Optimization of Workshop Layout Based on Adaptive Genetic Algorithm

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Abstract. In this paper, the problem of workshop layout optimization based on adaptive genetic algorithm is studied, and a multi-objective mathematical optimization model considering both the total handling cost and the adjacent correlation degree is established. Based on the traditional algorithm, an adaptive genetic algorithm is proposed. According to the fitness of the population, its crossover probability and mutation probability will automatically change to avoid the algorithm falling into local optimum. Finally, taking a production workshop as an example, the traditional genetic algorithm and adaptive genetic algorithm are compared respectively, and it is found that the adaptive genetic algorithm is obviously superior to the traditional genetic algorithm, which proves the feasibility and effectiveness of this method in workshop layout optimization.

Keywords: workshop layout; Adaptive genetic algorithm; multiple target

1 Introduction

With the rapid development of manufacturing industry and the improvement of intelligent level, the optimization of workshop layout has gradually become a key link to improve production efficiency and reduce production costs[1~2]. Workshop layout involves many aspects, such as production equipment, material handling, process flow, etc. Its goal is to achieve efficient cooperative operation of equipment, materials and personnel in the workshop under the premise of meeting production requirements and process constraints.

In recent years, the research on workshop layout optimization mainly focuses on genetic algorithm, simulated annealing algorithm[3] and particle swarm optimization[4]. Wan Jianye and others[5] adopted the traditional SLP method and genetic simulated annealing algorithm respectively, which shows that genetic simulated annealing algorithm is more feasible and reasonable than SLP in workshop layout planning. Wang Junjie et al[6]. established the mathematical model of facility layout optimization of double-decker workshop, and solved the optimization model based on genetic algorithm to get the final layout scheme. Guo Yuanyuan and others[7] combined the particle swarm optimization algorithm with the classical systematic layout design method, and verified

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the optimization performance of particle swarm optimization algorithm in continuous space layout problem through examples.

The purpose of this paper is to study the optimization method of workshop layout based on adaptive genetic algorithm[8], and realize the automatic search and optimization of workshop layout scheme by constructing fitness function and designing genetic operation. Firstly, the problem of workshop layout is modeled and analyzed mathematically, and the objectives and constraints of the problem are defined. Secondly, the appropriate coding method and genetic operation are designed, and then the effectiveness and feasibility of the model are verified by experiments.

2 Problem Description

2.1 Problem Hypothesis

This paper discusses the layout problem of multi-line linear equipment. In order to solve this problem, it is necessary to arrange the equipment reasonably in the workshop[9]. In order to facilitate the study, it is necessary to simplify the workshop layout appropriately, and the following assumptions are made[10].

1)It is assumed that the shape of each work unit in the workshop is rectangular, the length and width are known, and the details of its shape are ignored.

2)It is assumed that the placement direction of each work unit is horizontal and vertical.

3)It is assumed that materials can only be transported horizontally or vertically between work units.

2.2 Objective Function

According to the actual conditions of the enterprise, the appropriate optimization goal should be selected, and besides the total handling cost, the adjacent correlation degree should also be considered. Therefore, this paper establishes an objective function with the minimum handling cost K1 between work units and the maximum adjacent correlation degree K2 as the optimization goal. The total handling cost K1 between work units is:

$$minK1 = \sum_{i=1}^{n}\sum_{j=1}^{n} c_{ij} d_{ij} f_{ij} \tag{1}$$

Where K1 represents the total transportation cost between work units, c_{ij} represents the transportation unit cost between work unit I and work unit J, d_{ij} represents the distance between work unit I and work unit J, f_{ij} represents the logistics volume between work unit I and work unit J, and the function K2 of adjacency degree is:

$$maxK2 = \sum_{i=1}^{n}\sum_{j=1}^{n} a_{ij} e_{ij} \tag{2}$$

Where a_{ij} represents the strength of logistics relationship between work unit I and work unit J, and e_{ij} represents the proximity between work unit I and work unit J.

