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Cellular manufacturing layout on adding/removing machines

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Abstract: In order to rapidly respond to the complex and mutational market, a new facility layout plan based on cellular manufacturing is proposed, which gives consideration to high efficiency and flexibility. The plan designs two phases of integrated cell layout, i. e., cell construction and cell system layout, on the condition of adding/removing machines. First, in view of the costs of logics and machine-relocation, the cell construction based on the alternative processing routes and intra-cell layout are integrated as a whole, which achieves cell formation, process planning and the intra-cell layout in a single step. Secondly, an approach of a continuous optimized multi-line layout for solving the cell system layout problem is proposed, which eliminates the coupling relationship from the machine-relocation and realizes an integrated design of the two phases of the cell layout. An application based on real factory data is optimally solved by the Matlab 7. 0 software to validate and verify the models.

Key words: cell layout; adding/removing machine; genetic algorithm

In today's market economy environment, the manufacturing industry market is changed from the buyers' to the sellers', which causes the "product-focus" mode of production to the "customer-oriented" mode. In this environment, enterprises are faced with the changing needs of end users. The traditional manufacturing systems cannot adapt to this complex, mutating and non-stationary manufacturing environment. The cellular production mode is an advanced manufacturing method arising under the current environment, in which market demand is multi-various and small batch. The facility layout based on the cellular production mode has the flexibility, agility and other features which lay the foundation for agile manufacturing. The cellular manufacturing layout provides the important hardware support for lean production, and the business community and academia attached great importance to it when it was proposed[1-2]. Wang et al.[3] proposed an integrated design approach to consider the problem of facility layout in cells and cells layout comprehensively; Suer et al.[4] presented a method to design the independent cells and solve the model; Wang et al.[5] made the facility layout problem as a continuous optimization problem of a multi-line facility layout; Zheng et al.[6] optimized the reconfigurable manufacturing cell layout. However, these studies were all carried out under the premise of a determined number of machines, sizes and processes. To adapt to rapidly changing external environments and demands, the enterprises have the objective need to frequently add/remove the machines in the plant, which changes the facility layout[7]. So adding/removing machines becomes an important factor affecting production. In this paper, the facilities are placed by the cell layout under the condition of adding/removing machines. The kind of facility layout is divided into two stages. The first stage is designing the manufacturing cells; the second stage is regarding the manufacturing cells in the first stage to form the final facility layout. After reconfiguration, the manufacturing cell can restore flexibility and overcome all the disadvantages of the original cells, which improves the market responsiveness of the system.

The layout on adding/removing machines emphasizes agility and rationality of the production line layout. It forms dynamic reconfigurable manufacturing cells to increase efficiency by analyzing the process routes and requirements. It makes a rapid response to the new production task to adapt the multi-variety and variable volume production features. The main objectives of the system layout are as follows:

1) Choose the right process path. Ensure the smooth processing of parts, reduce the number of processing machines, and improve equipment utilization and system productivity.

2) Maximize the utilization of space. Make the utilization of space reach an appropriate building area factor (the ratio between the area of buildings and the total area), so that the device space and the system logistics costs tend to be minimal[8].

3) Minimize the costs of material handling and adding/removing machines.

4) Maintain the flexibility of production and arrangements. Make the cellular manufacturing system maintain good operating performance in its entire life cycle, and take the future expansion needs of production capacity into account.

1 Formation of Manufacturing Cells

Cell construction is the primary problem of cell layout design[9]. The result can form the processed parts family and the corresponding machine group which belongs to the cells. This paper uses the linear layout as the mode of the facility layout in cells, and studies the direction in the single logistics. Some layout forms of devices can be slightly adjusted by switching with corresponding logistics calculation methods. Considering the effect of logistics costs among cells on the cell construction, the unit logistics cost is supposed to be a constant.

