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Research on Cell Manufacturing Facility Layout Problem Based on Improved NSGA-II

Yanlin Zhao[1, 2, *], Jiansha Lu[1], Qing Yan[1], Lili Lai[1] and Lili Xu[1]

Abstract: With the rapid development of the individualized demand market, the demand for manufacturing flexibility has increased over time. As a result, a cell manufacturing system suitable for many varieties and small batches has been produced. With the goal of minimizing the area and logistics handling volume, and considering the arrangement order of facilities and channel constraints, a mathematical model was established, and the problem was solved by improved NSGA-II. After non-dominated sorting, traditional NSGA-II will cross-operate the individuals with the best sorting to generate new individuals. Such a selection strategy is extremely easy to fall into the local optimal solution. The improved NSGA-II is to improve the original selection operation, which is to select the first half of the excellent individuals in the non-dominated sorting into the cross operation, and then select the last sorted ones of the remaining individuals into the cross operation, and combine the best and the worst ones into the cross operation. Finally, an example is given to simulate and improve the solution of NSGA-II and NSGA-II. The simulation results indicate that the improved NSGA-II population shows more obvious diversity, it is easier to jump out of the local optimal solution than NSGA-II, and the satisfactory layout scheme of manufacturing cells is obtained. Therefore, it is more effective to use improved NSGA-II to solve the problem of manufacturing cell layout.

Keywords: Facility layout, improving NSGA-II, cell manufacturing, NSGA-II, dual objective problem.

1 Introduction

Cell manufacturing is an innovative manufacturing strategy that is based on the concept of group technology. Since it has the advantages of high flexibility and high productivity, it is suitable for the personalized market demand of multiple varieties and small batches. The research of cell manufacturing includes the research of cell formation and cell layout. In the cell formation stage, it mainly addresses the problems of optimal equipment and unit capacity balance, minimum cross-unit processing and so on. It also completes the division of production cell, and outputs the load balance rate between cell, the number of cross-unit processing of products and the production batch of products. Cell layout is to determine the placement position of each unit and is facilitated on the basis of unit

[1] Zhejiang University of Technology, Hangzhou, 310014, China.
[2] Panzhihua University, Panzhihua, 617000, China.
[*] Corresponding Author: Yanlin Zhao. Email: zhaoyanlin1987@163.com.

construction, and output the layout form and position between cells and facilities. Fazlela proposed a hybrid genetic algorithm to solve the unit layout problem in the dynamic manufacturing environment, in which the numerical verification has an effect. Ebrahimi. A further proposed an improved genetic algorithm to solve the layout of facilities with different areas and applied it in practical cases. Meanwhile, Deb K proposed the NSGA-II algorithm to solve the multi-objective problem of layout, and verified the effectiveness of the algorithm with a case study. In addition, CHU yan-ling used the NSGA-II algorithm in the binocular optimization with the maximum network accessibility and utilization rate as the objective. The present study focuses on a variety of algorithms to solve the layout problem of multi-objective, which is mainly divided into two categories. The first category is weighted by double target into a single objective problem, such as genetic algorithm. The second category is a multi-objective that considers seeking optimal at the same time, such as the NSGA and the NSGA-II algorithm. A large number of studies have shown that the latter has obvious superiority for multi-objective optimization. However, there are fewer articles applying NSGA-II to manufacturing cell layout, and fewer articles improving NSGA-II according to the characteristics of cell layout. Therefore, this paper improves NSGA-II to solve the bi-objective optimization of minimum moving distance and minimum occupied area in manufacturing cell layout.

2 Problem description

We assume that the facilities are cuboid, and one of the three surfaces of the facilities can coincide with the XOY plane (see Fig. 1(a)). The numbers in Figs. 1-7 refer to facilities, and they have the restriction of minimum spacing. The center of the same row of facilities must be on the same line. At present, the logistics handling mode of the workshop manufacturing units has been mainly linear. As such, the logistics handling mode in this paper also adopts the linear form, which is the top view of facilities (see Fig. 1(b)).

