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Design and Simulation of Workshop Layout Reconstruction Based on Flexsim and Multi-objective Genetic Algorithm

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***Abstract*—Research the problem of dynamic layout of equipment with multiple constraints in reconfigurable workshop. The logistics transport and restructuring of the layout cost as an optimization target. Transforming the dynamic layout problem into a static layout problem in single production cycle. Utilizing the theory of virtual manufacturing and computer simulation to construct a multi - constrained optimization model for dynamic layout of multiple devices with different equipments' acreage. Adopting new genetic algorithm with multi - fitness function and random competition roulette selection strategy to this NP problem that overcomed the shortcomings of a single fitness function that does not guarantee optimal optimization and can not provide multiple strategies for production risk decisions. This approach improved the convergence rate and obtained varieties of feasible solutions from multi-angle model. The effectiveness of the method is verified by examples and Flexsim simulation.**

Keywords-reconfigurable workshop; equipment dynamic layout; virtual manufacturing; multi - fitness construction genetic algorithm; random competition roulette; flexsim

I. INTRODUCTION

With the rise of mass customization production model and the maturity and development of computer integrated manufacturing network, manufacturing enterprises also will be miniaturized and flexible, and the workshop-level production system has also undergone profound changes. The design of the workshop processing system is also pre-operational and intelligent, so the layout of the reconfigurable workshop under the virtual manufacturing framework becomes the research focus of the manufacturing industry.

II. RECONFIGURABLE WORKSHOP LAYOUT

A. *Reconfigurable Layout*

Reconfigurable workshop floor layout is a branch concept of reconfigurable manufacturing. Reconfigurable workshop layout refers to the processing plant can be based on the production plan flexible and efficient combination of the processing equipment layout. When the new product and processing technology put into operation, it can according to the characteristics of production tasks, in the original layout of the environment efficient, low-cost update shop layout to meet the changing production needs. Reconfigurable shop layout should adhere to the following principles: process, economy, sustainability, safety.

B. *Workshop Restructuring Layout Problem Constraints*

The workshop layout problem has always been a very complicated problem. The constraints of the general conditions are: the layout of the equipment placed space; the layout of the equipment; equipment between the distance constraints; product processing process sequence; large equipment placed immovable restrictions and so on. At the same time, the workshop reconfigurable layout also needs to take into account the cost of the layout and the cost of the equipment location adjustment, which makes the reconstruction cost as small as possible. At the same time, the new layout should also make the new layout of the logistics cost less than the original logistics costs.

III. DESIGN OF RECONFIGURABLE WORKSHOP LAYOUT MODEL

A. *Description of the Relevant Parameters*

Combined with the reconfigurable workshop layout problem model design solution and the constraints, the following parameters are described. There are *n* device units in the layout space of the workshop. The relevant parameters are as follows:

L is the available space length;

H is the available space width;

M for the total equipment set, $M = \{m_1, m_2, \cdots, m_n\}$;

r_{ij} is the handling fee per unit of material per unit distance between device i and device j;

R_{ij} is the matrix of transport expense;

$$R_{ij} = \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{n1} & \cdots & r_{nn} \end{bmatrix}$$

s_{ij} is the transport frequency between device i and device j;

S_{ij} is the transport frequency matrix between devices;

$$S_{ij} = \begin{bmatrix} s_{11} & \cdots & s_{1n} \\ \vdots & \ddots & \vdots \\ s_{n1} & \cdots & s_{nn} \end{bmatrix}$$

h_{ij} is the minimum lateral distance requirement between device i and device j;

H_{ij} is the minimum lateral distance requirement matrix between devices;

$$H_{ij} = \begin{bmatrix} h_{11} & \cdots & h_{1n} \\ \vdots & \ddots & \vdots \\ h_{n1} & \cdots & h_{nn} \end{bmatrix}$$

H_{i0} is the minimum lateral spacing limit for device i and shop floor boundaries;

(x_i, y_i) is the coordinates of device i;

D_{ij} is the distance between the equipments, this paper will define two models of two logistics distance, as shown in figure 1:

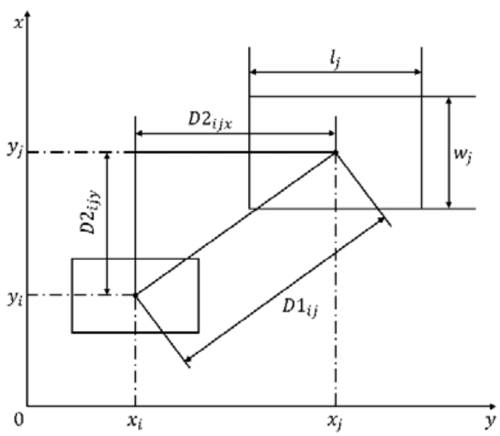

FIGURE I. RECTANGULAR AND LINEAR LOGISTICS DISTANCE

Rectangle distance method:

$$D_{ij1} = |x_i - x_j| + |y_i - y_j| \tag{1}$$

Straight line distance method:

$$D_{ij2} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \tag{2}$$

D_{ij} is the transport distance matrix between devices:

$$D_{ij} = \begin{bmatrix} d_{11} & \cdots & d_{1n} \\ \vdots & \ddots & \vdots \\ d_{n1} & \cdots & d_{nn} \end{bmatrix}$$

l_i is the length of device i;

w_i is the width of device i;

The above parameters are shown in the figure II.

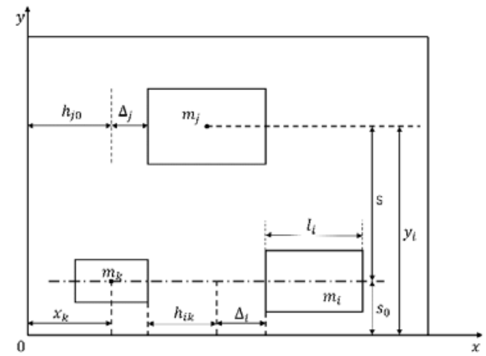

FIGURE II. DEVICE LAYOUT PARAMETERS, REFERENCE LINES, AND DECISION VARIABLES

B. *Mathematical Model Design of Reconfigurable Workshop Layout*

1) Minimum logistics cost target: Taking the cost of logistics between each device as main optimization function, the derivation process is as follows:

$$C1_{min}(R,S,D) = min\sum_{i=1}^{n}\sum_{j=1}^{n} R_{ij}S_{ij}D_{ij}$$

$$= min\sum_{i=1}^{n}\sum_{j=1}^{n} R_{ij}S_{ij}\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \tag{3}$$

The objective function of the total logistics cost is:

$$min\sum_{i=1}^{n}\sum_{j=1}^{n} R_{ij}S_{ij}\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$$

$$C2_{min}(R,S,D) = min\sum_{i=1}^{n}\sum_{j=1}^{n} R_{ij}S_{ij}(|x_i - x_j| + |y_i - y_j|) \tag{4}$$

2) Reconfigurable Constraints: For the reconfigurable equipment layout workshop, the initial placement of the equipment can be carried out twice or even multiple re-handling, is an important indicator of reconfigurability.

Coordinates and boundary constraints:

For $i, j \in \{1,2,\cdots,n\}$

$$|x_i - x_j| \geq \frac{l_i + l_j}{2} + hx_{ij} \tag{5}$$

$$|y_i - y_j| \geq \frac{w_i + w_j}{2} + hy_{ij} \tag{6}$$

The range Δ_i is the distance between the device i and the device i-1, that is, the residual distance outside the minimum distance requirement h_{ij} of the device, which is in the range [0, 1.7]; Set the first line of equipment and workshop under the border distance s_0, the establishment of the following formula:

Device i abscissa:

$$x_i = x_k + \frac{(l_i+l_k)}{2} + h_{ik} + \Delta_i \tag{7}$$

$$= h_{k0} + \Delta_k + \frac{(l_i + 2l_k)}{2} + h_{ik} + \Delta_i$$

Equipment i Vertical:

$$y_i = (k-1)s + s_0 \tag{8}$$

Device independent constraint

In order to meet the requirements of the device does not coincide, the abscissa and the ordinate of the constraints:

$$|x_i - x_j| \geq \left[\frac{(l_i+l_j)}{2} + h_{ij}\right] z_{ik} z_{jk} \tag{9}$$

$$i, j = 1,2,\cdots,n$$

$$z_{ik} = \begin{cases} 1, \text{device } i \text{ in row k} \\ 0, \quad \text{other} \end{cases} \quad i = 1,2,\cdots,n; k = 1,2,\cdots,m$$

At the same time, a device can only be placed once:

$$\sum_{k=1}^{m} z_{ik} = 1, i = 1,2,\cdots,n \; x_i, y_i \geq 0,$$

$$\Delta_i \geq 0, \qquad i = 1,2,\cdots,n$$

IV. Implementation of Layout Algorithm Based on Genetic Algorithm

Encoding, encoding using the device number and equipment net spacing mixed real number coding:

$$[\{m_1, m_2, \cdots, m_n\}, \{\Delta_1, \Delta_2, \cdots, \Delta_n\}]$$

m_i represents the device number; Δ_i represents the net spacing.