1.1 Mathematical model

The cell construction problem can be described as follows: The original cell layout is known. There are M machines and P parts. Each part has R_p kinds of process routes which correspond to the production quantity V_p; each machine processes at least one part and each process route of each part has at least one machine. In order to optimize the manufacturing

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process, M machines are formed in C manufacturing cells, and each part chooses the right process route, so as to minimize the sum of the inner-cell's and the outer-cell's logistics costs and the cell-reconfiguration cost, as well as to obtain maximum economic efficiency. The proposed model and constraints are as follows:

$$\min \text{cost} = \sum_{m=1}^{M}\sum_{m'=1}^{M}\sum_{p=1}^{P}\sum_{r_p=1}^{R_P}\frac{V_p}{B_p}O_{mm'}^{r_p}\,y_{rp}C_{mm'}^{p} + \sum_{c=1}^{C'}\sum_{m=1}^{M}C_m q_{mc} \tag{1}$$

s. t.

$$\sum_{c=1}^{C} x_{mc} = 1 \qquad \forall\, m = 1, 2, \ldots, M \tag{2}$$

$$\sum_{m=1}^{M} x_{mc} \geqslant 1 \qquad \forall\, c = 1, 2, \ldots, C \tag{3}$$

$$\sum_{r \in R_p}^{R} y_{rp} = 1 \qquad \forall\, p = 1, 2, \ldots, P \tag{4}$$

$$\sum_{j=1}^{J} z_{mj} = 1 \qquad \forall\, m = 1, 2, \ldots, M \tag{5}$$

$$\sum_{m=1}^{M} z_{mj} = 1 \qquad \forall\, j = 1, 2, \ldots, J \tag{6}$$

$$x_{mc} = \begin{cases} 1 & \text{If the machine } m \text{ belongs to cell } c \\ 0 & \text{Others} \end{cases} \qquad \forall\, m \in M,\ c \in C \tag{7}$$

$$y_{rp} = \begin{cases} 1 & \text{If part } p \text{ chooses the process route } r \\ 0 & \text{Others} \end{cases} \qquad \forall\, r_p \in R_p,\ p \in P \tag{8}$$

$$z_{mj} = \begin{cases} 1 & \text{If machine } m \text{ is placed in position } j \\ 0 & \text{Others} \end{cases} \qquad \forall\, m \in M,\ j \in J \tag{9}$$

$$q_{mc} = \begin{cases} 1 & \text{If machine } m \text{ is reconfigured} \\ 0 & \text{Others} \end{cases} \qquad \forall\, m \in M,\ c \in C' \tag{10}$$

$$O_{mm'}^{r_p} = \begin{cases} 1 & \text{If machine } m \,\&\, m' \text{ in the process route } r_p \text{ belong to the same cell} \\ 0 & \text{Others} \end{cases} \qquad \forall\, r_p \in R_p;\ m, m' \in M \tag{11}$$

$$C_{mm'}^{p} = \begin{cases} \sum_{j=1}^{J}\sum_{j'=1}^{J} |\, j - j' \,|\, C_p z_{mj} z_{m'j'} & \text{If machine } m \,\&\, m' \text{ are in the same cell} \\ \mathrm{CX}_p(\text{constant}) & \text{Others} \end{cases} \tag{12}$$

where M is the quantity of machines; P is the quantity of parts; C is the quantity of cells, $1 \leqslant C \leqslant M-1$; J is the quantity of machine locations; R is the quantity of process routes of parts; C' is the original number of cells; V_p is the production quantity of part p; B_p is the unit container loading of part p; $C_{mm'}^{p}$ is the unit logistics cost of the inner-cell and the outer-cell; C_m is the reconfiguration cost of machine m.

Constraint (2) guarantees that a machine can only belong to one manufacturing cell. Constraint (3) ensures that any manufacturing cell must contain at least one machine. Constraint (4) guarantees that any part can only choose one process route. Constraint (5) ensures that any machine can only be placed in one location. Constraint (6) ensures that any location can only contain one machine. Constraints (7) to (11) guarantee that the values of the decision variables are 0-1 binary variables.

1.2 Model solution based on GA

The genetic algorithm (GA) is a universal optimization algorithm. Its most notable feature is implicit parallelism and the search capabilities for global solution space.

On the condition of adding/removing machines, this paper uses the cell-reconfiguration cost as the part of the objective function to pursue the cell flexibility and achieve the lowest cost. In order to improve the calculation accuracy of material handling distance about the inner-cell, the inner-cell's facility layout problem in the cell formation stage is solved. In order to improve the cell's compactness and independence, the restriction of cell numbers is considered when the machines are grouped. Considering alternative process routes and available multiple machine types, the choice of process routes is an important guidance in cell construction. This paper will eventually give an integrated solution to solve the problems among the part design/process path selection, cell construction and inner-cell facility layout.

