Layout Optimization of Factory A Based on SLP-Whale Algorithm

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Abstract. In this paper, SLP method is used to improve the layout of a company's box processing workshop facilities. Firstly, work units are divided through the collected basic data, and then the logistics and non-logistics relations between each work unit are analyzed and integrated to obtain comprehensive mutual relations, and the location correlation diagram of SLP method is obtained. Then, the mathematical model of workshop facility layout is built on the basis of SLP method. Taking the minimization of handling cost, the maximization of comprehensive logistics relationship and the minimization of reconstruction cost as constraint objectives, the layout scheme is obtained by using the improved whale algorithm. Finally, by comparing with the traditional system layout design method, it is concluded that the optimization scheme of the improved whale algorithm is more reasonable.

The results show that the layout method combined with improved whale algorithm can effectively solve the workshop layout problem, help a company reduce the workshop handling cost, strengthen the close relationship between operating units, improve the workshop production efficiency, and at the same time, the layout optimization method combined with improved whale algorithm can be effectively implemented in the workshop layout. Solving layout planning problems for other manufacturing enterprises also has reference significance.

Keywords: System layout design (SLP) · Layout optimization · Improved whale algorithm · Material handling

1 Introduction

In recent years, as the industrialization process accelerated, the traditional manufacturing industry of our country is also facing some new opportunities and problems. Most small and medium-sized manufacturing enterprises aim to win in a stable way [1]. And due to the rapid transformation of the market, enterprises have to focus on more directions to reduce costs. Therefore, production facilities layout optimization into the public's vision. In the manufacturing industry, when the cost of raw materials is compressed to a certain range, the income brought by the cost saving of raw materials may fall far. In order to avoid the result of low income with effort, more directions are adjusted to improve the layout of the production workshop and adjust the material handling time

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S. H. B. D. M. Zailani et al. (Eds.): ICMSEM 2023, 259, pp. 603–615, 2024.
https://doi.org/10.2991/978-94-6463-256-9_62

[2, 3]. Especially since entering the 21st century, layout planning research has become more and more perfect, and has also been adopted by many manufacturing enterprises. Adopting reasonable workshop layout can not only effectively reduce the production cost of enterprises, but also reduce the working pressure of workers and create better earnings for enterprises [4].

SLP method is adopted to optimize the layout of the workshop, effectively improving the production efficiency of the production line and the flexibility of the layout, reducing the logistics intensity and making the layout more compact and scientific than the original one, and fully improving the logistics efficiency. Jin Junna [5] focused on the analysis of the multi-storey factory building of the research object, and after re-improving the layout with the daytime operation data, drew two schemes initially. Finally, Delphi method was adopted for evaluation and selection. Huang Qianqian et al. [6] used SLP method to optimize the initial layout scheme, and then used weighted factor comparison method to evaluate the feasibility of the scheme. Zhao Shan [7] took the No.1 library of D Company as the research object, combined EIQ-PCB analysis and SHA transport theory, obtained the initial scheme of functional area layout through the constraints of practical conditions of the enterprise, and established and solved the model with the lowest unit transport cost as the goal. Zhang Yongqiang [8] redesigned the warehouse layout of forest products by using the optimized system layout design method (SLP) combined with the transport system analysis method (SHA). Based on the relevant data of logistics, the area correlation chart is made, and the objective function of the lowest unit handling cost is established to optimize the solution.

2 Case Analysis and Production Analysis

A Company was established in 1997 with a registered capital of 30 million yuan and put into operation in 1999. Located in Changchun, Jilin Province, it is a small and medium-sized manufacturing enterprise engaged in auto parts manufacturing (except engine) and mechanical parts processing and production. The company covers an area of 20000 square meters, the company has more than 200 employees, most of which are technicians. Because the company occupies the market for a long time, the company's products are well received and trusted by users. At present, the company's main products are hydraulic steering gear.

In recent years, the company has always implemented the principle of "quality first" in the process of development, and always pursued the quality of products. Moreover, with the implementation of favorable national policies, customer demand is gradually increasing, the scale of production and personnel is expanding day by day, and the speed of product updating and iteration is accelerating.

