	T	M
840	11360	253	13296	271	13175	271	13175
720	11360	271	13175	274	12899	272	12323
600	11325	289	11479				
481	11695						
367	12348						
299	12975						
253	13296						

T: the total number of tools

M: makespan

duplications for each tool type is set to 7 (the total number of tools is 840). According to the simulation result, the makespan is less than 13 000 until the total number of tools becomes 253. For all the tool types of which no tool conflict occurs, the number of duplications will be decrease by one. In the first 3 runs, all tool types showed no conflict and thus 120 tools are deleted in total each time. This procedure will repeat until the number of duplications for some tool type becomes one. As shown in Table 1, the total number of tools is reduced 253 while the makespan increased to 13296 at the end of Step 1. In Step 2, the most frequently conflicted tools are increased to shorten the makespan. At the end of Step 2, the total number of tools is increased to 272.

In order to assure that the solution by Step 2 can satisfy the most of the cases of dynamical job arrival, various job release data are used in Step 3. If the makespan exceeds 13 000 at any set of job release data, Step 2 for the data set is applied to reduce the makespan by increasing tools. Table 2 shows the simulation results of Step 3 to examine the tool set obtained in Table 1 by R-1 to R-1 000. In Step 3, the tools are increased 13 times. At the first run of Step 3, no tools are added because the makespan is less than 13 000. At the second run of Step 2 by R-2, 16 tools are added and 35 tools are added in total to make the makespan less than 13 000 after testing 1 000 job release data sets. Table 3 shows a result in case that R-2 is applied to the tool sets in Table 1 resulting in the makespan 13 583 in Step 3 and thus Step 2 is repeated for R-2. In this case 16 tools are added to make the makespan less than 13 000. The number of data sets used in Step 3 is set to 1 000 in this study but the proper number for the reduction of the computational time solving the tool preparation problem is to be studied further.

Table 2 Simulation result of Step 3

R-i	T0	M0	T1	M1	A
1	272	12323	272	12323	0
2	272	13583	288	12419	16
7	288	13140	289	12905	1
74	289	13259	290	12727	1
80	290	13013	291	12678	1
94	291	13590	292	12738	1
98	292	13045	294	12671	2
109	294	13176	301	12881	7
144	301	13224	302	12831	1
510	302	13245	303	12895	1
589	303	13280	304	12280	1
610	304	13045	305	12690	1
654	305	13167	306	12538	1
981	306	13001	307	12871	1

R-i: the index of job release data in R

T0: the total number of tools at the beginning of Step3

M0: the makespan in case of T0

T1: the total number of tools from Step 2

A: the total number of tools added

Table 3 Greedy search of Step 2 for R-2

Step2(18)		Step2(3)		Step2(1)	
T	M	T	M	T	M
272	13583	272	13583	287	13273
290	12793	275	13424	288	12419
		278	13182		
		281	13296		
		284	13224		
		287	13273		
		290	12655		

T: the total number of tools

M: makespan

6.4 Investigation of dispatching rules with AMM

In the above, EDD rule is used as a dispatching rule. To investigate the effect of dispatching rules, following five rules are considered in this section:

- (1) SPT (Shortest Processing Time)
- (2) LPT (Longest Processing Time)
- (3) EDD (Earliest Due Date)
- (4) LAT (Largest number of Tools in high frequency class)
- (5) LET (Least number of Tools in high frequency class)

LAT and LET are dispatching rules that we proposed in this study to consider the frequency of tool usage. As for LAT, we count the number of tools

belong to high frequency class, middle frequency class and low frequency class respectively for each job. The job using high frequency tool most has the highest priority. If there is no difference with the number of tools in high frequency class, the number of tools in middle frequency class is compared, and then the number of tools in low frequency class. The LET rule is just the opposite of LAT.

