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Virtual Cellular Multi-period Formation under the Dynamic Environment

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Abstract

Virtual cellular manufacturing is an innovative way of production organization which both in the production of flexibility and efficient to meet today's rapid development of science and technology and replacement of products. The key process of the design of virtual cellular manufacturing system—cell formation is the focus of research. In order to meet the characteristics of small batch and dynamically changing market demand, this paper studies the problems of virtual cellular multi-period dynamic reconfiguration. A reconfigurable system programming model is developed. The model incorporates parameters of the problems of product dynamic demand, machine capacity, operation sequence, balanced workload, alternative routings and batch setting. The objective of mixed integer programming model is to minimize the total costs of operation, moving raw materials, inventory holding and process routes setup. Though a case study, demonstrates the feasibility and validity of the model in reality.

Keywords: virtual cellular; manufacturing system design; reconfigurable system modeling; mixed integer programming;

1. Introduction

With the development of science and technology, the product of the rapid upgrading and demand for the diversification of products, manufacturing is developing from the traditional mode of large-scale production to many varieties, small batch mixed flow mode of production, in order to meet the need of the shift, internal manufacturing resources of the enterprises have to reconfigure rapidly[1]. However, there are a lot of problems in production organization of enterprises, namely the design of the manufacturing system. Therefore, the

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enterprise must consider using advanced mode of production and scientific management method, so that enterprise can response to the market rapidly at a lower cost. Virtual cellular manufacturing system[2] is increasing to become a kind of advanced manufacturing mode in recent years. In the dynamic environment, the product mix is difficult to predict and virtual cellular has overcome the limitations of the traditional cellular production mode which gradually become an effective mode to realize many varieties and small batch production.

In the virtual cellular manufacturing system, machines don't move from one location to another, but logically form a virtual dynamic entities, and the logic reconfiguration has greatly reduced the time and cost of reconfigurable system and improved the flexibility of the system[3]. In order to make advantages of virtual cellular manufacturing system, and the key design of cellular manufacturing system is cell formation. Based on different environments, different scholars put forward different strategies of cell formation. For example, Bai Junjie[4] has studied the problems of virtual manufacturing cell formation in reconfigurable manufacturing system about the different delivery times with production orders coexisted, and 0-1 integer programming model is established.J. Slomp[5] has put forward to add labor force to virtual cellular manufacturing formation. First, group tasks and equipment, then assign workers to virtual cell, and goal programming model is established. Niu Li[6] has studied the problem of the selection of processing routes and batch setting up in a static environment. But many problems of cell formation are based on the ideal production environment, assuming that demand is stable, and the related production information is known and complete. But there are a large number of random disturbed factors in the actual manufacturing system. As a result, the first phase of cell formation may not meet successive periods. R.Jayachitra[7], R.Raju [8], etc have considered the reconfigurable system to respond to the dynamic environment. R.Kia [9], K.Rafiee[10] have analyzed the problems that are based on multi-period, multi-processing routes, and by optimizing production batch to reduce the total costs of production. But in the research of cell formation, if enterprises use the formation strategy of traditional cellular manufacturing system, there will be generated a lot of cost by manufacturing resources's layout again, and because of machines can't be moved that influence the cell formation. Hassan Rezazadeh[11], Iraj Hassan[12] have studied the design of virtual cellular manufacturing system.

The design of virtual cellular manufacturing system still need to improve, the paper presents a virtual cell formation model. In the model the demand of parts not only consider the size of the production batch, but also consider the inventory levels, dynamic of production batch size affect virtual cell formation in different periods. Enterprise considered the master production planning in the manufacturing system design will be more actual in production needs. Through the establishment of the virtual cellular manufacturing reconfigurable system model, which not only intends for supplement to the existing of the study on the theory of virtual manufacturing cell, but also provides certain guiding significance for the manufacturing enterprises to implement virtual cells.

