Research on optimization method of motor manufacturing layout based on genetic algorithm

Shuhai Fan\textsuperscript{1,2}, Qian Zhang\textsuperscript{1,2}, Jiaqing Tao\textsuperscript{1}, Qiyu Yang\textsuperscript{1} and Ning Ling\textsuperscript{1,3}

\textsuperscript{1}Nanjing Tech University, Nanjing 210009, China
\textsuperscript{2}MIT Quality Information Program “Data Quality & Info Security” Lab, Cambridge, MA, USA
\textsuperscript{3}E-mail: fan@njtech.edu.cn

Abstract. The current layout of the motor manufacturing workshop lacks flexibility, which leads to large logistics flow between some operation units, long logistics transportation path and large area occupied by semi-finished products inventory. Now, the motor manufacturing workshop matching mathematical model with the minimum material handling amount and the maximum tightness between each operating unit is established, and the mathematical model of motor manufacturing workshop layout optimization is solved by Matlab. In the solution step of the algorithm, the preliminary optimal layout of the motor workshop obtained by the system setting and arrangement method is combined with the randomly selected individuals to generate the initial population. Through a series of genetic operations and continuous iterative process, the final optimal layout scheme is obtained. Finally, it is verified that the improved genetic algorithm has certain research significance and application prospect for the layout optimization of motor manufacturing workshop.

1. Introduction
At present, our country's motor parts manufacturing is in the immature stage of development. Relying on traditional experience to carry out the layout of the workshop and equipment will lack flexibility. We have not yet realized the importance of using standardized processes or methods to plan the layout of the workshop, nor have we considered the impact of the layout of the workshop on production efficiency, which ultimately resulted in the waste of various resources in production. On the contrary, a reasonable workshop layout can reduce logistics handling costs and labor intensity of workers, shorten the processing cycle, and make the processing flow smoother [1-3]. Reasonable and correct regional facility planning of the motor manufacturing workshop [4-5] is the key to the scientific management of the logistics system of the motor manufacturing workshop. Therefore, it is very important to study the layout of the production workshop facilities of manufacturing enterprises.

There have been many studies on the layout of manufacturing facilities. Muther [6] first proposed the systematic layout planning method (SLP), which opened a new chapter in facility layout. Chew [7] introduced some high-level language programming in computer technology into layout design and optimization problems, forming a computer-aided facilities designs (CAFD). The effective use of computers greatly reduces the workload of facility planning, makes layout easier, and saves a lot of manpower and financial costs to a certain extent. With the development of information technology, the proposal of intelligent algorithms promotes the layout planning. Zouei [8] used heuristic algorithms based on genetic algorithms(GA) to optimize the layout of third-party logistics companies’ integrated...
facilities, and built a dynamic programming model for them; Teng [9] used the improved GA to study the layout of multi-level facilities on the factory floor, using Dijkstra algorithm to calculate the shortest distance between workshop units; Huang [10] has applied the SLP method to the retail supermarket service system, and designed the overall layout according to the passenger flow of the supermarket and the characteristics of various commodities in the supermarket; Fan [11] applied the system layout design method to the grain logistics center, and planned the layout of its logistics center to reduce logistics.

From the review of the above-mentioned literature, it is found that there are not many papers that combine the SLP method with the genetic algorithm for research, and most of them are single-objective when establishing the objective function for the layout. Therefore, this paper will use SLP and GA to combine to solve the motor manufacturing workshop layout problem; and then propose a comprehensive logistics handling capacity of the smallest and the greatest degree of closeness between the operation unit multi-objective function model. We finally achieved the goal of reasonable layout of the motor workshop.

2. The mathematical model of the layout of operation units in the motor shop

Genetic algorithms cannot be directly applied to solve practical problems in facility planning. It is just a way to optimize the problem [12]. To use it, knowledge in the field of mathematics is required to model the problem of facility planning, and then to quantify the problem of facility layout by establishing a matching mathematical model.