With the job release data sets IR-1 and R-1~R-1 000, the greedy search method is applied for LAT, LET, SPT and LPT. As shown in Table 2 and Table 4, SPT, LAT and EDD are better than LPT and LET

Table 4 Greedy searches with different dispatching rules

LAT		LET		SPT		LPT	
R-i	T	R-i	T	R-i	T	R-i	T
1	267	1	276	1	273	1	299
2	283	2	277	2	278	2	304
12	286	3	279	8	279	6	305
25	290	5	286	9	281	15	306
80	291	12	288	18	288	68	307
144	292	18	291	24	289	74	308
195	294	25	295	25	292	144	313
307	298	46	299	32	293	611	316
402	299	58	300	72	294	981	319
655	300	62	301	122	295		
714	302	72	308	150	296		
731	303	85	312	160	298		
929	304	139	313	334	299		
		176	314	375	300		
		266	315	426	301		
		303	321	517	302		
		610	322	924	303		
		731	323				

T: the total number of tools

Table 5 Comparison of different dispatching rules

IR-i	LAT	SPT	EDD	LPT	LET
1	304	303	307	319	323
2	307	313	310	323	322
3	308	313	306	323	329
4	311	315	304	319	318
5	308	310	311	325	328
6	309	315	310	318	328
Ave	307.83	311.50	308.00	321.17	324.67
Dev	2.11	4.15	2.52	2.61	3.99

IR-i: the index of job release data in Initial_R

Ave: average of the total number of tools

Dev: deviation of the total number of tools

according to the total number of tools decided after 1 000 runs in Step 3.

To examine the effect of initial job release data in Step 1 on the total number of tools, different job release data sets, IR-2~IR-6, for the same job set J are applied in Step 1 in addition to IR-1. The simulation results with IR-1~IR-6 are shown in Table 5 where R-1~R-1 000 are used in Step 3. Comparing the results of the average number of tools decided by different dispatching rules, LAT is better than other rules. Table 6 gives the ranking of the total number of the total number of tools for the dispatching rules

Table 6 Ranks of different dispatching rules

	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5
LAT	3	3	0	0	0
EDD	2	2	2	0	0
SPT	1	1	4	0	0
LPT	0	0	0	6	0
LET	0	0	0	0	6

Table 7 Increased tools by tool class for IR-1 (LAT)

R-i	T	Sum-A	Class-A	Class-B	Class-C
1	267	16	9	7	0
2	283	3	2	1	0
12	286	1	1	0	0
24	287	4	1	3	0
144	291	1	1	0	0
195	292	2	1	1	0
307	294	4	1	3	0
402	298	1	0	1	0
655	299	1	1	0	0
714	300	2	1	0	1
731	302	1	0	1	0
929	303	1	1	0	0
Result	304	37	19	17	1

Sum-A: the total number of tools added

Table 8 Increased tools by tool class for IR-1 (EDD)

R-i	T	AT	Class-A	Class-B	Class-C
1	272	0	0	0	0
2	272	16	5	9	2
7	288	1	0	1	0
74	289	1	1	0	0
80	290	1	0	0	1
94	291	1	1	0	0
98	292	2	1	1	0
109	294	7	5	2	0
144	301	1	1	0	0
510	302	1	1	0	0
589	303	1	0	1	0
610	304	1	0	1	0
654	305	1	1	0	0
981	306	1	0	1	0
Result	307	35	16	16	3

in Table 5. It is shown that LAT is better than other dispatching rules because it is ranked in the first and second.

In order to investigate the relation between tool increase and tool frequency, the number of tools for each tool class (A: high frequency tool, B: middle frequency tool, C: low frequency tool) added each time is listed in Table 7 for LAT and Table 8 for EDD. According to these tables, the most of the added tools are high frequency tools or middle frequency while few low frequency tools are added in both dispatching rules. This indicates that high frequency tools and middle frequency tools cause tool conflict more easily.

7. Conclusion

In this paper we proposed an FMS model with a tool center. Two tool-change methods, "Augmented Magazine Method" and "Magazine Carrier Method", are proposed for sharing tools between the tool center and machining centers.

By the simulation, the appropriate values of tool-change time, tool-transfer time and job-transfer time, are shown to be obtainable to satisfy the performance objectives. The results show that these factors can be the bottleneck to shorten the makespan and local improvement for one factor shifts the bottleneck to other factors. A greedy search method for AMM is proposed with illustrative simulation results. Five dispatching rules for job selection are investigated and

LAT rule is concluded to be the most effective among them for AMM tool change method. The greedy search method for AMM is, however, not directly applicable for MCM and a new method needs to be developed in further study.

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