Merge the above two objective functions into a single objective function model, that is:

$$minR = w_1 u_1 \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} d_{ij} f_{ij} - w_2 u_2 \sum_{i=1}^{n} \sum_{j=1}^{n} a_{ij} e_{ij} \quad (3)$$

$$u_1 = \frac{1}{\sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} d_{max} f_{ij}} \quad (4)$$

$$u_2 = \frac{1}{\sum_{i=1}^{n} \sum_{j=1}^{n} a_{ij}} \quad (5)$$

Among them, w_1 represents the weight of the total transportation cost between work units, w_2 represents the weight of the adjacent correlation degree, and the sum of the two is 1, u_1 and u_2 represent the normalization factor.

In the optimization of workshop layout, the strength of logistics relationship between work units is a key consideration. The strength of logistics relationship mainly involves the flow efficiency and smoothness of materials, semi-finished products and finished products between work units. Optimizing the intensity of logistics relationship between work units can improve production efficiency and realize the improvement of overall operating efficiency. The following is the comparison table of logistics relationship strength between work units [Table 1].

Table 1. Comparison table of logistics relationship strength between work units

Degree	Quantized value
Freeboard	4
Higher	3
Tall	2
Common	1
Negligible	0
Keep away from it	-1

Proximity is determined by the ratio of the distance d_{ij} between work unit I and work unit J and the maximum distance d_{max} between work units, and it is divided into six grades [Table 2], as shown in Table 2 (d_{max} represents the maximum distance between work units, that is, the sum of the length L and the width W of the workshop).

Table 2. Proximity Comparison Table

Range of d_{ij}/d_{max}	e_{ij}
$(0, d_{max}/6)$	1.0
$(d_{max}/6, d_{max}/3)$	0.8
$(d_{max}/3, d_{max}/2)$	0.6
$(d_{max}/2, 2d_{max}/3)$	0.4
$(2d_{max}/3, 5d_{max}/6)$	0.2
$(5d_{max}/6, d_{max})$	0

2.3 Constraints

1)Ensure that there is no overlap between work units.

$$\left|x_i - x_j\right| \geq \frac{l_i + l_j}{2} + q \tag{6}$$

$$\left|y_i - y_j\right| \geq \frac{w_i + w_j}{2} + q \tag{7}$$

Where x_i and y_i represent the abscissa and ordinate of the ith work unit, x_j and y_j represent the abscissa and ordinate of the jth work unit, l_i and w_i represent the length and width of the ith work unit, l_j and w_j represent the length and width of the jth work unit, and Q represents the minimum distance between work units.

2) Ensure that the work units in the same row or column are in the workshop.

$$x_i \leq L - \frac{l_i}{2} - q \tag{8}$$

$$y_i \leq W - \frac{w_i}{2} - q \tag{9}$$

3) Ensure that each work unit keeps a certain distance from the wall.

$$x_i \geq \frac{l_i}{2} + q \tag{10}$$

$$y_i \geq \frac{w_i}{2} + q \tag{11}$$

4) Ensure that each work unit can only appear once.

$$\sum_{i=1}^{n} Z_i = n \tag{12}$$

Where $z_i = 1$=1 indicates that the work unit I appears once.

3 Algorithm Description

3.1 Principle Description

Adaptive genetic algorithm is an improvement of traditional genetic algorithm, and its core idea is to dynamically adjust the key parameters of the algorithm according to the current evolutionary state of population, such as crossover probability and mutation probability. This adaptability makes the algorithm better adapt to different problems and scenarios, and improves the search efficiency and global optimization ability of the algorithm. Adaptive genetic algorithm dynamically adjusts crossover probability and mutation probability by monitoring the evolution state of population in real time, such as population diversity and fitness distribution. For example, when the population diversity is high, the intensity of crossover and mutation operations can be appropriately increased to maintain the population diversity; When the population diversity is low, the intensity of crossover and mutation operations should be reduced to avoid premature convergence of the population. This adaptive mechanism enables the algorithm to maintain efficient search ability in different evolutionary stages. By introducing adaptive mechanism, adaptive genetic algorithm overcomes the limitations of traditional genetic algorithm in parameter setting, and improves the search efficiency and global optimization ability of the algorithm.