2.1 Data Measurement

The area data of Company A is shown in Table 1.

Table 1. Area and length and width parameters of each operating unit of A company

Serial number	Operating unit name	use	Long (M)	Wide (M)	area (M^2)
1	Raw material warehouse	Storage of steel and ingots	20	30	600
2	Casting shop	casting	12	24	288
3	Heat treatment workshop	Heat treatment	12	12	144
4	Machine shop	Turning, milling, drilling	18	36	648
5	Precision shop	Fine boring and grinding	12	36	432
6	Standard room, semi-finished product warehouse	Storage external components, semi-finished products	12	24	288
7	Assembly shop	Assemble the steering gear	12	36	432
8	Performance test room	Steering gear performance inspection	12	20	240
9	Finished product warehouse	Finished product storage	12	12	144
10	Equipment repair shop	Machine tool maintenance	12	24	288

2.2 Quantitative Analysis

Through consulting workshop staff, the data of logistics intensity in the processing process of bridge crane was obtained. The data in the table reflected the total amount of material handling between the starting operation unit and the ending operation unit. The crossing position of rows and columns was the logistics intensity between the corresponding operation unit on the left side and the corresponding operation unit on the top. Among them, the first column on the left side represents the "from" end operation unit, the top row represents the "to" end operation unit, and the cross position between the row and column represents the total logistics intensity between the "from" end operation unit and the "to" end operation unit. Details are shown in Table 2.

Due to the different production workshops, the transportation costs from each production workshop to other operating units are also different, which shows the transportation costs between different operating units.

2.3 Qualitative Analysis

In addition to material handling activities in the process of product production, there are other correlation relationships between different operating units, such as information transfer, personnel transfer and material handover. As can be seen from the workshop layout diagram, the distance between the raw materials warehouse and the semi-finished products warehouse is far away. Although there is no direct material handling relationship

Table 2. Hydraulic steering gear processing technology from to table (Unit: kg)

From \ To		1	2	3	4	5	6	7	8	9	Add
		Raw-materi-alware-house	Casting shop	Heat treat-ment workshop	Ma-chine shop	Preci-sion shop	Semi-fin-ished prod-uctsware-house	Assem-bly shop	Perfor-mance test room	Fin-ished product ware-house	
	Raw mate-rial ware-house		163937	25690	32514						222142
2	Casting shop				98362						98362
1	Heat treat-ment workshop				25690	19555					45245
4	Machine shop			29152		15982	14880				60015
5	Precision shop						76080				76080
6	Semi-fin-ished prod-ucts ware-house							95680			95680
7	Assembly shop								95680	19136	114816
8	Perfor-mance test room							19136		76544	95680
9	Finished product warehouse										
Add			163937	54842	156567	35538	90960	114816	95680	95680	808023

between the two workshops, some material lists in the raw materials warehouse need to be sent to the temporary storage for the handover of production completion. If the distance between the working units is far, a certain distance will be wasted. After the completion of production, products need to be inspected, painted and assembled before entering the temporary storage. There are detour routes from the completion of product processing to the inspection workshop, painting workshop and assembly workshop, which will also produce handling waste.

3 SLP Logistics Relationship Analysis

3.1 Analysis of Logistics Relations

In this paper, SLP method is adopted to analyze the logistics relationship between the production workshop of Company A, mainly to analyze the logistics intensity and transportation distance between the operating units, that is, through sorting out the two types of data of logistics intensity and transportation distance in the workshop, to comprehensively analyze the closeness of the location of each operating unit.

1) The logistics intensity between the operating units of 1~2 (raw material warehouse and casting workshop) is divided into A grade, which belongs to the type of ultra-high logistics intensity.
2) The logistics intensity of operating units 7~8 (assembly workshop and performance inspection workshop), 2~4 (casting workshop and machining workshop), 6~7 (semi-finished products warehouse and assembly workshop) is divided into grade E, which belongs to the type of extremely high logistics intensity.
3) The logistics intensity of the four pairs of operating units, 8~9 (performance inspection workshop and finished product warehouse), 5~6 (machining workshop and semi-finished product warehouse), 3~4 (heat treatment workshop and machining workshop), and 1~4 (raw material warehouse and machining workshop), is classified as grade I, which belongs to the larger type of logistics intensity.

