Study on the Optimization of X Warehouse Layout Based on SLP and Flexsim

Tianjiao Wu[1,*], Ran An[2]
[1]*School of Economics and Management, Jiao Zuo College of Industry and Trade, Jiaozuo, Henan, China*
[2]*Beijing Wuzi University, Beijing, China*
**Corresponding Author.*

Abstract: A warehouse functions as a vital hub linking various departments, and its layout and management possess substantial potential for enhancement. Therefore, optimizing the warehousing structure is pivotal for enterprises to achieve success in a constantly evolving market environment. X Warehouse specializes in the production, storage, and sale of compound fertilizers and other related products. To address the inefficiencies in the layout of X Warehouse's operational areas, this paper adopts the SLP (Systematic Layout Planning) method to delineate the functional zones within the operational area. It conducts an in-depth analysis of the logistics and non-logistics relationships as well as the comprehensive interactions among these functional zones. Subsequently, a positional relationship diagram of each functional section is created. By integrating the specific conditions of the operational area, an optimized layout plan is formulated and further validated through Flexsim simulation analysis to determine the most effective scheme.

Keywords: SLP Method; Warehouse Layout Optimization; Flexsim Simulation Design; Operational Area Layout

1. Introduction

X Warehouse is a large-scale facility under the enterprise's umbrella, specializing in the production of compound fertilizers and other related products. This study focuses on X Warehouse, which is broadly divided into several functional zones, including the raw material storage, production area, processing area, conversion area, and finished goods storage. As the enterprise has expanded its operations, issues such as inefficient layout and low operational efficiency have surfaced. The current layout no longer suffices to meet the business needs. Against this backdrop, this paper aims to optimize the warehousing layout of the X Warehouse's operational areas, thereby enhancing the overall process efficiency and addressing the existing problems to facilitate further development of the enterprise.

2. Current Status and Problem Analysis of X Warehouse

Warehouse layout involves the scientific planning and design of various elements such as the scale, geographical location, facilities, and roadways within a designated area [1]. Based on the original data collected for X Warehouse, the basic area of each functional partition is determined, as shown in Table 1.

Table 1. Area Distribution of Functional Zones

No.	Functional Areas	Area (m²)
1	Raw Material Storage 2	39,600
2	Raw Material Storage 1	25,000
3	Feeding Area	6,000
4	Workshop Line 1	32,400
5	Finished Goods Storage 1	100,800
6	Raw Material Storage 3	40,500
7	Production Tower	21,000
8	Finished Goods Storage 2	94,500
9	Raw Material Storage 4	42,000
10	Hazardous Materials Storage	4,800
11	Absorption and Conversion Process	4,800
12	Workshop Line 3	4,800
13	Workshop Line 2	9,600
14	Finished Goods Storage 3	52,500

To meet the layout planning requirements, the arrangement of X Warehouse must adhere to the product operations workflow, ensuring the accuracy of each step. This paper selects three

Copyright @ STEMM Institute Press

different product processes that cover each functional area to analyze specific issues, namely Product A, Product B, and Product C. The operation workflows and the daily forklift transport volumes are detailed in Table 2.

Table 2. Process Routes and Transport Volumes in X Warehouse

Product No.	Process Route	Daily Forklift Transport Weight (kg)
A	Raw Material Storage 2—Raw Material Storage 1—Feeding Area—Workshop Line 1—Finished Goods Storage 1—Finished Goods Storage 2	130
B	Raw Material Storage 2—Raw Material Storage 3—Production Tower—Finished Goods Storage 2—Finished Goods Storage 1	56
C	Raw Material Storage 4—Hazardous Materials Storage—Absorption and Conversion Process—Workshop Line 3—Workshop Line 2—Finished Goods Storage 3	10

The operational workflow of X Warehouse is illustrated in Figure 1.

