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A multi-objective intelligent algorithm for cells formation

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ABSTRACT

Cells formation based on production requirements with a planning horizon and multiple objectives was addressed. This paper develops a nonlinear multi-objective mathematical method for dynamic cell formation with three objectives, including the total cost in the process of cell formation, the maximum deviation of load with available capacities of machines, and the total number of inter-cell moves. This paper propose an adaptive niche technique, penalty technique, double roulette wheel method, and reserving elite strategy, reserving elite-based random weight multi-objective genetic algorithm for the complicated combination optimization model. The model and algorithm are analyzed by a numerical example. The numerical results demonstrate that the proposed genetic algorithm is effective and efficient.

KEYWORDS

Cell formation; Intelligent algorithm; Multi-objective algorithm; Optimization model.

INTRODUCTION

Nowadays, cell manufacturing is adopted by companies of worldwide as one of the advanced production modes. It produces and processes the components and combines the flexibility of workshop production and the high efficiency of flow production. Many researches show that, cell manufacturing has the advantages of the inventory of work in process is less, the response time of order form is shorter, the floor space is smaller, logistics quantity is smaller, the time for equipment to adjust is shorter and the cost of production is lower[1,2]. For all these aspects, cell manufacturing is supposed to be the promising and viable production mode. Many documents did researches on cell grouping efficiency, the cost and the flexibility of cell formation.

However, products in today's markets have the features like life cycle and the time of delivery is shorten, the diversification of variety and the indeterminism of demand. Reduce to the necessity for cell manufacturing to work in a dynamic and changing environment. In the environment of changing demand, the quantity demand of different product is changing in no time. And the interior collocation of cell manufacturing needs adjustment. Because of the change of demand, the cell manufacturing designed for the manufacture requirement of former planning horizon may not be the optimal cell manufacturing system for the current planning horizon. In other words, the configuration of cell manufacturing system is "out of date". The research for this issue in our country on the stage is blank. Now, some foreign academics put forward that the interior collocation should be adjusted due to the dynamic change of manufacture requirement that is the formation of multi-objective dynamic cells[3,4]. Consequently adapt to the demand of changing market, and prevent the out of date of cells.

Actually, the demand of changeable market through dynamic regulation to the interior collocation of cell manufacturing of each plan period is developed to exploit the decomposition algorithm to format dynamic cell[5,6]. The optional manufacture path and stochastic production requirement is considered to build the uncertainty dynamic cell mathematic model and used simulated annealing method to solve the problem. The dynamic change of market requirement is considered to design the flexibility cell manufacturing frame and the dynamic cell manufacturing through static solution and dynamic recurrence. Much meta-heuristic arithmetic is exploited to solve the formation of dynamic cell, and compared the efficiency of the arithmetic through simulated analysis[7]. The optional process route, operating sequence, machine capacity, working load, operating cost, production arrangements cost and some other factors are considered, then set up dynamic cell formation mathematic model and designed a two-step genetic algorithm based on heuristic method to solve this model[8-10].

The studies above rarely consider each cell's capacity utilization rate after the formation of cell. It not only lead to the big differences between each cell's utilization rate and cause huge waste, but also the formation of cell itself is a complex multi-objective optimization problem. These studies are just form the cell by single target and simple weighing each target. Or see other target except cost as constraint to form cell. It is very difficult to design an optimal cell manufacturing system because the important factors were not disposed at same time.

Under the circumstances of dynamic manufacture requirement, this text thinks about the questions about optional process route, working ability of facilities and so on. Build the dynamic cell manufacturing system that can adjust the interior collocation by the demand of market through balancing the total cost, the biggest difference between facility's load and capacity and the total number of times that pats move across the cell during the process of formation of cell manufacturing.

DECISION MODEL FOR THE FORMATION OF DYNAMIC CELL

B is the production lot; D_{jt} is the demand for component j in the plan period t; P_{ijk} is the process i's time of the component j by facility k. A_k is the amortization cost of facility k; O_k is the processing charge of one hour of facility k; S_k is the installation charge of facility k; R_k is the unloading cost of facility k; W_1 is the minimum quantity of equipment of a cell; W_2 is the maximum quantity of equipment of a cell; β_k is the available capacity (hour) of facility k;

$$\alpha_{ijk} = \begin{cases} 1, & \text{Component j's process can be done by facility} \\ 0, & \text{Others;} \end{cases}$$

$$\lambda = \begin{cases} 0, & \text{First plan period;} \\ 1, & \text{Others} \end{cases}$$