4 Workshop Model Construction

4.1 Model Hypothesis Is Proposed

In order to design the layout scheme of the production workshop, in view of the problems existing in the current layout of the production workshop of hydraulic steering gear analyzed in Sect. 2.3, some simplification and abstraction of the operating units of the production workshop were made, and the following assumptions were listed:

(1) Each operating unit is abstracted into a variety of real physical equipment contained in it plus a minimum rectangle for workers to operate the area, and the length and width of the operating unit and the area required for layout can be calculated, in addition, each operating unit has a safety clearance distance, The distance between the operating unit and the workshop wall is greater than the safety clearance distance of all individual operating units;
(2) The working units in the workshop can be arranged randomly, and the layout direction should be parallel to the wall of the workshop, and all the working units should be arranged in the same two-dimensional plane;
(3) The inlet and outlet of each operating unit is its geometric center point;
(4) All operating units shall be arranged in the workshop area. Any two operating units shall not overlap, and the maximum safety clearance distance between them shall be taken as the two. Workshop facility layout is a combinatorial optimization problem. A topology model diagram of workshop operation unit layout is drawn according to the above assumptions.

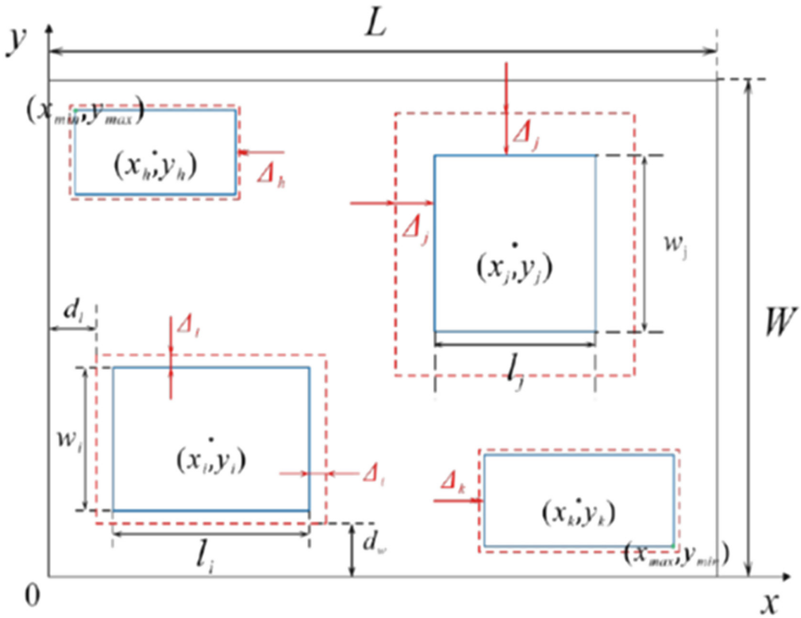

Fig. 1. Schematic diagram of operation unit topology model in production shop

The topology model built according to the constraints is shown in Fig. 1.

In the Fig. 1, the lower left corner near the original material warehouse (operation unit No. 1) in the current layout of the workshop is taken as the origin of coordinates. In the plane coordinate system established, the axis represents the length direction of the hydraulic steering gear workshop, and the axis represents the width direction of the workshop, respectively representing the length and width of the production workshop. The production workshop is divided into operation unit areas, which are respectively represented by, respectively represents the length and width of the operation unit on the axis and axis direction, represents the safety clearance distance of the operation unit, represents the minimum spacing distance between any operation unit and the workshop wall, and represents the geometric center coordinates of the operation unit.

