Workshop Layout Optimation and Simulation Analysis Based on SLP: A Case Study

Tongtong Wang and Yajuan Feng(✉)

School of Business Administration, Liaoning Technical University, Liaoning, China
1355764672@qq.com, 776704660@qq.com

Abstract. In response to the phenomenon of long transportation distances and high transportation costs due to the current workshop layout, this paper proposes a layout optimization scheme based on the System Layout Planning (SLP) method, which is verified for feasibility through Flexsim simulation. In the optimization process, focusing on the two important factors that affect the workshop layout, namely transportation distance and transportation cost, a qualitative solution is proposed using a real case study as the research scenario. The results show that the optimized layout scheme can significantly reduce transportation distance and transportation costs, when compared to the original layout scheme. This case study provides reference and inspiration for workshop layout optimization, and also provides guidance for ship equipment manufacturing enterprises to achieve efficient production processes and cost control.

Keywords: Facility Layout Problem · Layout Optimization · System Layout Planning · Flexsim Simulation · Case Study

1 Introduction

Due to the impact of the pandemic, most manufacturing enterprises have been affected, leading most of them to choose to reduce costs in response. As the main processing step in the production process, the workshop is an important place for ensuring smooth production, but it also generates large costs including manufacturing costs, transportation costs, and labor costs, which have a negative impact on the efficiency of enterprises [1]. Literature review shows that raw materials are processed and finally output in the form of products, but the time for adding value to raw materials only accounts for 5%–10% of the product lifecycle, while the remaining 90%–95% of time is wasted, seriously dragging down the efficiency of enterprises with too low added value time, which is not conducive to efficient development of enterprises [2, 3]. Within most manufacturing enterprises, 30%–75% of the funds for product manufacturing are spent on material handling and facility layout, with some companies even spending up to 50% on material handling costs [4, 5]. Therefore, optimizing the layout of production workshops, saving time for material handling and processing, and fundamentally reducing costs are key factors in improving the core competitiveness of manufacturing enterprises to cope with the pandemic and achieve steady development [6].

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The existing methods for improving workshop layout mainly use the SLP method, which comprehensively analyzes the current situation of the workshop and combines with the SLP method to redesign the logistics and non-logistics aspects of the workshop layout, effectively improving the efficiency of manufacturing workshop equipment [7]. In terms of workshop automation transformation, the specific scheme for production line process layout can be obtained through the use of system layout design method and PlantSimulation simulation planning method, and the feasibility of the scheme can be effectively verified [8, 9]. However, the application of existing SLP methods in the manufacture of ship equipment is limited, and transportation costs and production efficiency are rarely considered as improvement targets for workshop layout.

This paper focuses on the problem of high transportation costs caused by long logistics transportation distances in workshop layouts, using a real case study of a ship equipment manufacturing workshop. First, key parameters related to the current layout of the workshop are collected, including the occupied area of workshop facilities, the overall logistics transportation distance, and the logistics volume of production products. Second, a new layout scheme is proposed based on the SLP method, analyzing both logistics and non-logistics relationships, creating a comprehensive proximity ranking table for each operation unit, and drawing relevant diagrams for the operating units. A solution was proposed to place the storage area in a central location for logistics transportation. Third, combined with Flexsim simulation analysis, the transportation costs of the original and optimized layouts were compared using material handling distance as the analysis variable. The effectiveness of the proposed layout plan was verified using production efficiency as a performance indicator. The results show that the improved transportation costs decreased by ¥45,453.75 and production efficiency increased.

This study includes 6 sections. Section 2 mainly introduces the methodology. Section 3 introduces the Flexsim simulation analysis. Section 4 uses a real case study to verify the feasibility of layout optimization. Section 5 is the conclusion.

2 Methodology

2.1 Problem Description

Due to the limitations of logistics management, most ship equipment manufacturing companies currently face constraints in workshop layout. This is mainly because many managers have always viewed the workshop layout as an unchangeable factor and have thus used fixed workshop layouts. As a result, there are problems such as mismatch between the amount of logistics handling and the handling distance, excessively long handling distance, and low production efficiency during the production process. These issues directly lead to an increase in the company's production and transportation costs, a decline in corporate profits, and a serious impact on corporate performance. Especially during the pandemic, many companies have struggled to maintain normal operations. Therefore, how to optimize workshop layout has become the top priority for ship equipment manufacturing companies. To address the actual operational situation in the workshop, measures need to be taken to optimize workshop layout, improve production efficiency, reduce production costs, and enhance corporate performance.