Randomly generate the initial population.

Create a penalty function P_k:

$$P_k = \begin{cases} 0, s_0 + (m-1)s \leq H \\ T, \qquad \text{other} \end{cases}$$

H is the maximum width of the workshop; P_k is the ordinate beyond the penalty term; T is a positive and large value of the penalty value, according to different circumstances generally take 500 ~ 10000.

Fitness function, according to two definitions for the physical distance can be identified two fitness functions FitnessfuncA and FitnessfuncB.

Center point straight-line distance fitness function:

$$FitnessfuncA = 1/(C1_{min} + P_k) =$$

$$1\Bigg/\left(min \sum_{i=1}^{n}\sum_{j=1}^{n} R_{ij} S_{ij} \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} + P_k\right) \tag{10}$$

Rectangular distance fitness function:

$$FitnessfuncB = 1/(C2_{min} + P_k) =$$

$$1\Bigg/\left(min \sum_{i=1}^{n}\sum_{j=1}^{n} R_{ij} S_{ij} \left(|x_i - x_j| + |y_i - y_j|\right) + P_k\right) \tag{11}$$

Selection using the Stochastic Tournament-Roulette Wheel Selection. This is a putative random sampling method. This essay adds random competition operation into standard selection, that is, each time the use of roulette operation when the selection of a pair of individuals, so that the two individuals compete alone, leaving the high fitness of individuals, so the cycle, until the election full.

Crossover, due to the use of two sets of data encoding, so the use Part-Mapping Crossover on the device serial number chromosome cross; Arithmetic cross is used to deal with net spacing chromosomes.

Part of the mapping cross, randomly selected two cross points, the two points need to cross the part of the chromosome one by one. Replacing the duplicate symbols at the same time.

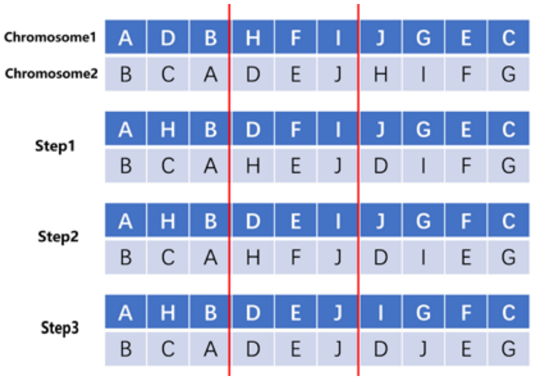

FIGURE III. PMC CROSS GRAPH

Assuming that two individuals X_A', X_B' are subjected to an arithmetic cross, the new individual is:

$$\begin{cases} X_A^{t+1} = aX_B^t + (1-a)X_A^t \\ X_B^{t+1} = aX_A^t + (1-a)X_B^t \end{cases}$$

Since the serial number of the device is encoded as an integer, only the net spacing of the device is mutated. The net spacing chromosome is:

$$[\cdots, \{\Delta_1, \Delta_2, \cdots, \Delta_i, \cdots, \Delta_n\}]$$

V. CALCULATION EXAMPLES STUDY

A. *Standard Calculation Example*

On the basis of a series of experiments, the parameters of the algorithm are set as follows: population number nchr = 50, genetic algebra G = 400, crossover probability pc = 0.65, mutation probability pm = 0.1, large penalty value T = 1000, r = 12.

In a 11m long, 9m wide workshop to set up 12 sets of equipment, device size, R_{ij}, S_{ij}, H_{ij} and H_{i0} are given.

TABLE I. DEVICE SIZE

Device1	Device2	Device3	Device4	Device5	Device6
0.5*0.4	1.7*0.8	0.8*0.8	0.7*0.7	1*0.8	0.9*0.4
Device7	**Device8**	**Device9**	**Device10**	**Device11**	**Device12**
0.8*0.8	1.2*1	0.5*0.8	1.4*0.8	1.2*0.6	1.4*0.8

In order to shorten the optimization process, a set of initial feasible solutions are obtained with SLP [2 8 5 4 11 1 7 3 12 9 10 6] to replace the initial solution.