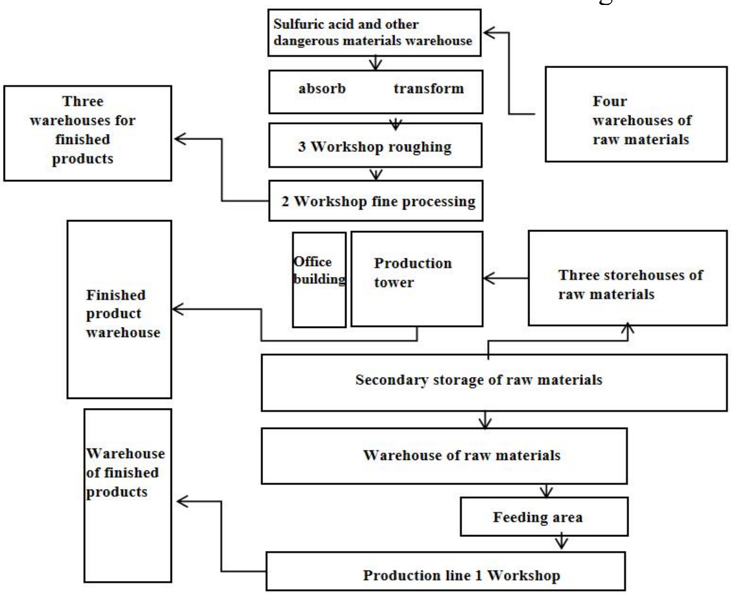

Figure 1. Operational Workflow of X Warehouse

Firstly, there exists an irrational layout of the operational zones. The Raw Material Storage 2 is located far from the feeding area and the production line for Product A, resulting in long transport distances. Additionally, the raw material storage areas are spread out. During processes such as raw material storage, replenishment, and inspection, the transport routes are excessively long, leading to increased management time costs.

Secondly, there is a low efficiency in certain operational processes. According to operational data, during material handling, goods experience prolonged congestion, up to 4.52 hours. Analyzing the entire process comprehensively, the average congestion time at intermediate stages reaches 1.96 hours. Moreover, in X Warehouse, forklifts and racks remain idle for approximately 2.16 hours. Additionally, there is a queue congestion issue with vehicles during the dispatch of finished products.

3. Warehouse Layout Planning Based on SLP Method

3.1 SLP Method

Generally speaking, Systematic Layout Planning (SLP) is a systematic, progressive method applicable to various fields [2]. Research indicates that using SLP technology can significantly reduce material handling moments by 17%, thereby considerably lowering material handling costs [3].

Based on the original data from X Warehouse, the suppliers provide sufficient supply, and upon receiving orders, the warehouse can either proceed with production and dispatch according to the order quantity or directly extract goods from the finished goods area for dispatch. The original data is detailed in Table 3.

Table 3. Original Data of X Warehouse

Symbol	Meaning	Original Data
P (Production)	Product, Material, or Service (Logistics Object)	Bagged Compound Fertilizer
Q (Quantity)	Quantity or Production Volume (Material Amount)	Single handling 50 kg, daily output unstable
R (Routing)	Routing or Process Route (Logistics Operation Route)	Three operational routes
S (Supporting service)	Supporting Service (Functional Management, Service Department)	Management departments such as offices
T (Time)	Time or Schedule (Logistics Operational Technical Level)	Single working day 8 hours, average production line output 3,271 tons (for March)
E (Entry)	Entry or Customer	Demand unstable
I (Item)	Item	Bagged compound fertilizer and other fertilizers
Q (Quantity)	Order Quantity	Daily order minimum averages 4,845 tons
Y (BP Forecast Value)	Forecast value of storage demand	Average storage demand is 1,607,060 tons

3.2 Analysis of Logistic Correlation in Functional Areas

X Warehouse is divided into 14 functional areas. First, the operational distances between each functional area are determined based on their locations, and a table is created to detail the distances between operational units. Next, a table is drawn to represent the transport volumes between these operational units according to the warehouse's logistic operational processes. Finally, by multiplying the transport volumes by the corresponding distances, as indicated in the distance and transport volume tables, the logistic intensity is calculated.

The logistic intensity table is summarized as shown in Table 4.

Based on the classification of logistic intensity and the logistic intensity table, 13 logistic routes are identified. After recognizing the logistic intensity for each route, a logistic interrelationship diagram of the various operational units is drawn, as illustrated in Figure 2.

