Layout optimization of thyristor production line of F Company

Tongcan Gao[1*],Hang Shang[1],Jiangdong Wu[2]

[1] College of Business Administration, Liaoning Technical University, 125105 Huludao, Liaoning, China
[2] College of Electronic and Information Engineering, Liaoning Technology University, Liaoning,China

605809840@qq.com

Abstract. In recent years, with the development of manufacturing industry, it has brought opportunities and challenges to related enterprises. These enterprises are facing increasingly fierce market competition, so reasonable planning of workshop layout is of great significance for the long-term development of enterprises. Through field research, it is found that the production facility layout of the thyristor production workshop in F company is cumbersome, and the logistics route is crosswise and circuitous. This article aims at the above problems existing in the company. Firstly, it uses the SLP method to carry out preliminary planning and design of the workshop layout, and then combines with the particle swarm algorithm to obtain the final layout optimization scheme through MATLAB software programming, which improves the efficiency of logistics transportation.

Keywords: Layout Optimization;Particle Swarm Optimization; Matlab

1 Introduction

With the advent of the Industry 4.0 era, China has proposed the "Made in China 2025" plan. In order to adapt to the current market orientation and production form, reducing production costs, exploring and maximizing benefits can enable enterprises to remain invincible in the market.In the context of this issue, scholars at home and abroad have also done a lot of research. Based on the concept of lean manufacturing, Facility layout planning is the arrangement and rearrangement of facilities and work units in the workshop, which was proposed by R Muther [1]in the United States as a systematic layout design and computer modeling simulation.Based on the concept of lean manufacturing, Lista et al.[2]used the SLP method to analyze the logistics relationships between workshop operation units and designed a new layout plan, improving the utilization of space.Liu et al.[3] used the SLP method to analyze the logistics relationships between workshop area units, and designed an improved facility layout based on the location correlation diagram of the operation units.Zhang Zhongyu et al.[4] combined the SLP method with the artificial bee colony algorithm, and conducted a

T. Yao et al. (eds.), *Proceedings of the 2024 3rd International Conference on Engineering Management and Information Science (EMIS 2024)*, Advances in Computer Science Research 111,
https://doi.org/10.2991/978-94-6463-447-1_5

comparative analysis of the logistics volume and footprint before and after optimization.Liu J et al.[5]proposed a multi-objective particle swarm optimization (MOPSO) algorithm, which uses a heuristic configuration mutation operation based on gradient method and subsequent local search strategy to satisfy non-overlapping constraints, and proved its strong effectiveness in solving multi-objective problems.

2 Layout Optimization of the Thyristor Production Workshop

F Company is a designated enterprise for the production of thyristors and rectifiers by the General Armament Department of the state. Through on-site research, the thyristor production workshop covers an area of about 2,400 square meters, and the layout of the workshop is arranged in the order from left (west) to right (east), from top (north) to bottom (south), followed by 1 production planning area, 3 chemical processing area, 5 oxidation area, 6 lithography area, 11 electric lighting area, 2 batching area, 4 diffusion area, 9 mid-test area, 7 sintering area, 8 evaporation area, 10 spraying area, 12 packaging area, and 13 modeling area. The current layout of the workshop is shown in Figure 1.

