第 9 卷第 2 期
1992 年 4 月

控制理论与应用
CONTROL THEORY AND APPLICATIONS

Vol. 9, No. 2
Apr., 1992

A Scheduling Algorithm for Flexible Manufacturing Cell

WU Naiqi, ZHANG Lijuan and XUE Jinsong
(Shenyang Institute of Automation, Chinese Academy of Sciences·Shenyang, 110003, PRC)

Abstract: In this paper, a new scheduling algorithm for the flexible manufacturing cell is presented, which is a discrete time control method with fixed length control period combining with event interruption. At the flow control level we determine simultaneously the production mix and the proportion of parts to be processed through each route. The simulation results for a hypothetical manufacturing cell are presented.

Key words: flexible manufacturing cell; scheduling; hierarchical control

1 Introduction

In this paper, we consider the FMC with job-shop type, and the production process in the FMC is MRP-driven. It is well known that a job shop is more difficult to be scheduled than a flow line, and the routing flexibility in a job shop makes it more complex.

We propose a new scheduling algorithm for this kind of cells to obtain a good makespan as well as high machine utilizations. To avoid the complex computation and, at the same time, to respond the stochastic disturbances effectively we suggest a discrete time control strategy called fixed control period with event interruption (FCPEI). In the production process we monitor the cell status continually, and based on the status information obtained at the beginning of each control period and at the moment of a change of the machines status, an optimization problem is solved to determine the flow plan, in which the part mix and proportion of parts through each route for each part are determined in real time together at discrete time points. The simulation results for a hypothetical manufacturing cell are presented to show the effectiveness of the method.

2 Notation

First, for convenience, we list the notations used in this paper below:

n	number of part types
m	number of machines
i	part type index, $i=1,2,\cdots,n$
j	machine index, $j=1,2,\cdots,m$
r_i	number of routes for part type i
k	route index
a_{ikj}	process time for part type i on route k at machine j

Manuscript received Feb. 27, 1990, revised Nov. 21, 1991.

d_i demand number of parts for part type i

$p_i(t)$ number of parts remaining to be processed at time t for part type i

$\sigma_i(t)$ at time t, if machine j is broken down or in repairing then $\sigma(t)=0$, otherwise $\sigma(t)=1$

Δ length of a control period

t_i planned idle time of machine i during a control period

x_i planned flow amount of part type i

x_{ik} planned flow amount of part type i on route k

3 Control Functions

The method proposed in this paper has a hierarchical structure, at each level a control function is provided.

3.1 Flow Control

The flow control is the function of the highest level of this scheduling algorithm.

Because the part mix and the proportion of parts through each route affect each other and the parts must share the processing time of the machines, these two problems cannot be determined separately and must be determined together. We model this problem by a linear programming and solve it at the beginning of each control period or when an interruption occurs.

3.2 Release Control

At the beginning of each control period or when an interruption occurs the flow control problem is solved and the production mix of parts is obtained. This time the number of parts for each part type to be release into the cell must be determined to follow the ratio obtained at the flow control level.

Assume that before release there are b_i parts of type i in the cell, the number of parts of type i to be released into the cell can be calculated as follows

$$g_i = x_i - b_i, \quad i = 1,2,\cdots,n, \tag{1}$$

where x_i obtained from the flow control level.

3.3 Routing Control

At the flow control level, the proportion of parts through each route for each part type is also determined. The routing control is designed to implement this proportion in the production process.

If a part of type i through machine j will be sent to one of the alternative machines, we calculate the following index

$$t_{ik} = \frac{f_{ik}}{x_{ik}}, \quad k = 1,2,\cdots,r_1, \tag{2}$$

where f_{ik} is the number of parts of type i which has been sent to route k in the control period. If t_{ik} is the smallest one then the part will be sent to the machine belong to the route k for part type i. If two t_{ik} are equal and the value of them is the smallest one in all of calculated value, then we can choose one of them arbitrarily.

3.4 Dispatching Control

In implementing this function, we use some simple heuristic rules such as first come first served (FCFS), shortest remaining processing time (SPT) or large remaining processing time (LPT).

4 Linear Programming Model for The Flow Control

In this section we give the linear programming model for the flow control.

4.1 The Objective

As an automated manufacturing system, a flexible manufacturing cell is very costly, it is important to maintain high machine utilizations to gain overall system effectiveness. Hence our objective of the flow control is to achieve a good makespan value as well as high machine utilizations.