1) Chromosome encoding: Chromosomes have three parts: machine-location codes, cell-split codes and process-route codes. The machine-location codes are the integer sequence whose length is M and the gene number is $[1, M]$; the cell-split codes are the 0-1 binary encoding string whose length is $M-1$. It is the split of manufacturing cells when the value of a location gene is 1; the process-route codes are the integer sequence whose length is P and the value intervals are [1, RP] (RP is the largest number of alternative process paths). For the sake of solving potential illegal solutions, the codes' output can be legalized by the following formula: the process path of part $p = \lceil \text{gen}(p) R_p / \text{RP} \rceil$ (R_p is the number of alternative process paths of part p).

2) The fitness function: The objective function is to minimize the cost. The lower the program cost, the better it is. Therefore, the fitness function is as follows: Fit = 1/cost.

3) Initialization: According to the information of machines and processes, by the form of chromosomes codes, a certain number of chromosomes randomly emerges as the initial population.

4) The selection operator: Use the roulette wheel method as a selection operator. The probability that the individual is selected is proportional to its fitness value.

5) The crossover operator: Different parts of the chromosomes have different crossover operators. The machine-location codes use a single-point crossover which is similar to a binary-coded operation. The single-point crossover means to select a gene locus randomly and partly exchange the structure of two parent-strings at the head of the locus or at its back. The codes of cell-splits and process paths use the operation of the traditional single-point crossover.

6) The mutation operator: Three parts of the codes apply the mutation operation separately. Machine-location variation means to exchange the sequence position of two machines' codes randomly; cell-split variation means to select a gene locus randomly and change its value into its opposite; process-route variation means to select a gene locus

randomly and change its value by the new one being randomly generated.

The algorithm flow is as follows:

Step 1 Generate the first-generation population. Create pop_size chromosomes to compose the first-generation population. Set the current generation $t = 0$.

Step 2 Determine whether it satisfies any of the following conditions: $t \geqslant$ gen_size (the max-evolution generation) or the optimal solution is not improved within 10 consecutive generations. If it meets any one of them, the algorithm terminates, otherwise turn to step 3.

Step 3 Calculate the fitness value of each individual. Decode the process route of each part and form the "from-to" matrix $\boldsymbol{C}$ of logistics costs between machines by the initial input information; decode the machine-location and the cell-split and obtain the distance matrix $\boldsymbol{D}$ between machines and relocated machines. Combined with the above three areas, the result is the objective function value, whose reciprocal is the fitness value.

Step 4 Use the roulette wheel method to select pop_size chromosomes from the current generation to form a new population. According to the crossover probability p_c and the mutation probability p_m, the new population is adjusted by crossover and mutation. Use the adjusted population to replace the current generation. Set $t = t + 1$. Return to step 2.

2 Cell System Layout

Although minimizing the logistics cost among cells is one of the optimization goals in the cell construction phase, it is always unrealistic to pursue a "zero" logistics configuration among cells. Many studies have shown that the cell system layout plays an important role in the overall performance of the system.

This article considers the cell system layout as the continuous optimization problems of the multi-line cell layout. Using the method of the previous section, the formation of manufacturing cells has finished beside the layout in cells. Suppose that the shapes of the machines needing a spatial layout are rectangle and their sizes are known (ignore the details of their shapes); the form of the inner-cells' layout is linear so that the shapes of the cells form a rectangle composed of several machines. Each of them has 1 machine at least. To better solve the combination problem between discrete and continuous optimization in the multi-line layout, this paper divides the multi-line layout problem into three parts: allocate the cells to lines; order the cells in line; adjust the location of each cell slightly.

2.1 Mathematical model

The problem can be described as follows: The cell areas of N cells, the material paths and the logistics costs are known. It supposes that the cells cannot be overlapped; a cell can only be allocated in one row. Each cell is eventually assigned to each row and finds the best location in each line. The purpose is to minimize both the logistics costs among cells and the cell-relocation costs to obtain the maximum benefit. The proposed model is as follows:

$$\min \text{cost}' = \sum_{i=1}^{N} \sum_{j=1}^{N} C_{ij} F_{ij} D_{ij} + \sum_{n=1}^{N} C_n p_n \qquad (13)$$

s. t.