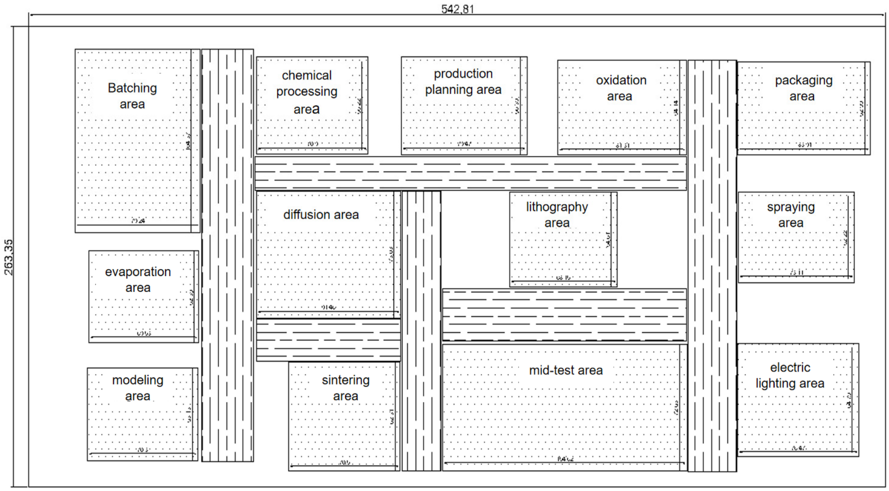


Fig. 1. Original workshop layout

2.1 Optimization of Traditional SLP Methods

After obtaining the distance and material transportation volume of the operation pairs, it was found that the product of the distance and transportation volume between the three pairs of operations 8-13, 7-8, and 11-12 was relatively large, indicating that the transportation between the operation pairs was difficult.The F-D analysis diagram is shown in Figure 2. The abscissa represents the distance (m) and the ordinate represents the transportation volume (t).The upper right area represents five pairs of work units with large logistics volumes and long distances. This section will optimize the work pairs in this area.

Firstly, the logistics relationship is analyzed. A, E, I, O, and U represent five levels from ultra-high to negligible, and the product of the distance and material transportation volume of each pair of operations results in the product of the distance between each operation unit. The product of the distance is sorted according to its size, and the logistics intensity is allocated according to the ratio. In the analysis of non-logistics relationships, A, E, I, O, U, and X represent six levels from absolute importance to negative intimacy. Based on the survey of workshop directors, there are six indicators that affect the non-logistics relationship in the workshop, namely material handling weight, process fluency, convenience of supervision and management at work, safety and hygiene, closeness of personnel contact, and versatility of facilities.

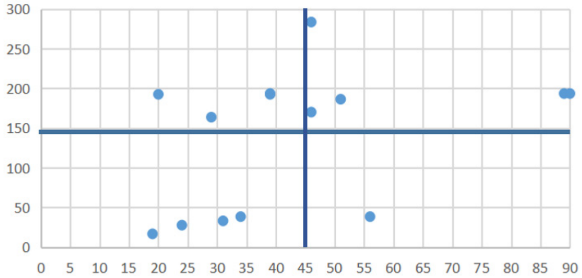


Fig. 2. Logistics Intensity F-D Analysis Diagram

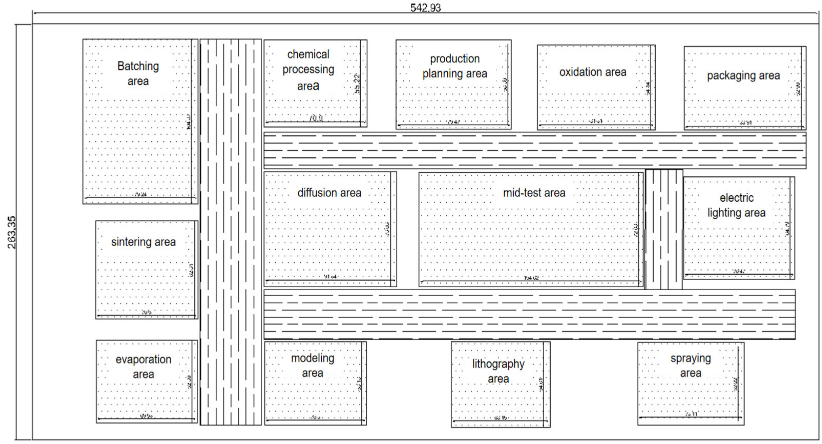
Finally, a comprehensive analysis of the relationship between logistics and non-logistics is conducted by using A, E, I, O, U, and X to represent six levels from absolutely important to not close. A weighted summation method is used to combine the logistics and non-logistics relationships, resulting in a comprehensive inter-unit relationship value. The weighted summation formula is as follows:

$$TL_{ij} = mML_{ij} + nNL_{ij} \tag{1}$$

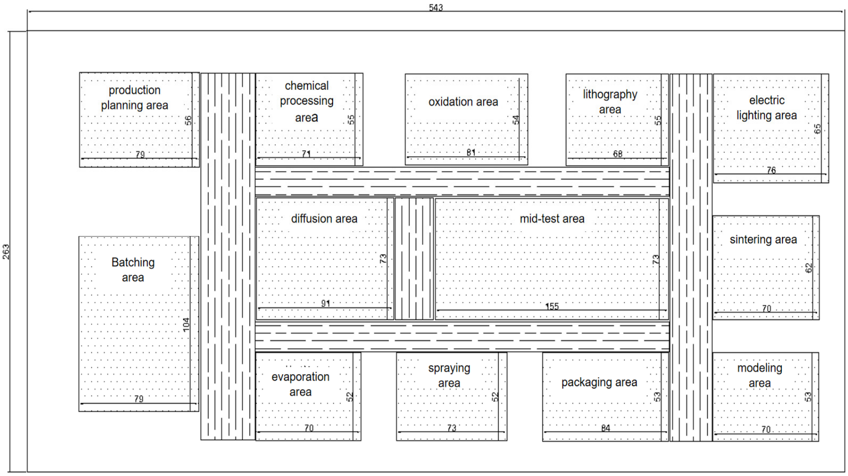
TLij represents the comprehensive logistics relationship; MLij represents the quantitative value of the logistics relationship; NLij represents the non-logistics relationship; m represents the weight of the logistics relationship; n represents the weight of the non-logistics relationship. Combining with the material handling situation between workshop operation units, the ratio of m and n is taken as 1:1.

The production workshop has a total of 78 pairs of operations. The comprehensive relationship levels corresponding to each score segment and the proportion of each operation unit pair are calculated. The closer the comprehensive relationship between operation pairs is, the closer they are to the middle position, and vice versa. A map of the location of operation units is drawn, as shown in Figure 3.

The product of the two optimized layout schemes obtained through SLP is less than the product of the original layout. Compared with scheme 2, scheme 1 shortens the distance by 45.8 m and reduces the product of the distance by 7621.08 (t·m). Compared with the original workshop, scheme 1 shortens the distance by 96.6 m and reduces the product of the distance by 12930.75 (t·m). Therefore, scheme 1 is the optimal scheme.



(a) Layout plan 1



(b) Layout plan 2

Fig. 3. Layout scheme obtained by SLP method

2.2 Particle Swarm Optimization

In the process of constructing the mathematical model, based on the actual situation of the workshop, it is first assumed that the shape of each work unit is rectangular and parallel to the Cartesian coordinate system. The coordinate axis at the lower left corner of the workshop is set as the origin, and the length direction of the workshop is consistent with the X axis, and the width direction of the workshop is consistent with the Y axis. It is assumed that the entry and exit points of the work units are the center coordinates, and the unit transportation costs of materials between different work units are basically the same. The material handling distance between two adjacent work units is calculated using the Manhattan distance formula, which is shown below

$$d_{ij} = |x_i - x_j| + |y_i - y_j| \tag{2}$$

(x_i, y_i) represents the starting work unit coordinates for material handling, and (x_j, y_j) represents the ending work unit coordinates for material handling.Therefore, assuming that the company has an existing workshop layout plan X, let i and j be the work units in the plan, f_{ij} represent the material flow between i and j, d_{ij} represent the distance between i and j, and C_{ij} represent the transportation cost between i and j. We construct a material flow matrix, distance matrix, and transportation cost matrix.

$$f_{ij} = \begin{bmatrix} f_{11} & f_{12} & \cdots & f_{1n} \\ f_{21} & f_{22} & \cdots & f_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ f_{n1} & f_{n2} & \cdots & f_{nn} \end{bmatrix}, \quad d_{ij} = \begin{bmatrix} d_{11} & d_{12} & \cdots & d_{1n} \\ d_{21} & d_{22} & \cdots & d_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ d_{n1} & d_{n2} & \cdots & d_{nn} \end{bmatrix}, \quad C_{ij} = \begin{bmatrix} c_{11} & c_{12} & \cdots & c_{1n} \\ c_{21} & c_{22} & \cdots & c_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ c_{n1} & c_{n2} & \cdots & c_{nn} \end{bmatrix} \tag{3}$$

Assuming that the material handling cost of job units i and j is c_{ij}, and the total material handling cost is Z_1, the material handling cost function expression of job units i and j can be derived based on logistics volume and distance.