3.2 Chromosome Coding

When dealing with the optimization problem of workshop layout in this paper, the real number coding method is selected to code chromosomes, which is very efficient and can simplify the work unit of the workshop. At the same time, the word wrap strategy is adopted to automatically switch to the next line when the work units in the same line are full.

3.3 Fitness Function

In adaptive genetic algorithm, fitness function is a key index to evaluate the merits of individuals, which determines which individuals are more likely to be selected for genetic operation, thus affecting the search direction and efficiency of the algorithm. An effective fitness function should accurately reflect the needs of the problem and guide the algorithm to approach the optimal solution step by step. In this paper, the fitness function is expressed by the reciprocal of the objective function, that is:

$$Y = \frac{1}{R} \tag{13}$$

3.4 Generation of Initial Population

N individuals are randomly generated to form the initial population, but in order to accelerate its convergence speed, the arrangement of the actual work units in the current workshop is adopted as the arrangement number of the first chromosome work unit of the initial population.

3.5 Selection, Crossover and Mutation

When roulette is used for selection operation, the probability of each individual being selected is directly proportional to its fitness value, and the greater the fitness value, the greater the probability of being selected. The crossover operation is carried out by using the partial matching crossover method, which can ensure that the genes in each chromosome only appear once and avoid the occurrence of duplicate genes. The crossover mutation method is used for mutation operation, which can effectively change the gene order of chromosomes, thus producing a better solution.

3.6 Adaptive Crossover and Mutation Strategy

When the fitness of individuals in the population is equal to or close to the maximum fitness, the crossover probability P_c and mutation probability P_m in the adaptive genetic algorithm are equal to or close to zero, which is not conducive to the evolution of the algorithm, resulting in the excellent individuals in the population not changing at the initial stage, thus improving the probability that the overall evolution tends to local optimum. So, we made a change:

$$P_C = \begin{cases} \dfrac{P_{c2} - P_{c1}}{1 + v\dfrac{y_2 - y_a}{y_1 - y_a}} + P_{c1}, y_2 \geq y_a \\ P_{c2} - \dfrac{P_{c1}}{1 + v(y_1 - y_a)}, y_2 < y_a \end{cases} \tag{14}$$

Among them, P_{c1} is the minimum crossover probability in the process of genetic operation, P_{c2} is the maximum crossover probability in the process of genetic operation, y_1 is the maximum fitness value of individuals in the population, y_2 is the larger fitness value of two individuals performing crossover operation, y_a is the average fitness value of individuals in the population, and V is a constant.

$$P_m = \begin{cases} \dfrac{P_{m2}(y_1 - y)}{y_1 - y_a} + P_{m1}, y \geq y_a \\ P_{m2}, y < y_a \end{cases} \tag{15}$$

Among them, P_{m1} is the minimum mutation probability and P_{m2} is the maximum mutation probability in the process of genetic operation.

4 Case Application

The case in this paper comes from a production workshop. The length of the workshop is 320m and the width is 161m m. The size table of work units [Table 3] is shown in Table 3, the corresponding table of adjacency degree between work units[Table 4] is shown in Table 4, the corresponding table of freight volume between work units[Table 5] is shown in Table 5, and the corresponding table of handling cost between work units[Table 6] is shown in Table 6.