Although the bottleneck machine is unknown in a job-shop type FMC, by using the routing flexibility in our flow control method, the idle time of the machines can be made as small as possible. Meanwhile, the makespan is shortened as well so as to achieve the objective. Let

$$T = \sum_j a_j t_j \tag{3}$$

be an optimization criterion in the performance function, where $a_j > 0$ is designed to maintain higher utilizations for preferred machines.

When the idle time is minimized, it is possible that a larger proportion of parts are assigned to be processed through the non-preferred routes, which makes the makespan unsatisfactory. To avoid this in the performance function a corresponding criterion is added. Let

$$w_{ik} = \frac{\sum_j a_{ikj}}{\sum_i \sum_k \sum_j a_{ikj}}, \quad i = 1, \cdots, n; \quad k = 1, \cdots, r_i \tag{4}$$

and

$$R_{ik} = \beta_{ik} w_{ik}, \tag{5}$$

where $\beta_{ik} > 0$ can be used to give higher priorities to the preferred routes.

Although for the MRP-driven cell, the production ratio is not necessarily a constraint at each time point, we want to keep the production ratio as close to the desired ratio as possible when it does not affect the utilizations and makespan significantly. In fact, this is possible if the flow control does well because of the flexibility. We consider it by adding the penal terms in the performance function. Let

$$c_i = \frac{p_i(t)}{\sum_i p_i(t)} - \frac{d_i}{\sum_i d_i}, \quad i = 1, 2, \cdots, n. \tag{6}$$

This index gives the difference between the desired ratio and that finished for part type i at time t. Then the penal term for part type i can be

$$F_i = p_i c_i \quad (p_i > 0). \tag{7}$$

In summary, the performance function for the flow control is given by

$$J = T + \sum_i \sum_k R_{ik} x_{ik} - \sum_i F_i x_i.$$

4.2 The Constraints

In each control period, the parts entering the cell during the period must share the time at the machines. In other words, the following capacity constraints must be satisfied.

$$\sum_i \sum_k a_{ikj} x_{ik} + t_j \leqslant \sigma_j(t)\Delta, \quad j = 1,2,\cdots,m. \tag{8}$$

In the constraints both the production mix and routing are considered.

We also have the following constraints.

$$\sum_k x_{ik} \leqslant p_i(t), \quad i = 1,2,\cdots,n, \tag{9}$$

$$\sum_k x_{ik} - x_i = 0, \quad i = 1,2,\cdots,n. \tag{10}$$

The implication of constraints (10) is clear and constraints (9) indicate that the planned production amount of part must not be greater than the remained work in the job set.

4.3 The Linear Programming Model

The flow control problem can be realized by solving the following linear programming model.

minimizae $$J = T + \sum_i \sum_k R_{ik} x_{ik} - \sum_i F_i x_i$$

subject to (8), (9), (10) and the nonnegative constraints

$$x_{ik} \geqslant 0, \quad \text{for all } i \text{ and } k, \tag{11}$$

$$x_i \geqslant 0, \quad \text{for all } i, \tag{12}$$

$$t_j \geqslant 0, \quad \text{for all } j. \tag{13}$$

5 Simulation Results

The proposed method has been applied to a hypothetical manufacturing cell by using SLAM Ⅱ Simulation Language under different combinaton of part types and routes, and machin failures. The simulation results for one case are described as follows.

5.1 The System Description

There is a flexible manufacturing cell with three machines A, B and C, and there are three types of parts to be processed through the cell, the routes and processing time unit for parts are given in Table 1. the average machine failure 100 time unit and average repairing time is 24 time unit.

Table 1 Routes and Processing

Part No.	Demand	route No.	Processing Time		
			A	B	C
1	1000	1		0.4	0.3
		2		0.9	
		3	0.5		0.3
2	800	1	0.8		
		2		0.5	
		3			0.6
3	600	1	0.3	0.2	
		2	0.7		

5. 2 The Method For Comparison

In order to evaluate the proposed method, two methods are selected for comparison.

* Proportionally Mixed Flow (PMF) method:

The mehtod releases the parts to the cell with part flow ratio as close as possible to part ratio in the job set. And the routing is done in real time such that the idle time of machines is as small as possible.

* Fixed Route (FR) method:

By using this method, the routing problem is solved by heuristic method in advance and one preferred route is chosen for each part type.