2. Problem description

In the virtual cellular manufacturing system, when the product mix and technological requirements of manufacturing enterprises are made changes, the existing virtual manufacturing cells can't meet the production requirements, then manufacturing enterprises need to reconfigure manufacturing resources, the frequency of reconfiguration depends on new tasks to cause changes in volumes and mix of demand.

To design a more actual dynamic cell formation strategy, this paper establishes a mixed integer programming model of virtual cellular multi-period dynamic formation. The target of this model is to minimize the sum costs of the operating, raw material moving, inventory holding and setting up. The model includes the actual parameters that including the capacity of manufacturing resources, inventory balanced constraints, product dynamic requirements and operation sequence, and each job in the manufacturing system can have different process routes. In the available manufacturing resources to select suitable manufacturing resources and to determine the batch setting of parts. In the virtual cells the sharing of equipment resources cause workload unbalanced that consider the factor of workload balance, and decision makers can adjust the degree of workload balance according to their wishes.

3. Model formation

This article designs a mixed integer programming model that integrate master production planning and virtual cellular manufacturing reconfigurable system. This article assumes that the sequences of operations of each of the parts is known. All machine types are multi-functional. Each part type can have several alternative process routes with different processing times, and processing time is known and determined. Each machine types have more than one machine. The demand for each part type in each period is known and determined. The capabilities of each machine type in each period is known. The number of cells to be formed in each period is specified in advance, and over the entire range of the whole plan remains the same. The variable cost of each machine type is known, and the variable cost implies operating cost that is dependent on the workload of the machine. Allow the inventory, and the inventory cost is known. No delivery of the goods is allowed.

3.1. Model parameter

3.1.1. Parameter input

h —— index for time periods， $h = 1,2,...,H$
c —— index for virtual cells， $c = 1,2,...,C$
m —— index for machine types， $m,k = 1,2,...,M$
p —— index for part types， $p = 1,2,...,P$
r —— index for process routes of each part type， $r = 1,...,R_p$
j —— index for operations of part type p in route r ， $j = 1,2,...,J_{rp}$
D_{ph} —— demand for part p in period h
β_m ——operating cost per unit time per machine type m ;
γ_p —— inventory holding cost per time period for per part type p
S_{rph} ——setup cost of route r for part p in period h
α_p ——moving cost for per part type p
t_{jrp} —— processing time required to process operation j of part type p on route r
T_m —— capacity of machine m in each period
Y_m —— the number of available machine m
B_U —— maximum number of machines in each cell
B_L —— minimum number of machines in each cell
q —— factor of workload balance between virtual cells
A —— large positive number

3.1.2. Decision variables

N_{mch} —— number of machines type m in cell c during period h
Q_{rph} —— the quantity of part type p processed on route r in period h
I_{ph} —— inventory level of part type p kept in period h ,and carried over to period $h+1$
x_{jrpch} —— 1, if operation j along route r of part type p is processed in cell c in period h; 0, otherwise
z_{rph} —— 1, if route r of part type p is setup in period h; 0, otherwise
q_{mrph} —— 1, if machine type m is used for operation j along route r of part p in period h; 0, otherwise

3.2. Decision variables

$$\min Z=\sum_{h=1}^{H}\sum_{p=1}^{P}\sum_{r=1}^{R_p}\sum_{j=1}^{J_{rp}}\sum_{m=1}^{M}\beta_m\cdot t_{jrp}\cdot Q_{rph}+\sum_{h=1}^{H}\sum_{c=1}^{C}\sum_{p=1}^{P}\sum_{r=1}^{R_p}\sum_{j=1}^{J_{rp}}\alpha_p\cdot Q_{rph}\cdot\left|x_{j+1rpch}-x_{jrpch}\right|$$
$$+\sum_{h=1}^{H}\sum_{p=1}^{P}\gamma_p\cdot I_{ph}+\sum_{h=1}^{H}\sum_{p=1}^{P}\sum_{r=1}^{R_p}S_{rph}\cdot z_{rph}. \qquad (1)$$