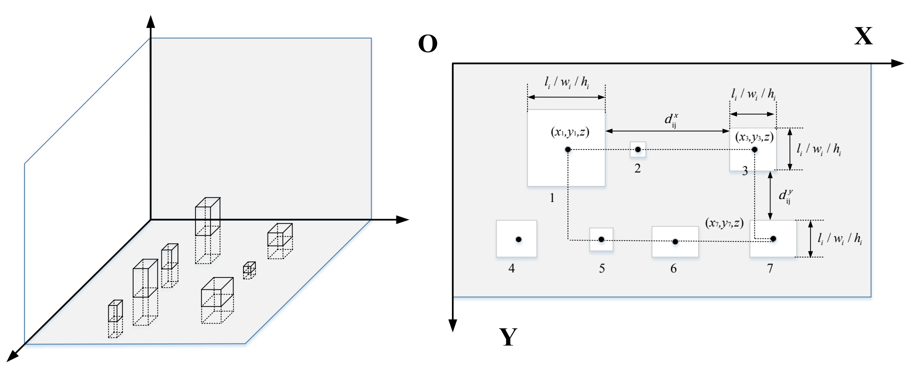

Figure 1: Schematic diagram of cell manufacturing

3 Mathematical model

3.1 Objective function

3.1.1 Logistics of Cell Manufacturing

In the manufacturing system, material handling is mainly carried out with unitized handling facilities, which can carry one or more unit products at a time. If V_p is the processing batch of product P and the handling batch of H_p product, then the material handling amount between facility i and facility j will be $n_{ij}^{p} \cdot ceil\left[V_p / H_p\right]$. n_{ij}^{p} represents the number of times from facility i to facility j when processing a product P, while *ceil* is the upward integer. The distance between facility i and facility j is from the central point of the facility as the starting point. Thus, the moving distance in this paper is expressed by $\left|x_i - x_j\right| + \left|y_i - y_j\right|$. In sum, the objective function of establishing a material handling quantity is expressed as follows:

$$\min D = \sum_{i=1}^{M} \sum_{j=1}^{M} \sum_{p=1}^{P} n_{ij}^{p} \cdot ceil\left[V_p / H_p\right] \cdot \left(\left|x_i - x_j\right| + \left|y_i - y_j\right|\right) \tag{1}$$

3.1.2 Area of cell manufacturing

Assuming that the layout of the manufacturing unit is limited to the range of L * W, and the minimum spacing between facilities is DG, the minimum objective function of space occupation is expressed as follows:

$$\min V = \left(\mathrm{L} \cdot \sum_{r} \left(\max w_{rm} + \mathrm{DG}\right) + \left(\sum_{i=1}^{m} \left(l_i + \mathrm{DG}\right) + \mathrm{DG} \right) \cdot \left(\max\left(w_{rm}\right) + 2\mathrm{DG}\right) \right) \tag{2}$$

As shown in Fig. 2, $\max w_{rm}$ represents the facility with the maximum W direction in row r; $\mathrm{L} \cdot \sum_{r} \left(\max w_{rm} + \mathrm{DG}\right)$ means that when r=1 and r=2, the area occupied by the manufacturing unit is the product of the unit length L and the facility with the longest W direction along the line and its minimum spacing.

$\left(\sum_{i=1}^{m} \left(l_i + \mathrm{DG}\right) + \mathrm{DG} \right) \cdot \left(\max\left(w_{rm}\right) + 2\mathrm{DG}\right)$ is the area of the last row.