$$|x_i - x_j| z_{ik} z_{jk} \geqslant \frac{1}{2}(l_i + l_j) + d_{ij} \qquad \forall i, j = 1, 2, \ldots, N \qquad (14)$$

$$y_i = \sum_{k=1}^{W} l_0 (k-1) z_{ik} \qquad \forall i = 1, 2, \ldots, N \qquad (15)$$

$$\sum_{k=1}^{W} z_{ik} = 1 \qquad \forall i = 1, 2, \ldots, N \qquad (16)$$

$$\sum_{i=1}^{N} z_{ik} \leqslant N \qquad \forall i = 1, 2, \ldots, W \qquad (17)$$

$$x_i, y_i \geqslant 0 \qquad \forall i = 1, 2, \ldots, N \qquad (18)$$

$$p_n = \begin{cases} 1 & \text{If cell } n \text{ changes the position} \\ 0 & \text{Others} \end{cases} \qquad \forall n \in N \qquad (19)$$

$$z_{ik} = \begin{cases} 1 & \text{If cell } I \text{ is located in row } k \\ 0 & \text{Others} \end{cases} \qquad \forall i \in N, k \in W \qquad (20)$$

where N is the quantity of cells; W is the quantity of the layout lines; C_{ij} is the logistic cost in unit distance between cell i and cell j; F_{ij} is the access frequency between cell i and cell j; $D_{ij} = |x_i - x_j| + |y_i - y_j|$ is the rectangular distance between cell i and cell j; C_n is the cell relocation cost; l_i is the length of cell i; l_0 is the center distance between adjacent two lines; d_{ij} is the obligatory spacing between cell i and cell j; x_i is the distance between the center of cell i and the vertical reference line l_V; y_k is the distance between the center of cell i and the horizontal reference line l_H; Δi, Δk are clear spacing between cells.

Constraint (14) guarantees that any two cells do not overlap; constraint (15) provides the vertical coordinate values of cells in any row; constraint (16) guarantees that a cell can be placed only in one line; constraint (17) ensures that the quantity of the layout rows are not more than those of the cells'; constraints (19) and (20) ensure that the values of decision variables are 0 or 1. Parameters, decision variables and reference lines are shown in Fig. 1.

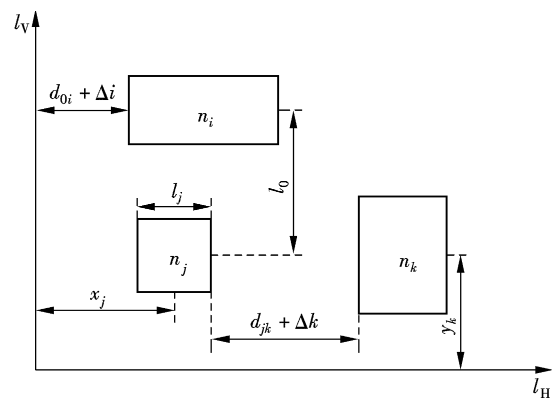

Fig. 1 Parameters, decision variables and reference-line diagram

2.2 Model solution based on GA

Although minimizing the cell-reconfiguration costs is one of the optimization goals in the cell construction phase, the machine locations are probably changed in the stage of cell system layout. Therefore, this paper considers the cell relocation costs as a part of the cell-construction cost to achieve the lowest cost based on the optimal cell layout, as well as to avoid double counting the relocation costs. Suppose that the cell is relocated when its coordinate is beyond a certain range. To avoid cells overlapping during the layout, it uses the horizontal clear coordinates to express the coordinate l_H, and uses the row-separator and cell sequence and obligatory vertical spacing to express the coordinate l_V. This article studies the case that N cells are placed in two lines.

1) Chromosome encoding: Chromosomes have three parts: separator codes, cell-sequence codes and clear-spacing between cell codes. The separator codes are the integer sequence whose length is 1 and the gene number is from 1 to $N-1$; the cell-sequence codes are the integer sequence whose length is N and the gene number is from 1 to N; the clear-spacing between cells codes is the integer sequence whose length is N and the sum of the gene numbers is less than $L' = (2L - L_k^1 - L_k^2)$, where L is the maximum work area, L_k^w is the largest obligatory work area in row w.

2) The fitness function: It includes the total cost and unreasonable penalty. The total cost can be computed by the objective function. Considering the encoding mechanism, the unreasonable solution is usually generated due to excess work area. Set the penalty factor

$$\lambda_k = \begin{cases} 0 & \text{If } L_k^w - L \leqslant 0 \\ L_k^w - L & \text{Others} \end{cases}$$

Then the fitness function is $\text{Fit} = \dfrac{1}{\cos t_k + \lambda_k P}$; $\forall k = 1, 2, \ldots, \text{pop\_size}$, P is a positive large penalty value.

3) Initialization: According to the form of chromosome encoding, a certain number of chromosomes is randomly generated as the initial population.

4) The selection operator: Use the roulette wheel method as selection operators.