X_{1kt} is the number of facility k that distribute to cell 1 during plan period t; Y_{1kt} is the number of facility k that add to cell 1 at the beginning of plan period t; Z_{1kt} is the number of facility k that unload from cell 1 at the beginning of plan period t;

$$V_{ij1kt} = \begin{cases} 1, & \text{During the plan period t, component j's process i was done by the facility k in} \\ 0, & \text{Others;} \end{cases}$$

In order to form the cell manufacturing systems that have superior performance, we need 3 targets: total cost is minimum, the utilization rate of equipment is maximized and the number of components move across the cell is minimized. So, based on the adequate consideration of methods abroad to the formation of cell, this text is the first to build a mathematic model for the formation of multi-objective dynamic cells. It can be described by the followed multi-objective nonlinear programming model (MDCFP):

Min {*f* 1 (*X*), *f* 2 (*X*), *f* 3 (*X*)}, **(1)**

Where

$$\mathbf{f_1(X)=\sum_{t=1}^{T}\sum_{l=1}^{L}\sum_{k=1}^{K}X_{lkt}A_k+\sum_{t=1}^{T}\sum_{l=1}^{L}\sum_{k=1}^{K}(S_kY_{lkt}+R_kZ_{lkt})+\sum_{t=1}^{T}\sum_{l=1}^{L}\sum_{k=1}^{K}\sum_{j=1}^{J}\sum_{j=1}^{I_j}D_{jt}P_{ijk}O_kV_{ijlkt}}, \quad \mathbf{(2)}$$

$$\mathbf{f_2(X)=\max_{k}\left\{\left|\sum_{t=1}^{T}\sum_{t=1}^{L}\beta_kX_{lkt}-\sum_{t=1}^{T}\sum_{l=1}^{L}\sum_{j=1}^{J}\sum_{i=1}^{I_j}D_jP_{ijk}V_{ijlkt}\right|\right\}}; \quad \mathbf{(3)}$$

$$\mathbf{\sum_{i=1}^{I_j-1}\left|\sum_{k=1}^{K}V_{i+1,jlkt}-\sum_{k=1}^{K}V_{ijlkt}\right|}. \quad \mathbf{(4)}$$

S t.

$$\sum_{l=1}^{L}\sum_{k=1}^{K}\alpha_{ijk}V_{ijlkt}=1,\forall i,j,t \quad \mathbf{(5)}$$

$$X_{lk,t-1} + Y_{lkt} - Z_{lkt} = X_{lkt}, \forall k, l, t = 2,...,T; \quad (6)$$

$$\beta_k X_{lkt} \geq \sum_{j=1}^{J} \sum_{i=1}^{I_j} D_{ij} P_{ijk} V_{ijkt}, \forall k, l, t \quad (7)$$

$$Y_{lkt} = \max\{\lambda(X_{lkt} - X_{lk,t-1}), 0\}, \forall l, k, t \quad (8)$$

$$Z_{lkt} = \max\{\lambda(X_{lk,t-1} - X_{lkt}), 0\}, \forall l, k, t \quad (9)$$

$$W_1 \leq \sum_{k=1}^{K} X_{lkt} \leq W_2, \forall l, t, \quad (10)$$

$$V_{ijkt} = 0,1 \forall i, j, l, k, t \quad (11)$$

$$X_{lkt}, Y_{lkt}, Z_{lkt}, V_{lkt} \geq 0, \quad (12)$$

Formula (1) is the overall objective, minimize (2)~(4) and get the three subtotals. Formula (2) is the total of purchased cost of equipment, equipment operating cost and cost of equipment configuration of each plan period; Formula (3) show the largest deviation between each equipment's load and capacity. It is nonlinear integer expression; Formula (4) expresses the total number of component move across the cell. Formula (5) shows that certain operation of a component only can be arranged to the only equipment to produce and process; formula (6) is the balance equation of the total number of equipment. Formula (7) shows that production capacity of each cell during every plan period that can satisfy the manufacture requirement. Formula (8) shows the amount of equipment k that add to cell I at the beginning of plan period t, it is decided by the differences between the amount of equipment k in cell I during the current plan period and the former plan period. Formula (9) shows the amount of equipment k disassembly from cell I at the beginning of plan period t. Formula (10) limits the maximum number and the minimum number of each cell. Formula (11) and (12) shows the decision variable's 0-1 constrain and the nonnegative integer constrain.

ALGORITHM DESIGN

This research uses advanced random weight multi-objective genetic algorithm to format the multi-objective dynamic cells. In this algorithm, chromosome coding is designed to be a code form of a multi-module two-dimension integer matrix. It also uses the adaptive niche technology, the penalty technology; double disc bet method and reserve essence strategy.

In genetic algorithm, crossover and mutation are two very important genetic operators. We need to use special crossover operator and mutation operator because chromosome in this text is multi-module two-dimension integer matrix, and its coded format is very special.