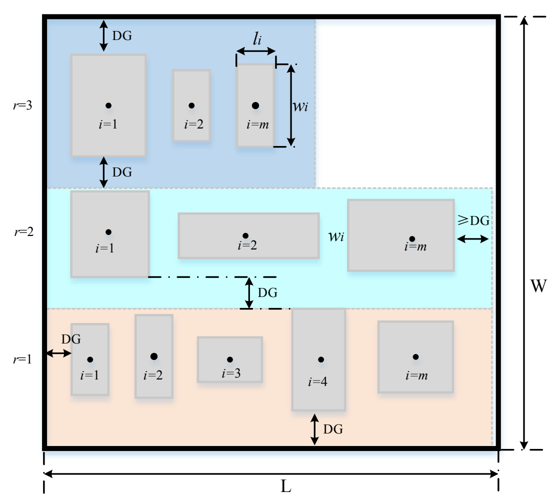

Figure 2: Area objective function builds the graph

3.2 Constraint

Considering the actual situation, the following assumptions are made:
(1) The facilities are arranged in three directions: horizontal, vertical and vertical. The facilities are cuboids;
(2) The central point of the facility lies at the same horizontal line;
(3) The minimum clearance between facilities is required;
(4) The logistics transportation between facilities shall be conducted in a straight line;
(5) The manufacturing unit can accommodate a specified number of facilities.
The constraint conditions are established as follows:

$$\left|x_i - x_j\right| \geq \frac{V_i^{lx} \bullet l_i + V_i^{wx} \bullet w_i + V_i^{hx} \bullet h_i}{2} + \frac{V_j^{lx} \bullet l_j + V_j^{wx} \bullet w_j + V_j^{hx} \bullet h_j}{2} + \mathrm{DG} \tag{3}$$

$$\left|y_i - y_j\right| \geq \frac{V_i^{ly} \bullet l_i + V_i^{wy} \bullet w_i + V_i^{hy} \bullet h_i}{2} + \frac{V_j^{ly} \bullet l_j + V_j^{wy} \bullet w_j + V_j^{hy} \bullet h_j}{2} + \mathrm{DG} \tag{4}$$

$$V_i^{lx} + V_i^{wx} + V_i^{hx} = 1 \tag{5}$$

$$V_j^{lx} + V_j^{wx} + V_j^{hx} = 1 \tag{6}$$

$$V_i^{ly} + V_i^{wy} + V_i^{hy} = 1 \tag{7}$$

$$V_j^{ly} + V_j^{wy} + V_j^{hy} = 1 \tag{8}$$

$$V_i^{lx} + V_i^{ly} = 1 \tag{9}$$

$$V_i^{wx} + V_i^{wy} = 1 \tag{10}$$

$$V_i^{hx} + V_i^{hy} = 1 \tag{11}$$

$$V_j^{lx} + V_j^{ly} = 1 \tag{12}$$

$$V_j^{wx} + V_j^{wy} = 1 \tag{13}$$

$$V_j^{hx} + V_j^{hy} = 1 \tag{14}$$

$$\mathrm{L} \bullet \left(\max w_{rm} + \mathrm{DG}\right) \leq \mathrm{L} \tag{15}$$

Eqs. (3) and (4) respectively indicate that the distance between facilities in the X axis and Y axis must not be less than the minimum distance DG. V_i^{lx}, V_i^{wx} and V_i^{hx} are 0-1 variables, indicating which side of the l, W and h sides of facility I is parallel to X. Also, formula (5)-(8) indicate that only one surface of the facility can coincide with the ground. Formula (9)-(14) show that only one edge of the facility can be parallel to the X-axis. Meanwhile, formula (15) shows that the length of a row cannot be greater than the limit of the manufacturing unit because the plane can accommodate all facilities, and the width direction limit is not required.

4 Problem-solving

The basic idea of NSGA-II is that the initial population with a random size of N is generated. After non-dominant sequencing, the first-generation sub-population is obtained through the selection, crossover and mutation of the genetic algorithm. Secondly, starting from the second generation, the parent population and the child population are combined to make a rapid non-dominant ranking. At the same time, the crowding degree of each individual in the non-dominant layer is calculated. The appropriate individuals are then selected according to the non-dominant relationship and the crowding degree of the individual to form a new parent population. Finally, a new sub-population is generated through the basic operation of the genetic algorithm, and so on, until the condition of the program termination is satisfied.