2.1. Assumptions of mathematical models

The research object of this paper is the plane layout of the motor workshop of company G based on the actual situation of the enterprise and the relevant literature, four assumptions are set. The details are as follows: (a) all operation units in the workshop are rectangular with known side lengths; (b) workshop work units are arranged in multi-line work units; (c) the actual distance between workshop units is the sum of the horizontal distance and the vertical distance of the two units. (d) the arrangement form of workshop work units is consistent with the direction from left to right and from bottom to top while keeping parallel with the horizontal axis. The area arranged in the workshop is rectangular. According to the production requirements, we divide the workshop into 18 work units and each work unit is also a rectangle, the area of the work unit m down into \( S_m \) \((x_m, y_m)\) \((x_n, y_n)\) are the coordinates of the job unit m, n, that is the center of the rectangle. The layout model of the specific workshop operation unit is shown in Figure 1 below.

![Figure 1. Schematic diagram of layout model of operation unit in motor workshop.](image)

Where: \( L_m \) and \( L_n \) respectively represent the length of operation unit m and n; \( W_m \) and \( W_n \) respectively represent the width of operation unit m and n; \( \Delta x_{mn} \) represents the net spacing between the unit m and n; \( x_m \) and \( y_m \) respectively represent the horizontal and vertical distance from the operation unit m to the X-axis and the Y-axis.
2.2. The establishment of the objective function

Suppose that the work units $m$ and $n$ are the two work units of the layout plan A of the motor workshop facilities. $f_{mn}$ is used to represent the logistics matrix between the operation units $m$ and $n$ ($m, n=1,2,...t$). The logistics distance matrix between the operation unit $m$ and $n$ is $d_{mn}$ ($m, n=1,2,...t$). The matrix $f$ and $d$ of scheme A can be obtained as follows.

$$
\begin{align*}
  f &= \begin{bmatrix}
    f_{11} & f_{12} & \cdots & f_{1t} \\
    f_{21} & f_{22} & \cdots & f_{2t} \\
    \vdots & \vdots & \ddots & \vdots \\
    f_{t1} & f_{t2} & \cdots & f_{tt}
  \end{bmatrix}, \\
  d &= \begin{bmatrix}
    d_{11} & d_{12} & \cdots & d_{1t} \\
    d_{21} & d_{22} & \cdots & d_{2t} \\
    \vdots & \vdots & \ddots & \vdots \\
    d_{t1} & d_{t2} & \cdots & d_{tt}
  \end{bmatrix}
\end{align*}
$$

Therefore, the total material handling cost of each operation unit in the workshop can be obtained:

$$Z_1 = \sum_{m=1}^{t} \sum_{n=1}^{t} C_{m}f_{mn}d_{mn}$$

Where, the $C_{mn}$ represents the actual logistics transportation cost required per unit distance.

Then, considering the objective function of the non-logistics relationship of each operation unit, the value of the sum of the closeness between the job units, namely $z_2$, can be obtained as:

$$Z_2 = \sum_{m=1}^{t} \sum_{n=1}^{t} T_{mn}b_{mn}$$

Where, $T_{mn}$ represents the close relationship between the operation unit $m$ and $n$ under the influence of non-logistics related factors; $b_{mn}$ represents the correlation factor between the degree of mutual affinity between operation units $m$ and $n$ and the distance between operation units under the influence of non-logistics related factors.