5) The crossover operator: The different parts of the chromosomes have different crossover operators. The separator code uses a random method to determine the separator; the cell-sequence codes use the PMX method to arrange sequencing; the clear-spacing between cells codes uses the arithmetic crossover method to deal with the clear spacing.

6) The mutation operator: Use the neighborhood search technology to adjust the location of each cell slightly.

Algorithmic process is the same.

3 Application on Real Data and Discussion

To verify the performance of the proposed model, both phases of the model are applied based on the data of one company whose problems are solved by the GA method under the Matlab 7.0 software. The original cell layout information is in Tab. 1. While the quantity of machines is changed, the process paths and production in new projects are shown in Tab. 2.

Tab. 1 Old cell layout information

Cell number	Machine number	Cell size	Cell coordinate	Process path
1	1, 6, 9	12.79 × 14.07	(15.62, 16.25)	
2	8, 10	13.06 × 18.07	(31.53, 16.25)	Random
3	2, 7	8.67 × 12.50	(22.54, 0)	

Tab. 2 New part/machine data

Part	Process path	Machine	Production V_p	Container loading B_p
1	1	M_1-M_3-M_5-M_9	144	6
	2	M_2-M_3-M_5-M_{10}	114	6
2	1	M_1-M_6-M_9	150	6
	2	M_1-M_4-M_5-M_{10}	126	6
	3	M_1-M_7-M_{10}	168	6
3	1	M_2-M_3-M_5-M_9	210	6
	2	M_8-M_{10}	174	6
	3	M_1-M_3-M_5-M_{10}	132	6
4	1	M_1-M_4-M_5-M_9	180	6
	2	M_9-M_{10}	168	6
5	1	M_2-M_7-M_9	198	6
6	1	M_2-M_4-M_5-M_{10}	138	6
	2	M_1-M_6-M_9	180	6
7	1	M_1-M_7-M_9	168	6
	2	M_2-M_6-M_9	126	6
	3	M_2-M_7-M_{10}	186	6

The new layout adds three machines and a new part. The quantity of processing paths about parts 2 to 6 also increases. According to the data in Tab. 2, the manufacturing cells are designed first. The genetic algorithm environment is as follows: pop_size = 100, gen_size = 800, $p_c = 0.9$, $p_m = 0.4$, $C_p = 1$, $CX_p = 600$, $C_m = 100$, distance matrix $(D_{ij}) = 5$. The result is shown in Tab. 3.

Tab. 3 Cell construction result

Cell number	Machine number	Part (path number)	Logistic cost		Cell reconfiguration cost
			Inner-cell	Outer-cell	
1	8, 10	1(1), 2(1), 3(2) 4(2), 5(1), 6(2) 7(3)	2 640	1 800	300

Based on the manufacturing cells formation, the cells are placed in two lines (the facility layout in the inner-cells is slightly adjusted by the distance conversion formula). The genetic algorithm environment is as follows: pop_size = 80; gen_size = 500; $p_c = 0.9$; $p_m = 0.4$; the obligatory vertical spacing between two rows is 1.5; the constraint of the working area length is 50; the width constraint is 40; the neighborhood search parameter is 10; the constraint of cell relocation coordinates is 0.5. The logistics cost between the cells matrix (C_{ij}) and the access frequency matrix (F_{ij}) is respectively estimated by the logistics and process paths among manufacturing cells; the obligatory horizontal spacing of the machines matrix $(D_{ij}) = 1$. The specific sizes of machines are shown in Tab. 4. The results of the layout are shown in Tab. 5 and Fig. 2.

Tab. 4 Machine area

Machine number	l_H	l_V	Cell number
1	3.65	10.50	2
2	3.65	10.50	3
3	1.09	1.90	2
4	2.90	1.43	3
5	2.05	4.25	2
6	7.00	3.04	2
7	6.02	7.81	3
8	5.50	12.00	1
9	6.10	16.07	3
10	4.56	13.43	1

Tab. 5 Cell system layout result

Cell number	Cell size	Row number	Cell coordinate	Logistic cost	Cell relocation cost
1	13.06 × 18.07	2	(31.54, 16.79)		
2	16.10 × 18.07	2	(17.86, 16.79)	813	800
3	12.67 × 12.50	1	(18.02, 0)		