$$Z_1 = \sum_{i=1}^{m} \sum_{j=1}^{m} c_{ij} f_{ij} d_{ij} \tag{4}$$

Next, we construct a non-logistics relationship maximization objective function, where k_{ij} represents the correlation factor between activity units i and j, Z_2 represents the sum of non-logistics relationships, and T_{ij} represents the non-logistics relationship level between activity units i and j. The non-logistics relationship equation is as follows.

$$Z_2 = \sum_{i=1}^{m} \sum_{j=1}^{m} T_{ij} k_{ij} \tag{5}$$

Then, combined with the non-logistics relationship close level quantification table, the relationship close level is divided into A, E, I, O, U, X, which decrease from absolutely important to unwelcome, with corresponding T_{ij} values of 4, 3, 2, 1, 0, -1. The quantitative values of the correlation factors are as follows

$$\begin{cases} K_{ij} = 1, & 0 < dij \le d_{max}/6 \\ K_{ij} = 0.8, & d_{max}/6 < d_{ij} \le d_{max}/3 \\ K_{ij} = 0.6, & d_{max}/3 < d_{ij} \le d_{max}/2 \\ K_{ij} = 0.4, & d_{max}/2 < d_{ij} \le 2d_{max}/3 \\ K_{ij} = 0.2, & 2d_{max}/3 < d_{ij} \le 5d_{max}/6 \\ K_{ij} = 0, & 5d_{max}/6 < d_{ij} \le d_{max}/6 \end{cases} \tag{6}$$

Based on the above analysis of logistics relationships and logistics relationships, a dual objective function expression is derived.

$$z_{1\min} = \sum_{i=1}^{m} \sum_{j=1}^{m} c_{ij} f_{ij} d_{ij}, \quad z_{2\max} = \sum_{i=1}^{m} \sum_{j=1}^{m} T_{ij} k_{ij} \tag{7}$$

For the problem of different dimensions of objective functions Z_1 and Z_2, we perform standardization as follows.

$$Z_1 = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} f_{ij} d_{ij}}{\sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} f_{ij} d_{max}}, \quad Z_2 = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} T_{ij} k_{ij}}{\sum_{i=1}^{n} \sum_{j=1}^{n} T_{ij}} \tag{8}$$

In addition to establishing the objective function expression, it is also required that the job units do not overlap and that there are boundary constraints. The corresponding formulas are as follows.

$$|xi - xj| \ge \frac{l_i + l_j}{2} + \Delta x_{ij}, \quad |y_i - y_j| \ge \frac{w_i + w_j}{2} + \Delta y_{ij} \tag{9}$$

$$|x_i - x_j| + \frac{Li + Lj}{2} \le L \, , |y_i - y_j| + \frac{w_i + w_j}{2} \le W \qquad (10)$$

L and W represent the length and width of the factory area, L_i and W_i represent the length and width of operation unit i, and L_j and W_j represent the length and width of operation unit j.The production workshop is 170 m long and 80 m wide.The initial layout scheme obtained by the SLP method is used as the initial population, and the particle swarm optimization algorithm program is compiled using Matlab2019a software. In the particle swarm optimization algorithm, the particle swarm size (Swarm Size) nPop is set to 50, the maximum iteration number MaxIt is set to 500, the inertia weight w is set to 1.0, the inertia weight decay rate is set to 0.99, the individual learning coefficient c1 is set to 0.7, and the overall learning coefficient is set to 1.5. The constraints related to the factory layout are set, and the objective function model is input. The iteration results are shown in Figure 4.

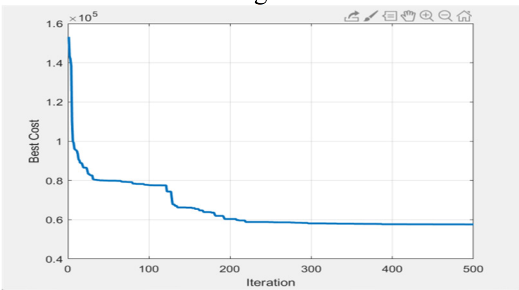


Fig. 4. Operation process diagram of particle swarm optimization algorithm

From Figure it can be concluded that when the algorithm runs for about 200 times, the objective function value approaches convergence, at which point the objective function achieves the optimal solution, and the corresponding coordinates of some work units are (0, 13.2), (24, 13.2), etc. Based on the coordinates obtained by Matlab, the final optimized layout is drawn using Auto CAD as shown in Figure 5.