Table 4. Summary of Logistic Intensity

No.	Route	Logistic Intensity	Classification
1	5-8	9300	A
2	1-2	6500	E
3	3-4	6500	E
4	2-3	4550	E
5	4-5	3900	I
6	7-8	2520	I
7	1-6	1120	I
8	6-7	560	I
9	9-10	300	O
10	13-14	300	O
11	12-13	200	O
12	10-11	100	O
13	11-12	50	O

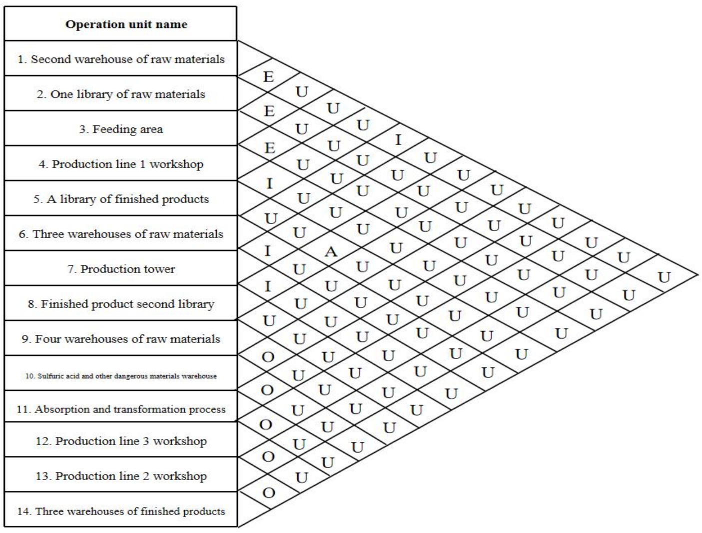

Figure 2. Logistic Interrelationship

3.3 Analysis of Non-logistic Correlations in Functional Areas

In addition to the logistic relationships, there exist complex non-logistic relationships among the various functional areas, such as equipment, personnel allocation, and environmental management, all of which are crucial factors influencing operational efficiency [4]. While logistic relationships can be quantified using logistic intensity, non-logistic relationships cannot be measured quantitatively and must be analyzed qualitatively. These factors should number fewer than ten and be included in the rationale for relationship classification to better assess their interrelationships [5].

Based on the issues in warehouse layout previously mentioned, the criteria for judgment are as shown in Table 5, with the degree of correlation detailed in Table 6.

Table 5. Evaluation Factors for Non-logistic Interrelationships in X Warehouse

No.	Rationale for Relationship Classification	Weight
1	Continuity of Operational Processes	a_1
2	Similarity of Operations	a_2
3	Management Convenience	a_3
4	Personnel Interaction	a_4
5	Material Handling	a_5
6	Segregation of People and Vehicles	a_6
7	Environmental Hygiene	a_7
Note: $a_1 + a_2 + a_3 + a_4 + a_5 + a_6 + a_7$=1		

Table 6. Degree of Correlation

Degree	Description	Weight
A	Absolutely Necessary	5
E	Very Important	4
I	Important	3
O	Fairly Important	2
U	Unimportant	1
X	Should Not Be Close	-1

Based on the actual operational process of X Warehouse, a non-logistic relationship diagram between the functional areas is drawn through qualitative analysis. The degree of connection between two areas is represented by the letters in the parallelograms of the diagram below, while the numbers beneath the horizontal lines indicate the type of association between the two areas. As illustrated in Figure 3.