Although the NSGA-II has a good effect in double-objective optimization and introduces crowding degree to ascertain the diversity of the population, many experiments have proved that the diversity of the population of this algorithm is weakened after several iterations and gradually falls into the local optimal solution. On the basis of the research of the NSGA-II algorithm, this paper improves and optimizes the method of selecting the next generation population. The algorithm flow is illustrated in Fig. 3.

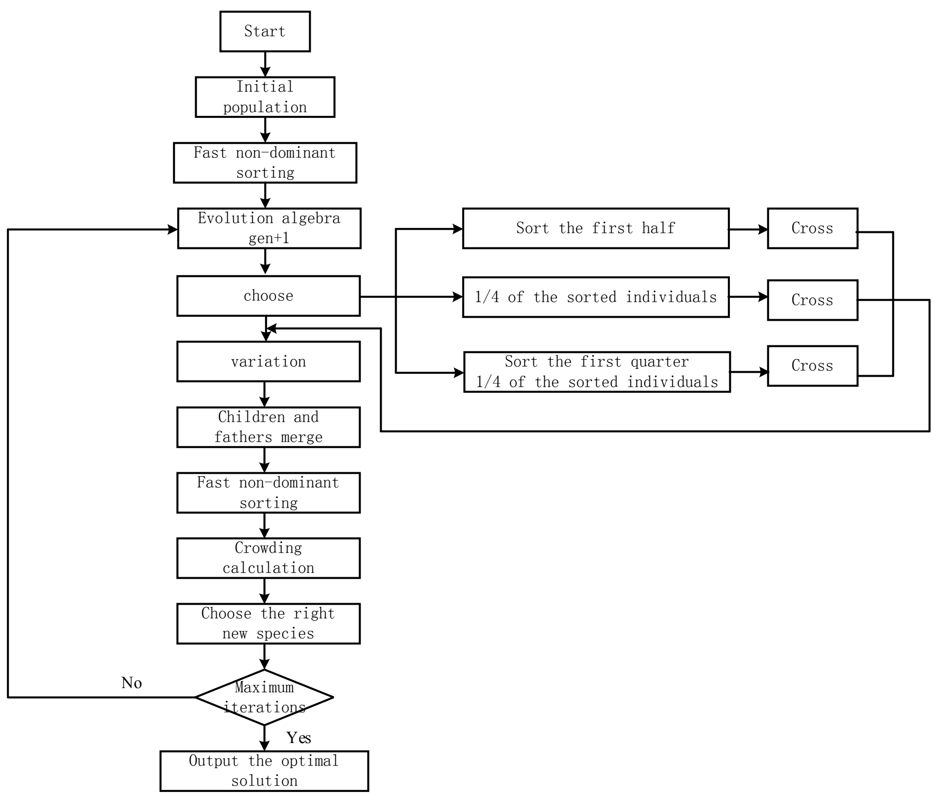

Figure 3: Area objective function builds the graph

(1) Initialize the population, randomly generate population P with size N;
(2) Population P is ranked in non-dominant order;
(3) The operator is selected. 1/2 progeny individuals are obtained by crossing the first 1/2 bodies of father generation non-dominated sorting, 1/4 progeny individuals are obtained by crossing the first 1/4 bodies of father generation non-dominated sorting and 1/4 progeny individuals are obtained by crossing the first 1/4 bodies of father generation non-dominated sorting and the last 1/4 bodies of father generation non-dominated sorting.
(4) A quarter of the individuals are selected to mutate;
(5) The offspring and the parent are merged to obtain 2N population;
(6) In this step, it is called non-dominant sort. The smaller the rank, the better the individual, and the easier it is to be selected;
(7) In this step, it is called crowding calculation. The larger the crowding distance, the easier it is to be selected;
(8) According to Step 6 and Step 7, N individuals are selected as the new generation population.
(9) Determine whether the number of iterations is reached, and if so, output the optimal result; otherwise, repeat Step 3.