4.2 Establish the Objective Function

Workshop layout often needs to be designed according to the production objectives of the enterprise, such as the maximum land utilization rate, the highest production efficiency, the maximum equipment utilization rate, the lowest production cost and other objectives. According to the problems proposed in the second chapter of this paper, the workshop facility layout model constructed in this paper sets three optimization objectives:

(1) The use of logistics tools or manpower is minimal, that is, the logistics handling cost is minimal

First, the minimization objective function of logistics handling cost was constructed, and the logistics handling cost was defined as inter-regional handling frequency, inter-regional distance and inter-regional transportation cost product, so as to obtain the expression of logistics handling cost as shown in the following formula

$$\min f_1 = \sum_{i=1}^{N} \sum_{j=1}^{N} Q_{ij} D_{ij} C_{ij} \tag{1}$$

where, is the transport frequency between regions. In this paper, transport intensity matrix is adopted:

$$Q_{ij} = \begin{bmatrix} q_{11} & q_{12} & \cdots & q_{1N} \\ q_{21} & q_{22} & \cdots & q_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ q_{N1} & q_{N2} & \cdots & q_{NN} \end{bmatrix} \tag{2}$$

Is the distance between regions, and Manhattan distance is taken in this paper:

$$D_{ij} = |x_i - x_j| + |y_i - y_j| \tag{3}$$

Represents the cost of transportation between regions:

$$C_{ij} = \begin{bmatrix} c_{11} & c_{12} & \cdots & c_{1N} \\ c_{21} & c_{22} & \cdots & c_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ c_{N1} & c_{N2} & \cdots & c_{NN} \end{bmatrix} \tag{4}$$

The product of the three is the logistics handling cost.

(2) The closer the arrangement between the two operating units with higher correlation, that is, the minimum logistics pressure

Next, the objective function of maximizing logistics relationship is constructed. In this paper, the correlation factor proposed by Lee is used for the calculation of non-logistics relationship, which is used to represent the closeness of comprehensive logistics relationship. The correlation factor between operating units and is used to product the two, so as to obtain the expression of comprehensive logistics relationship, as shown in the following formula:

$$\max f_2 = \sum_{i=1}^{N} \sum_{j=1}^{N} b_{ij} k_{ij} \tag{5}$$

Level of closeness and closeness correlation factor between regions follow the Table 3.

(3) Relayout costs the least, that is, layout reconstruction costs are minimized

Table 3. Quantized value of correlation factor between operation units and regions

Level of closeness	The closeness correlation factor between regions (k_{ij})
$0 < d_{ij} \leq \frac{d_{\max}}{6}$	4
$\frac{d_{\max}}{6} < d_{ij} \leq \frac{d_{\max}}{3}$	3
$\frac{d_{\max}}{3} < d_{ij} \leq \frac{d_{\max}}{2}$	2
$\frac{d_{\max}}{2} < d_{ij} \leq \frac{2d_{\max}}{3}$	1
$\frac{2d_{\max}}{3} < d_{ij} \leq \frac{5d_{\max}}{6}$	0

The third objective function is the cost minimization of layout reconstruction. The unit cost representing the mobile unit is used in the cost calculation of layout reconstruction, and represents the distance that the mobile unit moves after the mobile unit reconstructs the layout. The product of and is the cost of layout reconstruction.

$$\min f_3 = \sum_{i=1}^{N} oM_i \tag{6}$$

$$M_i = |x_i - x_i'| + |y_i - y_i'|$$

It is necessary to set the weight coefficient of the objective function. The relationship between the weight coefficients is as follows: The objective function formula of the equipment layout optimization design of the hydraulic steering workshop was finally determined by the construction:

$$F = u_1\omega_1 \sum_{i=1}^{N}\sum_{j=1}^{N} Q_{ij}D_{ij}C_{ij} - u_2\omega_2 \sum_{i=1}^{N}\sum_{j=1}^{N} b_{ij}k_{ij} + u_3\omega_3 \sum_{i=1}^{N} o_iM_i \tag{7}$$

$\omega_1, \omega_2, \omega_3$ Take separately 0.4, 0.3, 0.3.

$$\begin{cases} u_1 = \dfrac{1}{\sum_{i=1}^{N}\sum_{j=1}^{N} Q_{ij}d_{\max}C_{ij}} \\ \mu_2 = \sum_{i=1}^{N}\sum_{j=1}^{N} b_{ij} \\ \mu_3 = \dfrac{1}{\sum_{i=1}^{N} o_i d_{\max}} \end{cases} \tag{8}$$

4.3 Setting Constraints

In order to reasonably plan the layout of the workshop, it is necessary to understand the basic situation of various production equipment in the lead-acid battery workshop in detail, and then set appropriate constraint conditions according to the actual scene. The most common one is that the length and width of each operation unit arranged on the x and y axes in the workshop, plus their safety clearance distance cannot exceed the length and width of the inherent area of the workshop. The operation units do not overlap the phenomenon, in addition to the need to consider the safety of workshop processing.