5. 3 The Simulation Results

With and without machine failures, the proposed method and other two methods are used respectively to simulate the cell production process for comparison. The results are shown in Table 2 and Table 3 with $\Delta = 5$ time units, which is long enough to complete the necessary computation. In the FR method, we select the route which has the shortest processing time for each part type and in the simulation. For the results, in all methods, the FCFS rule is used in the sequencing.

From the simulation results, it can be seen that by using the FR method, the makespan is very long and the machine utilizations are lowest especially when the machines are unreliable.

Table 2 Comparison of Simulation Results Without Machine Failures

	utilization(%)			average queue lengty			makespan (time unit)
	A	B	C	A	B	C	
PMF	98. 5	100	100	6. 39	8. 26	8. 95	502
FR	21. 9	98. 9	36. 6	0. 47	8. 29	0. 0	820
FCPEI	96. 7	97. 5	94. 9	4. 85	3. 48	2. 89	485

Table 3 Comparison of Simulation Results with Machine Failures

	utilization(%)			average queue lengty			makespan (time unit)
	A	B	C	A	B	C	
PMF	99. 0	100	100	57. 25	54. 23	55. 35	554
FR	46. 9	100	31. 0	0. 64	104. 43	0. 0	926
FCPEI	99. 0	80. 6	93. 1	5. 95	3. 02	3. 49	529

By the PMF method higher machine utilizations are observed, because the routing is done in real time, but the value of makespan is larger than that by the proposed method. Intuitively, higher machine utilizations produce a better makespan, but the simulation results are not so. It can be explained that the non-preferred routes must be selected in order to achieve its goal by the PMF. It implies that by PMF method a higher machine cost is to be payed, but a worse result is achieved in comparison with the new method. Besides, a higher level of work-in-process is shown, this becomes worse with the disturbances of machine failures.

6 Conclusions

In this paper, a new scheduling algorithm for the flexible manufactiring cells of job shop type is presented. By using the interruption machinism in the discrete control strategy we can select a relatively long control period without reducing the adaptive ability of the random machine failures. Taking the advantage of the flexibility of the system, we determine the production mix and proportion of parts through each route at the flow control level in real time. Hence this method does not involve complex computation, and a good result can be achieved.

References

[1] Graves, S. C., Meal, H. C., Stefek, D. and Zeghmi, A. D.. Scheduling, in Reentrant Flow Shop. Journal of Operations Management, 1983, 3(4):197—207

[2] Wittrock, R. J.. Scheduling Algorithms for Flexible Flow Lines. IBM Journal of Research and Development, 1984, 29(4):401—412

[3] Kimemia, J. and Gershwin, S. B.. An Algorithm for the Computer Control of Production in Flexible Manufacturing Systems. IIE Trans., 1983, 15(4):353—362

[4] Han. M. H., Mcginnis, L. F.. Througthput Ratc Maximization in Flexible Manufacturing Cells. IIE Trans., 1988, 20(4):409—417

柔性制造单元的一种调度算法

伍乃骐　张丽娟　薛劲松

（中国科学院沈阳自动化研究所，110003）

摘要：本文提出了一种新的柔性制造单元的调度算法，它在离散周期控制的基础上加上事件中断以适应系统状态的随机干扰，在流控制中，我们不仅决定产品类型的混合比，同时决定每种工件在各加工路径的比．文中给出了一个制造单元的仿真结果，它表明了算法的有效性．

关键词：柔性制造单元；调度；递阶控制；离散时间控制策略

本文作者简介

伍乃骐　1988年在西安交通大学获博士学位．之后一直在中国科学院沈阳自动化所从事 CIMS 方面的工作，目前在美国普渡大学继续 CIMS 领域的工作．主要研究兴趣是 CIMS 系统的建模，分析及计算调度等．

张丽娟　1988年在东北工学院获硕士学位．现在中国科学院沈阳自动化所从事 CIMS 方面的工作．曾从事控制理论，自适应控制方面的研究．主要研究兴趣是 CIMS 系统的仿真以及单元控制器方面的研究及开发工作．

薛劲松　1964年毕业于清华大学．1968年在中国科学院研究生毕业．现在中国科学院沈阳自动化所工作．曾从事自动控制，系统工程方面的研究和开发．目前在国家863计划中承担 CIMS 专题中的系统理论方法和应用工程方面的有关课题．