$s.t.$

$$\sum_{c=1}^{C}x_{jrpch}=z_{rph}\forall p,r,h,j. \qquad (2)$$

$$Q_{rph}\le A\cdot z_{rph}\forall p,r,h. \qquad (3)$$

$$\sum_{r=1}^{R_p}\sum_{p=1}^{P}\sum_{j=1}^{J_{rp}}t_{jrp}\cdot Q_{rph}\cdot x_{jrpch}\le N_{mch}\cdot T_m\quad\forall m,h,c. \qquad (4)$$

$$I_{ph}=\sum_{r=1}^{R_p}Q_{rph}+I_{ph-1}-D_{ph}\qquad\forall p,h. \qquad (5)$$

$$\sum_{r=1}^{R_p}\sum_{p=1}^{P}\sum_{j=1}^{J_{rp}}t_{jrp}\cdot Q_{rph}\cdot x_{jrpch}\ge\frac{q}{C}\sum_{c=1}^{C}\sum_{r=1}^{R_p}\sum_{p=1}^{P}\sum_{j=1}^{J_{rp}}t_{jrp}\cdot Q_{rph}\cdot x_{jrpch}\ \forall c,h. \qquad (6)$$

$$B_L\le\sum_{m=1}^{M}N_{mch}\le B_U\quad\forall c,h. \qquad (7)$$

$$\sum_{c=1}^{C}N_{mch}\le Y_m\quad\forall h,m. \qquad (8)$$

$$\sum_{m=1}^{M}q_{mrph}=J_{rp}\quad\forall r,p. \qquad (9)$$

$$x_{jrpch}\in\{0,1\},z_{rph}\in\{0,1\},q_{mrph}\in\{0,1\}\forall j,p,c,h,r. \qquad (10)$$

$$N_{mch}\ge 0,\quad Q_{rph}\ge 0,\quad I_{ph}\ge 0\quad\forall m,p,c,h,r. \qquad (11)$$

The nonlinear mixed integer objective function given in equation (1) minimizes the total sum of the operating cost, the material handling cost, inventory holding cost and process routes setup cost over the planning horizon. The first term is the operating cost of all machines required in all cells over the planning horizon. The second term is the total material handling cost. The third term computes inventory holding cost. The last term represents process routes setup cost. Equation (2) shows that setup of process routes, while production after the setup is guaranteed by Inequality (3). Inequality (4) ensures that machine capacities within-cell can meet the demand. Equation (5) ensures that the quantity of parts is equation in two successive periods, namely inventory balanced constraints. Inequality (6) implies that workload balance between virtual cells and is used to determine the degree of workload balance. Inequality (7) guarantees the number of machines in the virtual cell does not exceed the maximum number of machines of upper limit and does not lower the minimum amount of machines of lower limit. Inequality (8) limits the total number of the available machines. Equation (9) ensures the relationship of machine types in each process route and the number of their related operations. Type (10) (11) imply 0-1 decision-variables and non-negative integer variables.

4. Case study and computational results

4.1. Case study

In order to verify the validity of the model, there will be pipe processing in a team of a shipyard as an example to illustrate the implementation of multi-period virtual cell dynamic formation, and calculated by Lingo11.0. The case comprises 5 different pipes, 8 different types of machines, the available number of each kind of machines is 2, 3 periods, the maximum number of virtual cells is 3, each kind of pipes includes three processes, each job can be processed in the two available paths. The number of maximum and minimum machines in each virtual cell are 3 and 6 respectively. The factor of workload balance between virtual cells is 0.9. Data for machine types are following as table 1. Table 2 shows the data for part types.