Optimize this example 15 times and find the best result. The optimal chromosome of the rectangular solution is [(5 12 1 4 11 2 8 10 3 6 9 7), (0.2975 0.0994 0.0324 0.6937 0.1755 0.0449 0.0743 0.8577 0.0948 0.1176 0.1234 0.0673)], the algebra of the optimal solution is 187 generation, the optimal solution is 3427.

Similarly, the optimal chromosome of the straight-line distance solution is [(5 4 2 6 11 9 1 8 7 10 3 12), (0.1354 0.2386 0.2521 0.2586 0.9279 0.1466 0.1268 0.1644 0.0221 0.0535 0.0060 0.0165)], the algebra of the optimal solution is 127 generation, the optimal solution is 2840.

It follows that the straight-line distance method can go beyond the general rectangular distance method in terms of convergence speed and accuracy.

B. *Example Calculation and Flexsim Simulation*

A factory will establish a new manual operation of the assembly plant, empty space size is 25m × 15m, the need for nine processing units for the layout. Population number nchr = 50, genetic algebra G = 400, crossover probability pc = 0.65, mutation probability pm = 0.1, large penalty value T = 5000, variation interval r = 9. Device line spacing of 4m; line 1 equipment ordinate 2.5.

Calculating the example and the resulting solution is as follows: [1x4 double] [1x4 double] [3]; [5 2 1 9 4 6 7 8 3]; The device coordinates are as follows: (9.9,2.5) (5.7,2.5) (2.9,10.5) (2.5,6.5) (1.4,2.5) (7.7,6.5) (12.7,6.5) (16.8,6.5) (16.1,2.5). The evolution of the target values and genetic algebra is shown in the figure:

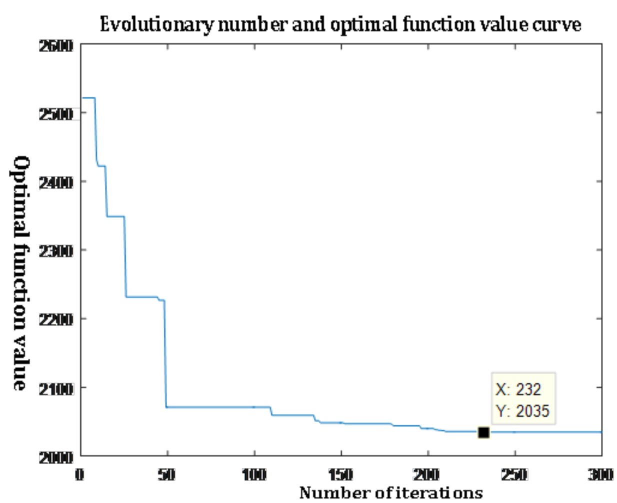

FIGURE IV. CONVERGENCE ITERATIVE GRAPH

After determining the coordinates of the device, use Flexsim to simulate the obtained data and get the simulated three-dimensional layout. The effectiveness of the method is further verified by simulation. FlexSim simulation results are shown below:

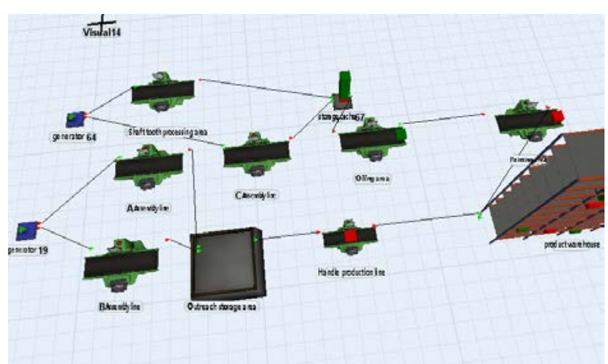

FIGURE V. FLEXSIM LAYOUT SIMULATION

VI. CONCLUSION

Using the dual fitness function of genetic algorithm, the choice of two logistics distance can not only bring faster optimization speed, while two different orientation of the decision-making program for enterprise decision makers to bring diversity.

Using the large number of punctuation values and automatic line breaks strategy; cleverly meet the equipment for the size of the site length and width of the two-dimensional constraints.

Improved stochastic tournament-roulette wheel selection select a pair of individuals to compete separately and then put into the mating pool. Reduce the error to ensure a high degree of fitness of the individual selected rate and improve the accuracy of the algorithm.

Based on virtual manufacturing and computer integrated manufacturing principles. The device is pre-arranged using a computer algorithm. And then use Flexsim software to simulate the results of the layout, not only to verify the results of genetic algorithms, but also makes the simulation results more intuitive for future adjustments.

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