Combining with the knowledge of GA and the actual company’s demand, we set the two basic objectives: the smallest logistics handling cost and the greatest degree of closeness of each operation unit in the workshop. Finally, the mathematical model is as follows:

$$\begin{align*}
  \text{min} z_1 &= \sum_{m=1}^{t} \sum_{n=1}^{t} C_{m}f_{mn}d_{mn} \\
  \text{max} z_2 &= \sum_{m=1}^{t} \sum_{n=1}^{t} T_{mn}b_{mn}
\end{align*}$$

When materials in the workshop are transported between work units, they generally move in a horizontal or vertical direction. $d_{mn}$ can be used to represent the logistics distance between work units $m$ and $n$: $d_{mn} = |x_m - x_o| + |y_m - y_o|$. Since the mathematical model has two objective functions, they are combined to a certain extent and then regarded as a single objective problem to facilitate the solution. Since these two parameters play inconsistent roles in the facility layout of the workshop, the above two objective functions $z_1$ and $z_2$ are respectively given certain weighted values of $w_1$ and $w_2$ ($w_1+w_2=1$), thus changing the importance of objective functions $z_1$ and $z_2$. Therefore, the expression of the single objective function can be derived as follows.

$$\text{min}Z = \omega_1 \sum_{m=1}^{t} \sum_{n=1}^{t} C_{m}f_{mn}d_{mn} + \omega_2 \sum_{m=1}^{t} \sum_{n=1}^{t} T_{mn}b_{mn}$$

Considering the different criterion of the target functions $z_1$ and $z_2$, these two functions are standardized. The specific expressions are as follows:

$$Z' = \frac{\sum_{m=1}^{t} \sum_{n=1}^{t} C_{m}f_{mn}d_{mn}}{\sum_{m=1}^{t} \sum_{n=1}^{t} C_{m}f_{mn}d_{\max}}$$
2.3. Constraints
The layout planning and design of the motor workshop is to optimize the design of the actual plant, so it is necessary to consider the constraints and limitations of various conditions. The main constraints of the layout planning are summarized as follows:

\[
\sum_{m=1}^{l} \sum_{n=1}^{l} T_{mn}D_{mn} = \sum_{m=1}^{l} \sum_{n=1}^{l} T_{mn} \neq 1 
\]

(7)

2.3. Constraints
The layout planning and design of the motor workshop is to optimize the design of the actual plant, so it is necessary to consider the constraints and limitations of various conditions. The main constraints of the layout planning are summarized as follows:

\[
\begin{align*}
|x_m - x_n| &= \frac{L_m + L_n}{2} + \Delta x_{mn} \\
y_m - y_n &= \frac{W_m + W_n}{2} + \Delta y_{mn} \\
|x_m - x_n| &= \frac{L_m + L_n}{2} \leq L \\
y_m - y_n &= \frac{W_m + W_n}{2} \leq W 
\end{align*}
\]

(8)

(9)

Where, \(L\) and \(W\) represent the length and width of the actual planning area of the motor workshop; \(L_m, W_m\) represent the length and width of workshop operation unit \(m\), respectively; \(L_n, W_n\) represent the length and width of workshop operation unit \(n\), respectively; \(\Delta x_{mn}\) represents the distance on the X-axis between the work unit \(m\) and \(n\); \(\Delta y_{mn}\) represents the distance on the Y-axis between the work unit \(m\) and \(n\).

3. Combination of SLP and genetic algorithm
SLP is a commonly used method for workshop layout, and this method has strong logic. According to the five basic elements of \(P(\)Production\), \(Q(\)Quantity\), \(R(\)Route\), \(S(\)Service\) and \(T(\)Time\), we can analyze the logistics intensity and non-logistics intensity between operation units, and draw the logistics-related tables and non-logistics-related tables between operation units. Then we can confirm the relative positional relationship between the work units [13-14]. But the traditional SLP method also has shortcomings. The designer will give the operation unit different non-logistics intensity based on subjective judgment. The weight of logistics relationship and non-logistics relationship is also affected by work experience and requires constant adjustment by designers. Therefore, the position relationship of the work unit analyzed by the SLP method may not be the optimal solution. The genetic algorithm obtains excellent offspring through continuous crossover and mutation. However, genetic algorithms are often computationally intensive. So the optimal solution can be obtained through computer-aided software. This article draws on the advantages of SLP and genetic algorithm, and combines SLP and GA. The method flow is shown in the Figure 2.