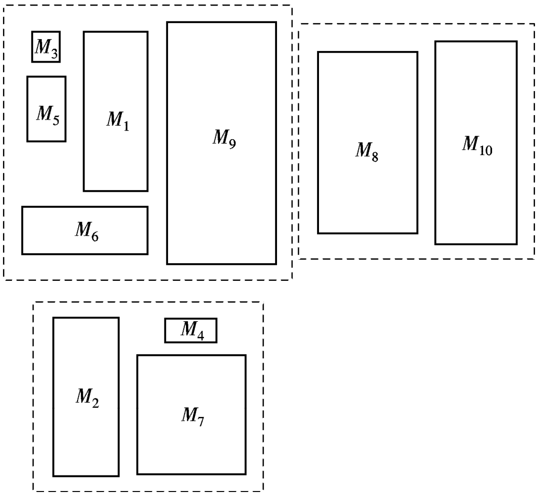

Fig. 2 Cell layout

In the project, the total logistics cost of the cell layout is 4 453 and the machine-relocation cost is 800. The advantages are as follows: Each part chooses an appropriate process; the new cells have better flexibility and independence; the new layout has high adaptability to the changeable orders with the lowest cost on the condition of adding/removing machines. Due to the machines being relocated, there is no proper cost to compare with. Compared with the original project, the logistics costs of the new method can be further reduced by 7.6%. It also proves the feasibility of this study.

4 Conclusion

This article studies the cell layout in the cellular manufacturing system. To solve the problems in previous studies, it establishes the cellular manufacturing models. The model can achieve the process flexibility and it is suitable for the product random demand whose method is the genetic algorithm and a numerical example is used to verify that the models are correct and effective and have guiding significance in practical application. At the same time, the models include the problems in a two-stage of the cellular manufacturing layout. If it achieves the overall optimization of the cellular manufacturing layout in multiple stages, it is more important for the dynamic demand of the product.

References

[1] Kioon S A, Bulgak A A. Integrated cellular manufacturing systems design with production planning and dynamic system reconfiguration [J]. *European Journal of Operational Research,* 2009, **192**(2): 414 − 428.

[2] Safaei N, Tavakkoli-Moghaddam R. Integrated multi-period cell formation and subcontracting production planning in dynamic cellular manufacturing systems [J]. *Intl J Production Economics,* 2009, **120**(2): 301 − 314.

[3] Wang T Y, Wu K B, Liu Y W. A simulated annealing algorithm for facility layout problems under variable demand in cellular manufacturing systems [J]. *Computers in Industry,* 2001, **46**(2): 181 − 188.

[4] Suer G A, Saiz M, Gonzalez W. Evaluation of manufacturing cell loading rules for independent cells [J]. *International Journal of Production Research,* 1999, **37**(15): 3445 − 3468.

[5] Wang Dingyi, Wang Liya. The facility layout study based on cellular manufacturing [J]. *Industrial Engineering and Management,* 2006, **2**(1): 10 − 13. (in Chinese)

[6] Zheng Yubin, Han Feng. Based on genetic algorithm reconfigurable manufacturing unit on the layout [J]. *Machinery Design and Manufacture,* 2009, **9**(9): 193 − 194. (in Chinese)

[7] Wu Chang. Adding/removing machines based dynamic layout optimization [D]. Shanghai: School of Mechanical Engineering of Shanghai Jiao Tong University, 2008. (in Chinese)

[8] Satoglu S I, Suresh N C. A goal-programming approach for design of hybrid cellular manufacturing systems in dual resource constrained environments [J]. *Computers & Industrial Engineering,* 2009, **56**(2): 560 − 575.

[9] Houshmand M, Jamshidnezhad B. An extended model of design process of lean production systems by means of process variables [J]. *Robotics and Computer-Integrated Manufacturing,* 2006, **22**(1): 1 − 16.

可添/删机器的单元制造布局

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摘要:为快速响应复杂、突变的市场,满足高效率和高柔性要求,在允许机器数量发生变化的条件下,从单元构建和单元系统布局进行集成设计与优化的高度提出了一种基于单元制造的可添/删机器的设施布局方法。首先,从物流成本和设备拆装成本的角度集成设计基于多工艺路线的单元构建与单元内设备布局,实现产品最优工艺路线、制造单元分组以及各单元内设备布局位置三者的同步输出;然后,采用连续优化的多行布局方法建立单元系统布局模型,避免设备重置带来的耦合关系,实现单元布局的集成性。利用 Matlab 7.0,结合实例进行验证,证明了该设备布局方法的可行性和有效性.

关键词:单元布局;机器添/删;遗传算法

中图分类号:F123