Step 1 Randomly choose one chromosome as parent population.

Step 2 Randomly choose one nonzero element m_{ji} from matrix M_{ji} to solve this problem (i and j are respectively represent its line number and column number).

Step 3 Randomly choose a positive integer k from 0 to K (K is the amount of the types of equipment). When parameter α_{ijk} =1, give k's value to m_{ji} or go back to step 2.

Step 4 Randomly choose a positive integer l from 0 to L(L is the amount of cells). Give l's value to the element which is in the line j and column i of matrix C_{ji}.

Step 5 Randomly choose a positive integer w from 1 to W_z . Give w’s value to the element which is in the line k and column l of matrix N_{kl} .

Step 6 The end of mutation operation

After the crossover operation and mutation operation, we get a chromosome may not satisfy formula (7) and (10), and need to use formula (14) and (15) and the penalty technology to correct it.

CALCULATION AND ANALYSIS

The algorithm above can be realized by programming with Matlab, and the mass simulating calculation can be done by Pentium IV with 512M memory. Both of them have good effect. Now we will give you a small-scale simulation example to explain the model and application of this method.

In certain machinery manufacturing enterprise, there is a job shop to produce several types of components. This text chooses 7 types of components, the job shop can open 3 cells at most, and each cell can accommodate 5 equipment at most and can accommodate 2 equipment at least. This enterprise does the dynamic formation of cell manufacturing system according to the plan of the following two months after the next month. The manufacture requirement and the basic data of technology are shown in the TABLE 1.

TABLE 1 : The manufacture requirement and the basic data of technology in living example

Components	Demand		Process			
			8	2	3	4
	Plan period 1	Plan period 2	1 2	1 2		
1	1300	2400	M3 or M2	M6	M4	
2	1400	2100	M2 or M5	M4 or M1		
3	0	1500	M5 or M3	M4 or M6		
4	1500	0	M3 or M2	M1 or M4	M5	
5	1700	2300	M2 or M4	M1	M6	M3
6	1600	2600	M1 or M4	M5		
7	1900	2800	M2 or M4	M6		

Take component 3 as example, from TABLE 1 we can get the production information of component 3, and component 3 doesn’t need to be produced in plan period 1. 1500 should be produced during plan period 2, and 2 processes are needed to produce component 3. The first process can be done by equipment 5 for 1.85s or equipment 3 for 2.43s. The second process can be done by equipment 4 for 3.47s or equipment 6 for 2.70s. The cost parameters of different equipment’s during the production process are shown in TABLE 2.

TABLE 2 : The cost parameters of equipment in the living example

The type of equipment	Buying expenses (ten thousand)	Operating cost (per hour)	Installation charge (ten thousand)	Removal cost (ten thousand)
1	61	80	4.2	2.5
2	51	40	5.8	3.4
3	64	50	6.2	4.2
4	74	70	4.8	3.6
5	58	60	5.8	2.8
6	49	50	5.6	3.4

Use the algorithm of this text and write the simulation program, we can get the non-dominated disaggregation in TABLE 3. From TABLE 3, we can clearly distinguish the quantitative and qualitative relationship of the 3 conflict targets. For example, component's total degree of move across the cells is increase with the decrease of total cost of production, but there is no secure relationship between the differences between equipment load and capability and the total cost of production. The wide spreading non-dominated disaggregation provides the sufficient gist for designer to consider the total cost, the rate of equipment utilization and the total number of component move across the cells, and to make the target trade-off decisions.

TABLE 3 : Non-dominated disaggregation

	Total cost (million)	Maximum difference (hour)	Total number of movements
1	2.2528	180	0
2	2.2473	160	1
3	2.2129	130	2
4	2.2052	180	1
5	2.1997	160	2
6	2.1954	180	2
7	2.0236	123	4
8	2.0222	130	3
9	1.9938	130	4
10	1.9628	85	5
11	1.9438	103	6
12	1.9418	130	6
13	1.8924	80	7
14	1.8400	74	8
15	1.8370	74	18

CONCLUSIONS

The formation of dynamic cell manufacturing is one of the hottest topics in the field of advance production operations. This text discusses the problem of the formation of dynamic cell. Through trade-off between 3 targets which are the total cost of the formation of cell manufacturing, the maximum difference between equipment load and equipment capability and the total number that components move across cells. The decision is made for the formation of dynamic cell manufacturing, and lastly put forward the random weigh multi-objective genetic algorithm based on the essence retention strategy. This text also analyzes the dynamic relationship between the 3 targets and looks for the non-domination disaggregation by doing the simulations for living examples.

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