2.2 Systematic Layout Planning (SLP)

The methods and techniques for factory layout have always been a topic of exploration in the field of industrial engineering. Among the numerous layout methods, SLP is the most famous systematic design [10]. This method can be used not only for factory and production system design, but also for the design of hospitals, schools, and office buildings [11]. Reference [12] proposed a decision-making solution based on data envelopment analysis for facility layout problems, with minimizing and maximizing standards as input and output variables respectively, and finally used VisFactory planning layout software for simulation to determine the feasibility of this method. References [13, 14] improved the facility layout of the workshop through the use of a systematic layout design method and listed some feasible solutions. The effectiveness of this method in layout was further validated through simulation using Flexsim. In this paper, a qualitative method is used to analyze the existing problems in the workshop layout of a ship equipment manufacturing company. Based on the SLP method, a layout improvement scheme is designed for the workshop, and Flexsim simulation is used to compare the simulation results to validate the feasibility of the improvement scheme.

2.3 Typical Plant Planning and Spatial Layout

In order to propose reasonable solutions for optimizing workshop layouts, a typical workshop layout is introduced in Fig. 1. The workshop is divided into six areas.

The raw material area is primarily designated to store various raw materials, purchased parts, outsourced parts, and auxiliary equipment. The production area is where the raw materials are processed and manufactured during the product production process. The inspection area is responsible for quality inspection of the structural components and finished products produced. The assembly area is where the semi-finished products, major components, etc., produced are assembled and docked using various professional machinery and equipment. The maintenance area is responsible for the maintenance of equipment and repair of defective products within the workshop. Finally, the storage area is used for storing finished products. During the logistics analysis process, logistics intensity levels are often introduced to overcome the difficulties of directly dealing with various data. In SLP method, logistics intensity levels of different operating units are represented by five symbols: A, E, I, O, and U, which decrease sequentially from A to U. Specifically, A represents ultra-high logistics intensity, E represents high logistics intensity, I represents significant logistics intensity, O represents general logistics intensity, and U represents negligible logistics intensity.

When using the SLP method, it necessary to draw a diagram of the positions of the work units. Different types of lines are used to represent the degree of closeness between work units. Usually, solid lines are used to represent the degree of closeness between work units, and the more there are, the closer they need to be arranged. Relationship level A is represented by four straight lines, indicating absolute importance, relationship level E is represented by three straight lines, indicating special importance, I is represented by two straight lines, indicating importance, and O is represented by one straight line, indicating general importance. As shown in Fig. 2.

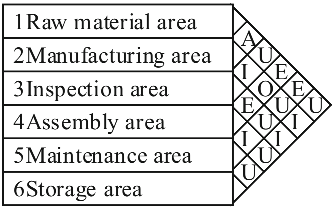

Fig. 1. Logistics-related diagram of each operation unit

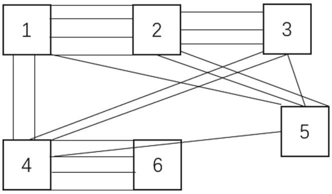

Fig. 2. Work unit location related graph

3 Flexsim Simulation-Based Layout Planning

3.1 Simulation Assumptions

In order to simplify the simulation model, some other interfering factors are excluded to ensure the effective output of the simulation results. Defining the production of products as the primary factor in job production, conducting logistics analysis on it becomes the key to simulation modeling. Before building the Flexsim simulation model, the following assumptions and explanations are proposed: (1) The production time is constant and does not consider any non-normal situations such as time waste and downtime during the processing, (2) The transportation time between the warehouse and the production line can be ignored, and the logistics transportation time is assumed to be zero. (3) The production plan and orders are stable and do not consider the impact of unforeseen events and market changes on the production plan. (4) The number of equipment and personnel in the production workshop is stable, and does not consider the impact of equipment failures, personnel adjustments, and other factors on production efficiency. (5) Only the production of a single product is considered and does not consider the production of multiple varieties or mixed production.