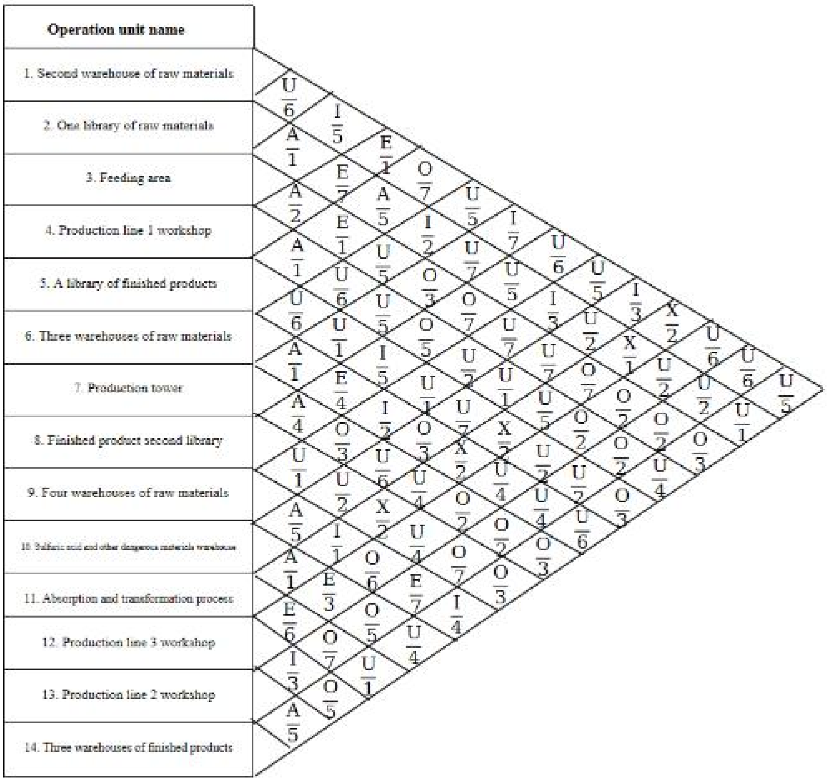

Figure 3. Non-logistic Interrelationship

3.4 Comprehensive Analysis of Interrelationships in Functional Areas

Both logistic and non-logistic relationships play a crucial role in X Warehouse, with the former having a greater impact. However, the importance of environmental hygiene and personnel management should not be overlooked. Therefore, this paper defines the contribution ratio of these two types of relationships as 2:1 [6]. The comprehensive correlation C_{ij} can be calculated using the following formula:

$$C_{ij} = mM_{ij} + nN_{ij} \quad (1)$$

Where, $m=2$, $n=1$, M_{ij} refers to the weight corresponding to the logistic relationship grade, and N_{ij} refers to the weight corresponding to the non-logistic relationship grade. By evaluating the non-logistic factors in different functional areas of the warehouse, we can determine their non-logistic relationship grades. Combining these with the comprehensive weighted coefficients of logistic and non-logistic relationships, we can draw a comprehensive relationship diagram, as shown in Figure 4.

The interrelationships between the various areas are expressed as comprehensive correlation degrees represented by letters such as A, E, I, O, and U, as shown in Table 7.

After analyzing the relative positions between the functional areas, the area of each functional zone is determined. By drawing a proportional area chart, the relative positions of each functional area are more accurately reflected, while fully considering the area proportions of the original functional areas [7], as shown in Table 8.