Table 1. Data for machine types

machine number	process name	machine	machine mode	The number of machines (set)	T_m/h	β_m
M1	Hole	Vertical drilling machine	H5-32D	2	240	8
M2		High temperature and press hole machine	YK114-377	2	240	9
M3	Cutting	Disc saw	HVS-355AC	2	240	7
M4		Pipe cutting machine	80A-200A	2	240	7
M5	Welding	Argon welder	MRA-600	2	240	8
M6		Anti electric shock AC welder	YK-505FL4HGJ	2	240	9
M7	Bending	2#CNC pipe cutting machine	PB-ER40D-F	2	240	7
M8	Test	Electric pressure test pump	4DY-74/6.3	2	240	12

Table 2. Data for part types

part	route	operation data(/min)	setup cost	demand		
				h1	h2	h3
P_1	1	(M3-35), (M7-53)	940	200	250	0
	2	(M4-66), (M5-35), (M7-50)	945			
P_2	1	(M1-45), (M4-50), (M5-43)	1200	160	100	95
	2	(M4-56), (M6-50)	1220			
P_3	1	(M3-32), (M5-67), (M7-47)	600	120	0	150
	2	(M4-38), (M6-75), (M7-50)	650			
P_4	1	(M2-35), (M7-69), (M8-50)	1000	150	200	100
	2	(M1-25), (M7-46), (M8-59)	900			
P_5	1	(M6-75), (M7-53), (M8-57)	1200	100	120	80

4.2. Computational results

We can obtain available processing route for each part and optimal production quantity for each period from table 3. And the results of virtual cellular manufacturing multi-period dynamic formation as Fig. 1.

Table 3. The level of production and inventory in each period

Part	R	h1			h2			h3		
		z_{rp1}	Q_{rp1}	I_{p1}	z_{rp2}	Q_{rp2}	I_{p2}	z_{rp3}	Q_{rp3}	I_{p3}

P_1	1	1	200	0	0			0	0	0
	2	0			1	250	0	0		
P_2	1	1	160	0	1	150	0	1	95	0
	2	0			0			0		
P_3	1	1	120	0	0	0	0	1	150	0
	2	0			0			0		
P_4	1	0			0			0		
	2	1	210	60	1	240	100	0	0	0
P_5	1	1	175	75	1	125	80	0	0	0

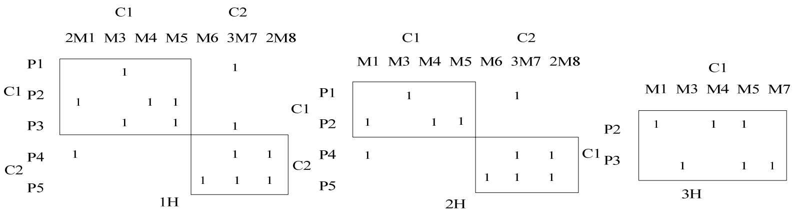

Fig. 1. Matrix of “machine--part”

Table 4. Cost comparison of virtual cell formation in different cases

	Case 1	Case 2
Operating cost	31434.95	31050.25
Material handing cost	24270	23270
Inventory cost	315	0
Setup cost	10885	12985
Total cost	66904.95	67305.25

Results: This paper aims at the problem of virtual cellular manufacturing system reconfiguration to design two cases. The case 1 considers the master production planning, and case 2 does not consider it. The results have shown in table 4. It can be drawn from the data scheme, case 1 can effectively reduce the setup cost so as to obtain the optimal total cost. At the same time, because reduce the number of setup, so decrease productive time as a whole which make shipyard to respond to market demand quickly.

5. Conclusion

This paper mainly studies virtual cellular manufacturing multi-period dynamic formation under the dynamic environment, and establish the reconfigurable model to verified. By considering the inventory level and optimizing production quantity to reduce the total cost, which have improved the efficiency of enterprises. The results of the case study show that the model of virtual cellular multi-period dynamic formation can better respond to changing market demand and reconfigure virtual cell quickly. Experiments show that the model not only can effectively reduce the total cost, but also be able to respond to market demand quickly. Since the model is an NP problem, therefore, the next step can make use of some meta heuristic methods, such as genetic algorithm, particle swarm optimization algorithm etc to solve complex problems of large-scale enterprises, so that can find the optimal solution in a short time.

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