Figure 2. GA-SLP method flow.
3.1. Encoding
Applying the idea of GA to the problem of workshop layout is to use various possible layout solutions as chromosomes to form a population, and each work unit is regarded as a gene on the chromosome, arranged in different ways to form different chromosomes. These chromosomes face the "survival of the fittest" environment, only the best individuals will be retained [15]. This article adopts a left-to-right, bottom-up arrangement, coded by the number of the work unit and the clear distance between the work units [16]. \( [m_1, m_2, m_3, \ldots, m_n; \triangle_1, \triangle_2, \triangle_3, \ldots, \triangle_n] \). \( m_i \) represents the device number; \( \triangle_i \) represents the net spacing.

3.2. Initial population
The initial population of the genetic algorithm is generally randomly generated [17], so the quality of the population cannot be guaranteed. And the number of iterations to find the optimal solution is increased. In this paper, the better solution calculated by SLP is used as one of the individuals in the initial population, and the other individuals are randomly generated. There are 18 working units in the motor workshop, and the initial population size is 50.

3.3. Fitness calculation
The fitness function reflects the pros and cons of individuals in the population, and is the basis for judging "survival of the fittest" [18]. The fitness function is generally related to the objective function. The objective function of this article is the smallest sum of logistics cost and the closeness of each unit of work. Therefore, the larger the individual objective function to be solved, the easier it is to be eliminated, otherwise, it will be retained. The fitness function \( Eval(v_k) \) of the k-th chromosome in the population is:

\[
Eval(v_k) = \frac{1}{F_k}
\]

Where, \( v_k \) is the k-th chromosome; \( F_k \) is the objective function.

3.4. Strategic choice
Selection is to select part of chromosomes for genetic manipulation. This article uses roulette as a selection strategy. This method is related to the fitness of chromosomes. The greater the fitness, the greater the probability of being selected. The probability \( p_i \) of chromosome i being selected is:

\[
p_i = \frac{Eval(v_i)}{\sum_{i=1}^{N}(Eval(v_i))}
\]

3.5. Crossover and mutation
Crossover is the process of selecting two chromosomes in the population and generating new individuals by exchanging the gene fragments on the chromosomes. Generally, the crossover probability in the iterative process is 0.5 to 0.9, and the crossover probability selected in this paper is 0.9. This article selects a single break-point for crossover calculation, the specific calculation process is as follows. The mutation operation is to prevent the population's solution from falling into the local optimal value, and to continue to search for feasible solutions in the neighborhood. Since mutation will change the new chromosome after crossover, the appropriate mutation probability will make the individual develop in a better direction. Therefore, the mutation probability selected in this article is 0.1.

Input: \( P_c \), parent generation \( P_{ot=1,2,3,\ldots,\text{pop}_\text{size}} \)
begin
for \( t \leftarrow 1 \) to \( \lfloor \text{pop}\_\text{size}/2 \rfloor \) do
if \( P_i \geq \text{rand} [0,1] \) then
\( m \leftarrow 0; \)
\( n \leftarrow 0; \)
repeat
m ← rand[1, pop_size];
n ← rand[1, pop_size];
until(m/n)
s ← rand[1, L-1]; // s: breakpoint location; L: chromosome length
Cm ← Pm[1:s-1]
Cn ← Pn[1:s-1]
end
end
Output the offspring Ci
end

4. Application of genetic algorithm in layout planning of motor workshop

4.1. Computing data consolidation
The specific data of the motor workshop are as follows: the horizontal distance of the workshop is 260m, and the vertical distance is 190m. This workshop needs to arrange 18 working units. The distance w0 between the center line of the first line of work unit and the lower boundary of the workshop is set as 10m; The row spacing l between the work units is set at 10m. Through genetic algorithm operation and using Matlab to run the programming data model, we finally get the area DeviceSize of each job unit, the minimum spacing between job units requires sib (m), and the minimum spacing between job units and left and right boundaries requires si0 (m) and si0 (m). The specific data are shown below:

![Scheme of layout planning of motor workshop](image)

4.2. MATLAB to solve the model results
Matlab is used to write the genetic algorithm optimization program for the layout of the motor manufacturing workshop, and the above data are input one generation at a time to solve the layout optimization scheme of the workshop. The optimal solution began to converge in the 160th generation, and the specific convergence figure is shown in Figure 3 below. Finally, the best chromosome is obtained, namely, the optimal layout among the operation units of the motor workshop is:\{18,17,8,13,16,15,14,6,10,5,9,7,2,11,3,4,12,1\}; and the net spacing between adjacent operation units is:\{10,10,10,0,10,0,10,10,10,10,10,10,10,10,10,10,10\}; the width of the channel is 10 m and the coordinates of each operation unit are shown in Table 1:
study the relationship development of flexibility and quickly responds to changes in the market environment. By combining SLP and GA, we can make full use of the advantages of both, comprehensively consider logistics factors and non-logistics factors in the layout. Through case analysis, it is proved that the improved algorithm has indeed improved the economic benefits of the enterprise, and also provides reference for the layout planning of other enterprises.

### Table 1. Coordinate conditions of each operation unit after optimization.

| Number | Name of operation unit        | Covered area (m²) | Coordinate point (m,m) |
|--------|------------------------------|-------------------|------------------------|
| 1      | Raw materials library        | 60*45             | (220, 157.5)           |
| 2      | Stamping workshop            | 25*35             | (167.5, 127.5)         |
| 3      | Production workshop          | 60*25             | (40, 167.5)            |
| 4      | Forging workshop             | 55*25             | (107.5, 167.5)         |
| 5      | Captan foundry               | 60*25             | (220, 72.5)            |
| 6      | Semi-finished products library| 35*30             | (97.5, 85)             |
| 7      | Heat treatment workshop      | 65*35             | (112.5, 127.5)         |
| 8      | Casting workshop             | 35*40             | (207.5, 30)            |
| 9      | Overlying workshop           | 60*35             | (40, 127.5)            |
| 10     | Finishing workshop           | 65*30             | (147.5, 85)            |
| 11     | Precision workshop           | 60*30             | (220, 110)             |
| 12     | Welding workshop             | 35*25             | (162.5, 167.5)         |
| 13     | Paint workshop               | 25*40             | (237.5, 30)            |
| 14     | Assembly workshop            | 50*40             | (130, 60)              |
| 15     | Performance test room        | 45*25             | (57.5, 77.5)           |
| 16     | Commissioning the repair shop| 45*35             | (27.5, 77.5)           |
| 17     | Shipping department          | 100*25            | (130, 27.5)            |
| 18     | Office district              | 60*35             | (40, 27.5)             |

The final optimized layout of the motor manufacturing workshop obtained based on the above data is shown in Figure 4.

**Figure 3.** Genetic algorithm evolution process diagram.

**Figure 4.** The final layout plan of the motor manufacturing workshop.

### 5. Conclusions

By modeling the facility layout of the motor production workshop, an objective function is established to minimize the logistics cost and maximize the closeness of each operation unit, which reduces the economic benefits of the enterprise. The research is closely related to the actual production of enterprises, and has certain research significance and application prospects. From a long-term perspective, the current human factors engineering is mainly used to study the relationship between humans and machines. In the future, more specific, in-depth and detailed layout planning of the layout of the workshop can be combined with the relationship between humans, machines and the environment. In turn, it meets the development of flexibility and quickly responds to changes in the market environment. By combining SLP and GA, we can make full use of the advantages of both, comprehensively consider logistics factors and non-logistics factors in the layout. Through case analysis, it is proved that the improved algorithm has indeed improved the economic benefits of the enterprise, and also provides reference for the layout planning of other enterprises.
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