(1) Boundary constraints

The length and width of the operation unit layout on the x axis and y axis are 0m and 110m, respectively.

The coordinates in the lower left corner of the operating unit are:

$$(x_i - \frac{l_i}{2}, y_i - \frac{w_i}{2}) \tag{9}$$

The coordinates in the upper right corner of the operation unit are:

$$(x_i + \frac{l_i}{2}, y_i + \frac{w_i}{2}) \tag{10}$$

(2) Spacing constraints between operating units

In the layout of the workshop, each operation unit should maintain a certain distance from each other, so as not to overlap. The minimum distance between the two adjacent operation units is the larger one in the safety gap distance $\max\{\triangle_i, \triangle_j\}$:

$$|x_{i-}x_j| \geq \frac{l_i + l_j}{2} + \max\{\Delta_i, \Delta_j\}, \forall_{i,j}, i \neq j \tag{11}$$

$$|y_i - y_j| \geq \frac{w_i + w_j}{2} + \max\{\Delta_i, \Delta_j\}, \forall_{i,j}, i \neq j \tag{12}$$

5 Whale Algorithm and Improvement

The whales may not be able to find the best prey location due to their blindness in their movement in search of food, and the trajectories towards the location are also zigzagging. In order to solve this problem of whale swarm algorithm, this paper proposes an adaptive weight adjustment method to improve the ability and efficiency of whale swarm to find the optimal target [9–11].

(1) $f(j)$ Less than or equal to f_{avg1}:

$f(j) \leq f_{avg1}$, This means that the confidence level of the headfish is better than the average confidence level of the whole school, indicating that the current headfish has a more reliable optimal position in the whole school. Restricting headfish to a smaller area allows them to search for the best prey. $f(j) \leq f_{avg1}$, Can be set $\overline{A} \in (0.8, 1.2)$.

(2) $f(j)$ Greater than or equal to f_{avg2}:

$f(j) \leq f_{avg2}$, This means that the headfish is in a worse position than the poorly placed individual in the entire school, and in order for the headfish to move to a better position, we need to move it over a wide area. At this point, the convergence factor needs to fluctuate in a large range to encourage the headfish to be more active. $f(j) \leq f_{avg2}$, Can be set $\overline{A} \in (0.3, 0.6)$ or $\overline{A} \in (1.3, 1.6)$.

(3) $f(j)$ between f_{avg1} and f_{avg2}:

$f_{avg2} > f(j) > f_{avg1}$, It means that the head fish is in a normal position relative to the rest of the school. At this point, the restrictions on the fish can be reduced and the fish can still follow the original will to move. $f_{avg2} > f(j) > f_{avg1}$, Can be set $\overline{A} = 1$.

It can be seen from the above research process that when the adaptive weight factor is adopted to guide the activities of headfish, the whole fish can be more scientifically promoted to move towards the best position with more efficient movement. That is, the algorithm has higher accuracy and convergence speed.

The specific steps to improve the algorithm are as follows:

(1) Start the calculation and clarify the initial information for the iteration. For a population composed of individuals $X = [X_1, ...X_n]$. Specify the parameters of the movement of whale groups towards prey and specify the starting point of their movement.
(2) To calculate the confidence of the population. If number of iterations $j < M$, update $a, \overline{A}, C, l, p$.
(3) Rank individual trustworthiness from smallest to largest $f(j)$, By simple calculation f_{avg1}, f_{avg2} and ω. The updated original population confidence was calculated. And replace the original value with better confidence.
(4) Now the whole shoal moves once, getting the best coordinates so far from the prey X^* And its credibility $f(*)$, At this time, judge whether the upper limit of the number of exercises originally planned has been reached. If not, start the next exercise, and the number of exercises is increased by one until the upper limit.