The above assumptions and explanations are aimed at ensuring the simplification and effectiveness of the simulation model, in order to better carry out logistics analysis and simulation. First, each workshop is treated as a processing entity, and the internal transportation time can be ignored. Each workshop is considered as a job unit, and the logistics transportation between job units is realized through AGV vehicles. Second, each processing workshop has five processing equipment, but only one equipment entity is displayed when building the simulation model. Third, the route of AGV is simplified, and they follow the same fixed route and perform handling tasks.

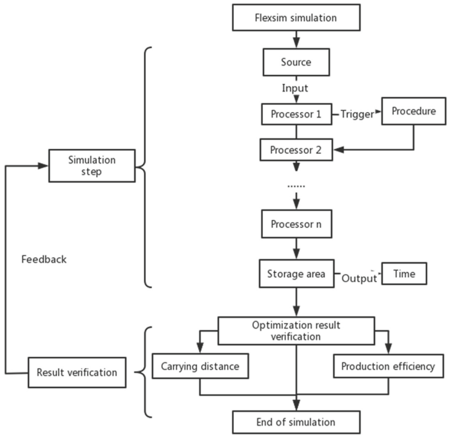

Fig. 3. Simulation flow chart

3.2 Simulation Process

The simulation consists of two main parts. The first part is the simulation steps. When building the simulation model, the specific location of the simulation model entity is determined. At the same time, appropriate model entities are selected based on the job task attributes of each workshop, and the working parameters of the entities are input to complete the static construction of the model. Finally, the logical linkage of the model is established, and the simulation experiment is completed by modeling. Clicking the "Run" button, the simulation model runs according to the preset time. The second part is result verification, which verifies the handling distance and production efficiency. The overall process is shown in Fig. 3.

3.3 Simulation Objectives

To demonstrate the rationality of the optimized layout scheme, the simulation evaluation of the production workshop layout optimization is mainly compared from logistics handling distance and cost, and production efficiency. Therefore, the 3 goals are proposed for the simulation evaluation of the production workshop layout optimization:

- Compare material handling distance and cost. By running the constructed simulation model and measuring the material handling distance between each workshop, the handling distance of the optimized layout scheme can be obtained. Then, the handling cost can be calculated as a basis for selecting the final layout scheme.
- Analyze the working status of equipment. Analyze the production efficiency of the proposed layout optimization scheme obtained after simulation and comparison analysis, and analyze which scheme is more reasonable.
- Determine the best layout optimization scheme. Combining the results of the comparative analysis, it is determined whether the optimized scheme has made progress compared to the original scheme.

Table 1. Demand for unit area of workshop operation

Number	Operating unit	Long (m)	Wide (m)	Area requirement (m^2)
1	Material area	35	15	525
2	Shear zone	30	15	450
3	Edge milling area	30	15	450
4	Coil area	25	15	375
5	Splicing area	20	15	300
6	Welding zone	25	15	375
7	Flaw detection area	15	15	225
8	Maintenance area	10	15	150
9	Paint area	30	15	450
10	Storage area	50	15	750

4 Case Study

4.1 Data Collection

This paper aims to use SLP to optimize the workshop layout, and then utilize FlexSim simulation to analyze the effectiveness of the proposed layout scheme. This section elaborates on the air cylinder production workshop layout of Company M as the research object. Company M was founded in 2004 and is a small and medium-sized enterprise specializing in the production, manufacturing, and maintenance of cranes. It is located in Jiangsu Province. The factory has more than 100 employees. The company has been committed to supporting services for the construction and repair of domestic and foreign ship products. The company covers an area of approximately 36,000 m^2 and has a building area of approximately 20,000 m^2. The workshop area is approximately 6,000 m^2, with a length of 120m and a width of 50m. There are 10 job units in the workshop. The handling cost of the workshop is roughly ¥65 $\times$ 10^{-3}/(m·kg). It also shows the area requirements for each job unit to meet production in Table 1.