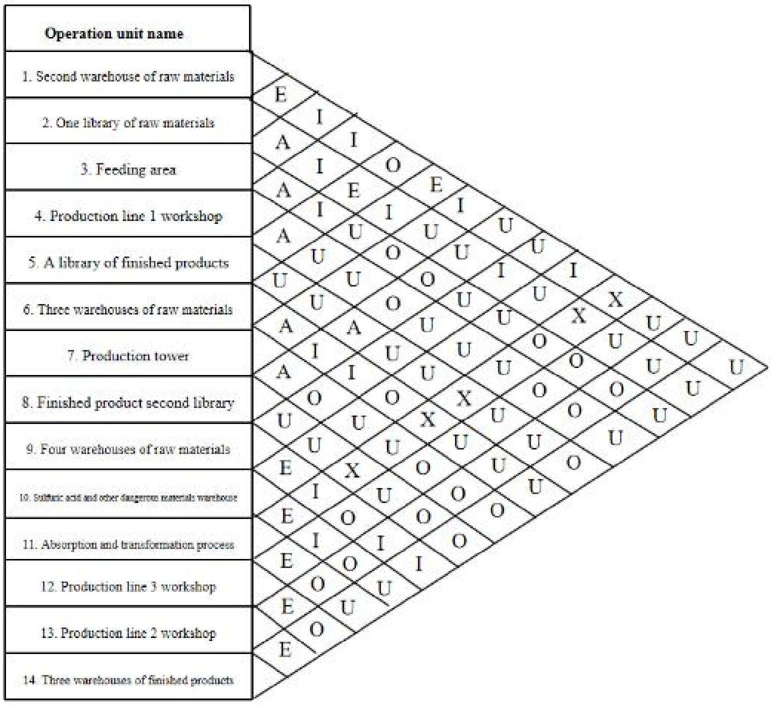

Figure 4. Comprehensive Relationship

Table 7. Comprehensive Relationship Degrees

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Raw Material Storage 2		E	I	I	O	E	I	U	U	I	X	U	U	U
Raw Material Storage 1	E		A	I	E	I	U	U	I	U	X	U	U	U
Feeding Area	I	A		A	I	U	O	O	U	U	O	O	O	U
Workshop Line 1	I	I	A		A	U	U	O	U	U	U	O	O	U
Finished Goods Storage 1	O	E	I	A		U	U	A	U	U	X	U	U	O
Raw Material Storage 3	E	I	U	U	U		A	I	I	O	X	U	U	U
Production Tower	I	U	O	U	U	A		A	O	U	U	O	O	O
Finished Goods Storage 2	U	U	O	O	A	I	A		U	U	X	U	O	O
Raw Material Storage 4	U	I	U	U	U	I	O	U		E	I	O	I	I
Hazardous Materials Storage	I	U	U	U	U	O	U	U	E		E	I	O	U
Absorption and Conversion Process	X	X	O	U	X	X	U	X	I	E		E	O	U
Workshop Line 3	U	U	O	O	U	U	O	U	O	I	E		E	O
Workshop Line 2	U	U	O	O	U	U	O	O	I	O	O	E		E
Finished Goods Storage 3	U	U	U	U	O	U	O	O	I	U	U	O	E	
Comprehensive Proximity Degrees	14	15	17	15	13	13	15	13	14	12	5	12	14	9
Ranking	5	2	1	3	8	9	4	10	6	11	14	12	7	13

Table 8. Proportional Area Data

No.	Functional Areas	Area (m²)	Proportion (%)
1	Raw Material Storage 2	39,600	8
2	Raw Material Storage 1	25,000	5
3	Feeding Area	6,000	1
4	Workshop Line 1	32,400	6
5	Finished Goods Storage 1	100,800	21
6	Raw Material Storage 3	40,500	8
7	Production Tower	21,000	4
8	Finished Goods Storage 2	94,500	20
9	Raw Material Storage 4	42,000	9
10	Hazardous Materials Storage	4,800	1
11	Absorption and Conversion Process	4,800	1
12	Workshop Line 3	4,800	1
13	Workshop Line 2	9,600	2
14	Finished Goods Storage 3	52,500	11

Three optimized layouts incorporating the proportional areas are obtained. Although SLP has certain limitations, its effectiveness can be significantly enhanced when combined with other techniques, thereby fully leveraging the advantages of SLP [8]. This study employs the Flexsim simulation software to run the above results, aiming to derive the optimal layout.

4. Flexsim Simulation Modeling and Operation

4.1 Simulation Elements

The simulation elements correspond to the functional area layouts, with the specific modeling entities detailed in Table 9 below [9].

Table 9. Simulation Modeling Entity Description

Entity Name	Simulation Description	Model Instance
Generator	Simulating the generation of products and pallets	Raw material warehousing, pallet creation
Storage Area	Simulating temporary storage of goods	Storage in each functional area
Processor	Simulating production activities	Production and processing
Forklift	Simulating transportation and unloading	Transportation of materials and finished goods
Shelf	Simulating storage of goods	Representing raw material and finished goods areas
Combiner	Simulating order picking and packaging	Goods processing and handling
Absorber	Simulating customer receipt of goods	Finished goods dispatch

4.2 Modeling and Simulation Operations of X Warehouse Layout

Based on the arrangement of functional areas in the X Warehouse, a simulation model of the X Warehouse layout is created, with the operation flow of each entity identified. Flexsim simulation software offers two viable methods for determining the termination time: adjusting the length of the simulation time and setting the number of simulation events [10]. To more accurately simulate the compound fertilizer operations of the X Warehouse, the simulation time is set to one day, or 8 hours, totaling 28,800 seconds, to make the warehouse operation process more realistic.