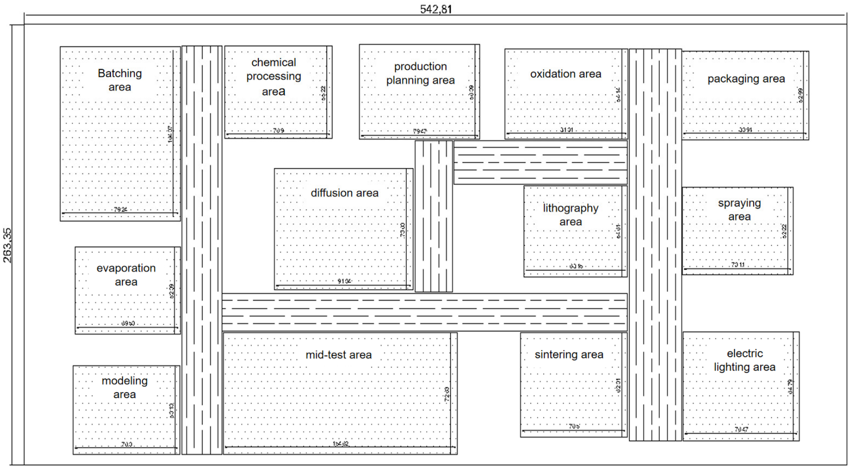


Fig. 5. Final optimized layout

2.3 Analysis of the layout effect of some operation units in the workshop

Due to practical limitations in the workshop, a green safety passage should be provided; reduce the amount of dust pollution generated during processing in the molding and painting areas, and arrange them in locations with smooth ventilation. The distance product between some operations in different layout schemes and the difference between the distance products before and after optimization are shown in Table 1. After optimization using a combination of particle swarm optimization, the logistics transportation distance was reduced by 20.85%; the total distance product was reduced by 20.93%, significantly improving the efficiency of logistics transportation between operations.

Table 1. Product of Range between Some Operation Units

Operation pair number	Range product of the original scheme (t·m)	After combining with POS (t·m)	Optimized difference (t·m)
2-3	1029.2	1098.92	-69.72
3-4	655.2	515.76	139.44
5-6	6087.03	5944.85	142.18
6-4	7827.82	7249.24	578.58
4-7	9691.24	8368.01	1323,23
7-8	11614.2	7839.59	3774.41

3 Conclusion

This article analyzes and optimizes the problems in the balance between the thyristor production workshop and production line in F company, and the research results are as follows: In response to the problems in the workshop layout, a combination of SLP and particle swarm optimization was used to re-optimize the design and selection of solutions for the workshop layout. In the final optimization scheme, the logistics transportation distance was reduced from 733 m to 580.2 m, a decrease of 20.85%; the total distance product was reduced from 100511.32 t·m to 79478.36 t·m, a decrease of 20.93%.

References

1. Zhang C X,Dong S L,Chu H Y,et al.Layout design of a mixed-flow production line based on processing energy consumption and buffer configuration[J].Advances in Manufacturing,2021,9(3):369-387.
2. Lista A P,Tortorella G L,Bouzon M,et al.Lean layout design:a case study applied to the textile industry[J].Production,2021,31:e20210090.
3. Liu H W,Liu X B,Lin L,et al.A study of the layout planning of plant facility based on the timed Petri net and systematic layout planning[J].Plos One,2020,15(9):e0239685.

4. Harshalatha and Patil Shantharam and Kini Pradeep G.. A review on simulation based multi-objective optimization of space layout design parameters on building energy performance[J]. Journal of Building Pathology and Rehabilitation, 2024, 9(1)
5. Liu J,Liu J,Yan X, et al. A heuristic algorithm combining Pareto optimization and niche technology for multi-objective unequal area facility layout problem[J]. Engineering Applications of Artificial Intelligence,2020,89.