5 Simulation analysis

5.1 Original data

The size of a manufacturing workshop is WLWH=[8.0,15.0,6.00]m, while the available height of the workshop is 4.5 m. Also, the minimum spacing of facilities is 2 m and the total number of facilities is 8 pcs. Tab. 1 indicates the production process path and batch processing of the workshop, while Tab. 2 shows the size of facilities.

Table 1: Product processing process path, processing batch, handling batch

Num.	Process path	Processing batch	Handling Batch
1	3,8, 1,5,8	120	10
2	4,7,6,5,2	100	10
3	1,2,8,3,7	180	18
4	3,8,2,1,5	200	10
5	1,3,4,2	140	10
6	1,2,7,8	200	25
7	1,4,2	250	20
8	1,2,5,7,8	300	15
9	1,2,7,3	260	26
10	3 ,8,1,2,5,8	120	10

Table 2: Facility size

Facilities number	Length, Width, Height	Facilities number	Length, Width, Height
1	0.8,0.5,0.8	5	0.8,0.7,0.9
2	1.2,0.6,0.5	6	1.0,0.5,1.0
3	1.0,0.8,1.0	7	0.9,0.5,0.7
4	1.0,0.5,1.0	8	1.0,0.8,0.5

5.2 Simulation analysis

For example, the codes of the three facilities are 1,2,3,0,1,2,0,1. The first 3 bits represent the sequencing of equipment numbers. The middle 3 bits represent one of the three planes of the facility overlapped with the ground. The latter 3 bits represent the edge parallel to the X-axis on the surface overlapped with the ground. MATLAB was adopted as the program development platform with the version number of 2014b. A MATLAB program was written to solve the above mathematical model with NSGA-II and the improved NSGA-II. The population N=100 and the iteration of 1000 generations were carried out. Figure illustrates the transportation process.

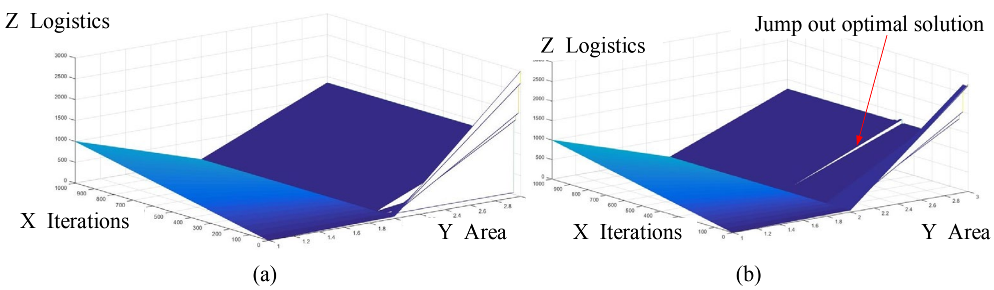

Figure 4: NSGA-II and the improved NSGA-II iterative figure

In Fig. 4, the Z axis represents the material flow, while the Y axis represents the area. Also, the X axis indicates the number of iteration steps. Fig. 4(a) represents the NSGA-II algorithm, while Fig. 4(b) represents the improved NSGA-II. As evident from the iteration diagram of the solving process, the NSGA-II algorithm soon fell into the local satisfactory solution, while the improved NSGA-II jumped out of the local satisfactory solution in about 200 generations (see Fig. 4(b)). Tabs. 3 and 4 indicate partial solutions of NSGA-II and the improved NSGA-II.