4.3 Analysis of Simulation Results for X Warehouse Layout

The simulation run yields a series of data. The dwell time of physical products on the shelves is assumed to be the same by default. The data is analyzed separately to compare the capacities of the entities. As illustrated in Figure 5 below:

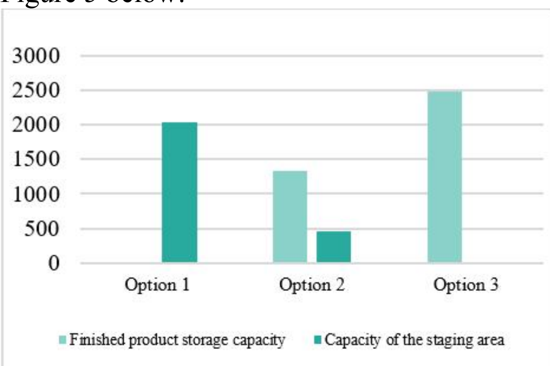

Figure 5. Comparison of Entity Capacities in the Finished Goods Storage

The simulation data is analyzed, and over a single 8-hour workday, the storage capacities for finished products and temporary storage areas are as follows: Scenario 1 stores a combined total of 2,037 entities, Scenario 2 stores 1,807 entities, and Scenario 3 stores 2,483 entities. In Scenario 3, the output storage capacity is 2,483 entities, whereas it is 0 and 1,340 entities for Scenarios 1 and 2 respectively.

Thus, Scenario 3 demonstrates the highest production storage capacity and flow rate among the three layout configurations.

A comparative analysis is conducted on the overall idle and loaded travel times for forklifts based on the simulation data. As illustrated in Figure 6:

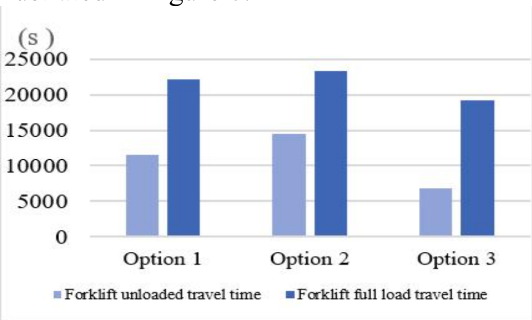

Figure 6. Forklift Travel Time

In the simulation of Scenario 1, the total idle travel time for all forklifts is 11,584.78 seconds and the loaded travel time is 22,087.39 seconds. For Scenario 2, the idle travel time is 14,521.73 seconds, and the loaded travel time is 23,270.08 seconds. Scenario 3 shows the shortest idle travel time of 6,832.9 seconds, with a loaded travel time similar to the other scenarios, at 19,241.76 seconds.

The idle travel ratio of forklifts (idle travel time/loaded travel time) for each scenario is shown in Figure 7:

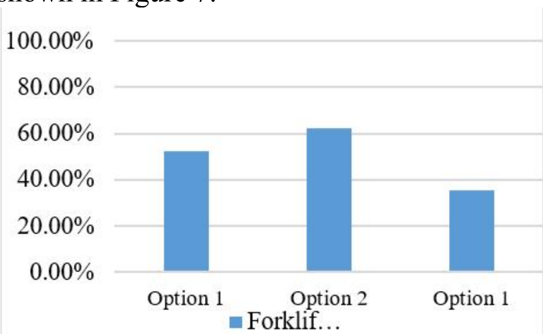

Figure 7. Forklift Idle Travel Ratio

In Scenario 1, the idle travel ratio is 52.44%. Scenario 2 has the highest idle travel ratio at 62.40%, while Scenario 3 has the lowest idle travel ratio at 35.51%.