The volume-distance product between each job unit is determined based on the formula "volume-distance product = logistics volume* transportation distance", and the results are shown in Table 2. The volume-distance product of a job unit reflects the overall logistics load between two job units with material handling relationship. The larger the value, the more difficult the transportation between the two job units, and the more consideration and attention should be given to the system layout planning.

4.2 Parameter Setting

Static parameter setting.

The main components of the simulation model include workshop layout setting, equipment location setting, and material and transportation vehicle setting. The workshop layout mainly includes the position of the workshop, the size of the workshop

Table 2. Operator's response to span product

Serial No.	Unit pair	Material flow (t)	Transport Distance (m)	Product (t·m)
1	1 ~ 2	13.32	25	333
2	1 ~ 5	2.38	15	35.7
3	1 ~ 6	0.32	35	11.2
4	1 ~ 8	0.85	65	55.25
5	2 ~ 3	10.88	65	707.2
6	3 ~ 4	10.55	35	369.25
7	4 ~ 5	10.55	25	263.75
8	5 ~ 6	12.93	45	581.85
9	6 ~ 7	13.25	60	795
10	6 ~ 8	0.34	20	6.8
11	6 ~ 10	12.26	40	490.4
12	7 ~ 8	1.98	35	69.3
13	7 ~ 9	13.25	25	331.25
14	9 ~ 10	13.25	35	463.75

area, and the specific situation of the transportation road. The static parameter design of the workshop layout will be imported into Flexsim according to the layout design of the original scheme and the improved scheme, scaled by a certain proportion. The equipment location setting refers to the production equipment and storage rack sizes in each workshop, which are set according to the default size in the Flexsim software. To facilitate layout, their positions are determined in the center of the workshop. The material and transportation vehicle settings are mainly set to default sizes in the simulation model, as different sizes of materials and transportation vehicles do not affect the simulation results.

Dynamic parameter setting.

The dynamic parameter setting mainly includes generator parameter setting, processor parameter setting, synthesizer parameter setting, and AGV parameter setting.

- Generator parameter setting: In the generator attribute, set the entity type to "product", set the item name to "product", and the product quantity is the input quantity of 50 components per week, with the arrival mode set to "arrival sequence".
- Processor parameter setting: The processing time required for each workshop varies depending on the nature of the work. Taking the coil area as an example, the standard processing time is 20 min under normal conditions. Due to the interference of other disturbance factors, the actual processing time is uniformly distributed within the range of $\pm$ 5 min. The processing capacity of each processor is set to 1.
- Synthesizer parameter setting: The synthesizer is located in the assembly workshop and represents the assembly of components into a whole. The standard assembly time

Table 3. The ranking table of the combined proximity of each job unit

Number	1	2	3	4	5	6	7	8	9	10
1		A/4	U/0	U/3	E/3	E/3	U/0	O/1	U/0	U/0
2	A/4		A/4	U/0	U/0	U/0	U/0	U/0	U/0	U/0
3	U/0	A/4		E/3	U/0	U/0	U/0	U/0	U/0	U/0
4	U/0	U/0	E/3		E/3	U/0	U/0	U/0	U/0	U/0
5	E/3	U/0	U/0	E/3		A/4	U/0	U/0	U/0	U/0
6	E/3	U/0	U/0	U/0	A/4		A/4	O/1	O/1	I/2
7	U/0	U/0	U/0	U/0	U/0	A/4		I/2	E/3	U/0
8	O/1	U/0	U/0	U/0	U/0	O/1	I/2		U/0	U/0
9	U/0	U/0	U/0	U/0	U/0	O/1	E/3	U/0		E/3
10	U/0	U/0	U/0	U/0	U/0	I/2	U/0	U/0	E/3	
Total	11	8	7	6	10	15	9	4	7	5
Sort	2	5	6	8	3	1	4	10	7	9

is set to 30 min, and the actual assembly time is uniformly distributed within the range of ± 5 min. Therefore, the time setting of the synthesizer follows a Uniform (25, 35) distribution.