Table 3. Work Unit Size Table

Work unit code	Work unit name	length (m)	width (m)
1	Material storage area	180	95
2	Production area 1	115	60

3	maintenance area	28	24
4	Production area 2	45	38
5	Polishing area	30	42
6	Production area 3	23	31
7	Finished Product Area	19	25

Table 4. Correspondence Table of Adjacency Degree between Work Units

Work unit	1	2	3	4	5	6	7
1	0	1.50	1.00	2.25	3.00	0	0.50
2	1.50	0	2.25	3.00	2.75	0.25	0.50
3	1.00	2.25	0	0.50	1.00	0	0.50
4	2.25	3.00	0.50	0	0	2.75	0.50
5	3.00	2.75	1.00	0	0	0.50	0.50
6	0	0.25	0	2.75	0.50	0	0.50
7	0.50	0.50	0.50	0.50	0.50	0.50	0

Table 5. Corresponding Table of Freight Volume between Work Units (ton/day)

Work unit	1	2	3	4	5	6	7
1	0	0	150	4800	0	360	0
2	0	0	120	4250	270	0	0
3	150	120	0	0	0	0	0
4	4800	4250	0	0	0	0	0
5	0	270	0	0	0	0	0
6	2800	0	0	0	0	0	0
7	0	0	0	0	0	0	0

Table 6. Corresponding Table of Handling Costs between Work Units (RMB/ton/meter)

Work unit	1	2	3	4	5	6	7
1	0	0.06	0.09	0	0.05	0.09	0
2	0.06	0	0.07	0.05	0.06	0.05	0
3	0.09	0.07	0	0	0.07	0.05	0
4	0	0.05	0	0	0	0	0
5	0.05	0.06	0.07	0	0	0	0
6	0.09	0.05	0.05	0	0	0	0
7	0	0	0	0	0	0	0

w_1 and w_2 were set to 0.6 and 0.4, respectively. Based on the above data, the initial population was set to 100 and the number of iterations was set to 400. For adaptive genetic algorithm, $P_{c1} = 0.8$, $P_{c2} = 0.5$, $P_{m1} = 0.08$ and $P_{m2} = 0.01$, while for traditional genetic algorithm, $P_c = 0.5$ and $P_m = 0.08$. The running results**Table 7** are shown in Table 7.

Table 7. Comparison of results

	Overall arrangement	W_1(yuan)	W_2	R	Cost saving(%)	Optimal correlation degree (%)
Original scheme	[7,4,1,5,3,2,6]	455724.6	39.8	0.02998		
GA	[2,3,4,1,7,5,6]	394283.4	40.5	0.00972	13.48	1.76
AGA	[4,2,7,6,3,5,1]	295724.1	43.1	-0.07132	35.11	8.29

Because the length and width of the workshop are limited, the first row of work units in the original scheme are 7, 4, 1 and 5, and the second row is 3, 2 and 6. The first row of work units in the traditional genetic algorithm scheme is 2, 3, 4 and 1, and the second row is 7, 5 and 6. The first row of work units in the adaptive genetic algorithm scheme is 4, 2, 7 and 6.

As can be seen from the table, compared with the original scheme, the traditional genetic algorithm scheme saves the total handling cost by 13.48% and optimizes the adjacent correlation degree by 1.76%. Compared with the original scheme, the adaptive genetic algorithm scheme saves the total handling cost by 35.11% and optimizes the adjacency degree by 8.29%. This shows that the adaptive genetic algorithm scheme is superior to the traditional genetic algorithm scheme in the optimization of the original scheme, and the optimal solution is [4,2,7,6,3,5,1].

5 Conclusion

Aiming at the optimization problem of workshop layout, this paper establishes an objective function with the optimization goal of minimizing the total transportation cost between work units and maximizing the adjacent correlation degree, and uses adaptive genetic algorithm to solve the problem. Compared with traditional genetic algorithm, this method is more effective. The results show that the optimization result of adaptive genetic algorithm is obviously better than that of traditional genetic algorithm, which verifies the feasibility and effectiveness of adaptive genetic algorithm and provides reference for studying more complicated workshop layout problems in the future.

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