The average dwell time of entities in the raw materials storage is summarized in Figure 8:

Figure 8. Average Dwell Time of Entities in Raw Materials Storage

It can be seen that the average residence time of the raw material warehouse in Scheme 1 is 14954.82091s, that in scheme 2 is 15114.05733s, and that in scheme 3 is 12988.06658s. By comparison, the average residence time of the raw material warehouse in scheme 3 is the shortest and the highest.

Based on the above data analysis of the finished product area, forklift, raw material area, etc., the layout of plan 3 is the optimal layout from the perspective of the output of goods, the flow of entities, and the handling of transport vehicles such as forklifts.

4.4 X Warehouse optimal layout scheme determined

According to the above, a series of optimization of the layout of X warehouse is carried out, and the optimal layout scheme of X warehouse operation area is obtained, as shown in Figure 9.

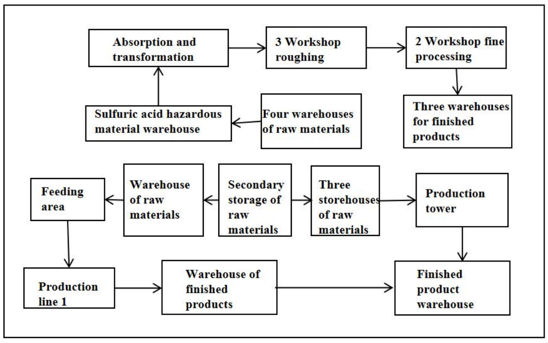

Figure 9. Optimal layout scheme diagram

On the whole, scheme 3 takes a long time to get out of storage, and the efficiency of operation process is low. After the solution is proposed, the simulation results show that the average capacity of the optimized simulation scheme is 1122.27, and the total output capacity is 17633. By comparison, the operation capacity of X warehouse is increased

Copyright @ STEMM Institute Press

by 28.71%, and the physical output of X warehouse is increased by 16.54%. At the same time, the average residence time of the entity on the equipment in each functional area was 5529.849s, and the working time was shortened by 21.08%.

5. Conclusion

Compared with the original layout diagram of the X warehouse, the raw material warehouse in the layout diagram of the optimization scheme is concentrated together, which facilitates the quick extraction of materials for each production line, and the finished product warehouse is concentrated in the periphery, which facilitates the timely and rapid exit of the warehouse. The driving route of each functional area is the shortest straight line, and the process flow is concentrated together, which shortens the working time. Therefore, this study has certain reference significance.

References

[1] Sun Jiaying. Research on Optimization of storage facility layout of X Company. Shenzhen University,2019.
[2] Ding Heping, Yang Hailong. Application of Dynamic SLP method in supermarket facility layout: A case study of Suzhou RT-Mart Supermarket. Journal of Suzhou University,2016,31(07):38-41.
[3] Pratami D, Iqbal M, Puspita I A, et al. The Development of Plant Layout Design Framework. Advanced Science Letters,2017.
[4] Giopelin, Shang Meng. Research on layout planning of supermarket facilities based on improved SLP. China Collective Economy,2021(22):74-76.
[5] Zhou Lei. Application of SLP in warehouse layout optimization. Jiangsu Science & Technology Information,2016(26):17-20.
[6] Zhang Mengxia, Shen Hui. Research on Warehouse layout optimization of S Company. China Storage & Transport,2021(10):161-162.
[7] Zhang Yongqiang, Li Xingyuan. Optimization of forest products storage layout based on SLP and SHA. Journal of Forestry Engineering, 2019,6(01):171-177. (in Chinese)
[8] LI Min. Research on Warehouse Layout Optimization of LS Company. Dalian University of Technology,2017.
[9] Zhao Lingxing, Zhong Liangwei. Optimization Simulation of Intelligent Warehouse System based on Flexsim. Software Guide,2018,17(04):161-163.
[10]Lu Shichang, Wang Yawei. A Study on Layout simulation and Optimization of Enterprise automated Warehouse: Based on Flexsim and TOPSIS. Manufacturing Automation, 2019,42(07)10-14

 Copyright @ STEMM Institute Press