- AGV parameter setting: The transportation of materials between workshops is performed by AGV vehicles, and the time parameter settings are consistent, with the unit being m/min. The maximum speed of the AGV vehicle for executing transportation tasks is set to 60 m/min, the capacity of each transportation is set to 1, and the acceleration and deceleration time are both set to 1.

4.3 Optimal Work Shop Layout Scheme Design

Based on the existing workshop layout, the job units within the workshop are numbered as follows: 1. material area, 2. shearing area, 3. milling area, 4. rolling area, 5. splicing area, 6. welding area, 7. inspection area, 8. maintenance area, 9. painting area, and 10. storage area.

First, a table of comprehensive closeness degree ranking is drawn based on the above data. The comprehensive closeness degree represents the "status" of the job unit in the layout process. The larger the comprehensive closeness degree, the closer the unit is placed to the center position, and the smaller the comprehensive closeness degree, the further away from the center position. As shown in Table 3.

Second, draw a chart of job unit area correlation. Draw a rectangular geometric frame with the symbol of each job unit's nature of work as the center. The job unit area correlation chart of M company's production workshop is shown in Fig. 4.

Finally, based on the simulation model parameters set in the previous text, a simulation model is established, and the final result is shown in Fig. 5.

4.4 Results

Based on the simulation results, an analysis table is drawn as shown in Table 4.

Obviously, the proposed scheme includes the following significant improvements:

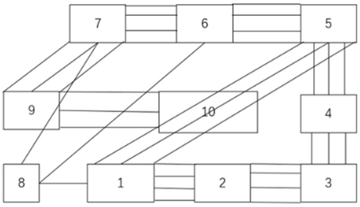

Fig. 4. Operating unit area chart

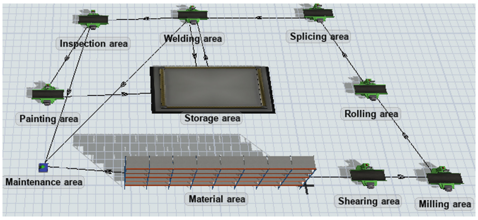

Fig. 5. Static effect diagram

Table 4. Comparative analysis table

Comparative item	Initial plan	Improvement plan
Carrying distance (m)	405	380
Handling cost (¥)	284852.75	239499
Production efficiency (per hour)	1.1	1.4

- The transportation distance is shorter. The original scheme has a transportation distance of 405 m, while the improved scheme has a transportation distance of 380 m. The improved scheme shortened the transportation distance by 25 m compared to the original scheme, so the transportation distance of the improved scheme is shorter.
- The transportation cost is lower. The transportation cost of the original scheme is ¥284,852.75, while the transportation cost of the improved scheme is ¥239,499. The transportation cost of the improved scheme is reduced by ¥45,453.75 compared to the original scheme.
- The production efficiency is higher. The original scheme produces 1.1 products per hour, while the improved scheme produces 1.4 products per hour. The production efficiency of the improved scheme is higher than that of the original scheme.

5 Conclusion

Currently, ship equipment manufacturing enterprises face problems such as high internal transportation costs and low production efficiency in their production processes. In particular, their ability to respond to risks is insufficient, as seen during the COVID-19 pandemic where poor management seriously affected the development of enterprises.

This study focuses on the layout of a typical ship equipment manufacturing enterprise workshop. Based on the existing problems in the internal workshop layout of the enterprise, an optimization scheme is proposed qualitatively based on the SLP method. Using Flexsim simulation analysis with transportation cost and production efficiency as two important evaluation indicators, the changes before and after the layout are compared. The results confirm that the proposed scheme reduces production costs by ¥45,453.75 and increases production efficiency by 0.3 products per hour.

The workshop layout scheme designed in this study provides inspiration for layout optimization of ship equipment manufacturing enterprises of the same type and contributes to improving internal costs and efficiency of enterprises. However, this study still has limitations: (1) the proposed assumptions have not been fully released yet; (2) variable costs were not considered in the layout optimization to enable more comprehensive thinking and adjustments; (3) other related factors such as personnel fatigue and waiting time for processes were not considered. The research content is not comprehensive enough, and future research needs to improve and address these details.

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