Table 3: NSGA-II partial solver

Num	Coding	Area	Logistics
1	5,2,1,7,8,3,4,6,0,2,2,2,2,2,2,0,0,1,1,1,0,1,1,0	41.06	1351.175
2	7,8,3,5,1,2,4,6,2,2,2,0,0,2,2,2,1,1,1,1,0,1,1,1	41.86	1353.775
3	3,8,7,5,2,1,4,6,0,2,2,0,2,2,2,0,0,1,1,0,1,1,1,0	41.06	1457.525
4	2,8,3,5,7,1,4,6,0,2,2,0,0,2,2,0,0,1,1,0,0,1,1,0	41.06	1718.825
5	4,5,6,3,7,2,8,1,1,0,1,1,1,1,1,1,0,1,1,0,0,1,1,1	47.68	2223.775

Table 4: Improved NSGA-II partial solver

Num.	Coding	Area	Logistics
1	3,8,7,1,2,5,6,4,2,2,2,2,2,0,0,0,1,1,0,1,1,0,0,0	41.06	1260.225
2	7,8,3,5,2,1,4,6,2,2,2,0,2,2,2,2,1,1,1,1,1,0,1,1	41.86	1241.6
3	7,8,3,5,2,1,4,6,0,2,0,0,2,0,0,0,0,1,0,0,1,0,0,0	41.06	1279.925
4	3,8,7,1,2,5,6,4,2,2,2,2,2,0,0,0,1,1,0,0,1,1,0,0	41.86	1259.2
5	5,2,1,7,8,3,4,6,0,2,0,2,2,2,2,0,0,1,0,0,0,1,1,0	41.06	1342.575

From Tab. 3 and Tab. 4, it can be seen that the satisfactory solution obtained by NSGA-II is 5, 2, 1, 7, 8, 3, 4, 6, 0, 2, 2, 2, 2, 2, 0, 0, 1, 1, 0, 1, 1, 1, 1, 1, 1, 0, with an area of 41.06 and a logistics volume of 1351.175. The satisfactory solution obtained by improved NSGA-II is 3, 8, 7, 1, 2, 5, 6, 4, 2, 2, 2, 2, 2, 2, 0, 0, 0, 0, 1, 1, 1, 0, 0, 0 with an area of 41.06 and a logistics volume of 1260.225. The satisfactory solution area obtained by the two algorithms is the same. However, the NSGA-II with the improved material flow is superior to NSGA-II. Tab. 5 shows the individual coordinates of satisfactory solutions obtained by improving NSGA-II.

Table 5: Satisfactory solution coordinate of improved NSGA-II

Facilities number	X	Y	Facilities number	X	Y
3	1.7000	1.6000	2	3.4500	3.5500
8	3.6500	1.6000	5	5.3000	3.5500
7	5.3500	1.6000	6	1.7000	5.3500
1	1.6000	3.5500	4	3.9000	5.3500

The individual decoding of the satisfactory solution of improved NSGA-II is arranged as a cell (see Fig. 5).

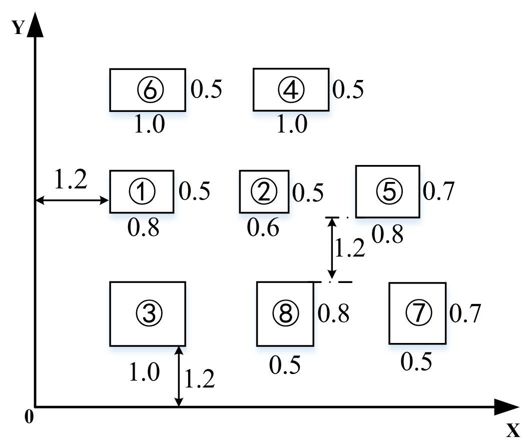

Figure 5: Improved NSGA-II cell manufacturing layout

6 Conclusion

This paper studies the dual-objective problem of the improved NSGA-II algorithm in the layout of manufacturing units. The mathematical model is established by taking into account the area occupied, the minimum objective optimization of the logistics handling capacity and the arrangement order of facilities and the channel constraints. The improved NSGA-II process is designed and the solution of NSGA-II and NSGA-II is improved by simulation with an example. The simulation results show that the improved NSGA-II population has an obvious diversity, and is easier to jump out of the local optimal solution than NSGA-II, thus obtaining a satisfactory manufacturing cell layout scheme. Therefore, it is effective for the improved NSGA-II to solve the problem of manufacturing cell layout.

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