6 Optimization Effect and Evaluation

The total area of A company's hydraulic steering workshop is 110*70m. The layout of the workshop is only one layer, no lower differentiation. There are 11 areas in the workshop. Each processing area covers a different area, processing technology is different, the function can not be replaced with each other.

In the process of algorithm programming, Matlab software is mainly used, and the improved whale algorithm is used to optimize the layout of the workshop. Among them, relevant data such as minimum distance between workshops, comprehensive logistics relationship, workshop size and logistics relationship, operation unit cost and other data are filled in the location. m file. The initial population number (Popsize) of the improved whale algorithm is 100, which does not significantly increase the amount of computation under the premise of fully guaranteeing the differences between groups. The number of iterations (Max_iteration) is set to 1000. To ensure algorithm convergence, set the code running time to 500 s.

The figure shows the comprehensive objective function and unit layout of the improved whale optimization algorithm. However, the comprehensive objective function is the comprehensive result of three objective functions, which cannot clearly and intuitively show the optimized effect. Therefore, the three objective functions are analyzed respectively, and the optimal positions of 11 operation units are respectively 3,1,6,5,4,2,7. 8,9,11,10.

This paper constructs three objective functions, namely, moving cost, integrated logistics relationship and reconstruction cost. By bringing the optimized operation unit coordinates into the objective function constructed in this paper, it is found that the comparative results of moving cost and integrated logistics relationship are shown in the Table 4.

The objective function of the optimized layout by the improved whale algorithm is 131866, and the objective function of the original layout of enterprise A is 266541, and the improvement degree is 50.53%. Compared with the comprehensive logistics relations, the optimized layout of the improved whale algorithm is 4595, and the objective function of the original layout of enterprise A is 3836. The improvement degree is 16.52%. For the reconstruction cost function, it is a comparison scheme for comparing different optimization schemes.

By using the improved algorithm and the corresponding central coordinates of each operation unit in the above table, we can put them into the objective function constructed in the third chapter to get the value of the objective function under different layout schemes.The Objective function values under different algorithms follow Table 5.

(1) If the original layout of Company A is adopted, the monthly handling cost is 266,541 yuan, and the comprehensive logistics relationship between each operation unit is 3,836. The original layout means that the operation unit will not be moved, so the reconstruction cost is naturally zero, but the handling cost and the comprehensive logistics relationship are the worst value. Combined with the analysis in Chapter 2, It means that Enterprise A must optimize the original layout.
(2) The SLP algorithm described in Chapter 3 is used to draw the operation area map. It is found that the handling cost is 153,723 yuan, the comprehensive logistics relationship is 4204 yuan, and the reconstruction cost is 1140,305 yuan, which optimizes the original layout to a certain extent.

Table 4. Optimize the comparison of objective functions

	Handling costs	Comprehensive logistics relationship
Improving Whale Algorithm to Optimize Layout	131866	4595
Original layout	266541	3836
Improvement degree	50.53%	16.52%

Table 5. Objective function values under different algorithms

	Whale Optimization SLP algorithm improves whale optimization original layout	Whale Optimization SLP algorithm improves whale optimization original layout	Whale Optimization SLP algorithm improves whale optimization original layout	Whale Optimization SLP algorithm improves whale optimization original layout
Handling cost	132078	153723	**131866**	266541
Comprehensive logistics relationship	4569	4204	**4595**	3836
Reconstruction cost	711914	1140305	**540894**	0

7 Conclusion

As an important way to study the layout of traditional industrial engineering, system layout design directly affects the production efficiency of a company. A reasonable workshop layout can help enterprises save a lot of unnecessary costs and waste of human resources. Therefore, on the basis of mastering relevant layout optimization theories, this paper takes the workshops of A company as the research object, and adopts the method of combining SLP and intelligent algorithm to re-plan the workshop for the problems of workshop layout, which has good practical value for the improvement of logistics cost of A company.

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