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SLP Approach Based Facility Layout Optimization: An Empirical Study

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Abstract: Favorable facility layouts could effectively improve production efficiency, reduce production cost, and improve comprehensive competitiveness. Take the inefficient workshop facility layout of the H Company as an example, the paper studies both transportation and processing cycle for raw materials of its main products, records statistically transport distances and transport weights for each raw material in each processing workshop, and discovers principal issues in the transportation and processing cycle for the H Company. This paper adopts the Systematic Layout Planning (SLP) approach to optimize the layout design of the H Company, and compares non-optimized layout scheme with optimized one from qualitative and quantitative analysis aspect by using the analytic hierarchy process approach. The results show that the application of SLP approach in the H Company could enhance obviously the performance of its workshop facility layout.

Keywords: Systematic Layout Planning (SLP), Facility Layout Optimization, Empirical Study, Analytic Hierarchy Process

1. Introduction

From the beginning of the first industrial revolution, the world economy kept developing rapidly, especially for the manufacturing industry. In order to meet individualized requirements for candidate consumers, enterprises are required to possess favorable yet flexible facility layout for reducing material transportation costs. Favorable facility layouts could effectively reduce production cost and improve production efficiency [1]. Substantial productive practices indicate that costs from non-processing cycles, such as material transportation and material storage, account usually for 20% to 50% of the overall cost occurred in the production manufacturing process [2]. As a result, it makes sense to study the workshop facility layout of the referred H Company based on the SLP method.

2. Related Theories

2.1. SLP Approach

Systematic Layout Planning (SLP) approach was developed by Muther [3] in 1961. There are many subsequent applications of the SLP approach. Ye [4] et al. introduced the Genetic Algorithm into the SLP approach for solving optimized plane layout scheme. Zhao [5] et al. combined the Genetic Algorithm and the Simulated Annealing Algorithm for solving the layout issue in mechanical operation workshops. In the 21st century, many emerging technologies or systems, such as Modern Manufacturing Technology, Flexible Manufacturing Systems (FMS), Computer Integrated Manufacturing Systems (CIMS), and Just In Time (JIT) Manufacturing, are used to assist designs of material transportation and material layout [1]. Chang [6] et al. performed a comprehensive research on the facility layout by using the modern design technology. Huang et al.[7] proposed a discretized cell optimization model to optimize site space usages. Xin et al. [8] presented a layout optimization methodology for the topside deck of a floating-liquefied-natural-gas facility (FLNG) using inherent safety principles.

The application of the SLP approach transfers solutions of facility layout issues from independent qualitative analysis or quantitative analysis, to a combined qualitative and quantitative analysis. Furthermore, the SLP approach could take into account not only logistics factors but also non-logistics factors among workshop operations. There are five elements in the SLP approach, which are Product (P), Quantity (Q), Routing (R), Support Services (S), and Timing Data (T) [9].

2.2. Analytic Hierarchy Process Approach

Analytic Hierarchy Process (AHP), based on mathematics and psychology, is a multi-criteria approach for organizing and analyzing complex decisions. It was widely used in almost all the applications related with decision-making [10].

Besides, after the design of the workshop facility layout, AHP approach could be adopted to evaluate generally three layout schemes, and thus to generate an optimized scheme with the SLP approach.

3. Present Situation Analysis for the Workshop in the H Company

The H Company is a large auto parts manufacturing enterprise, and provides automotive manufacturers with auto parts and corresponding automotive product services. The geographical scope of its product markets covers multiple provinces in China, and several foreign countries. Chief products of the H Company includes windshield wipers (available sizes includes A-350mm, A-400mm, A-450mm, A-475mm, A-550mm, A-600mm, A-650mm, B-450mm, B-550mm, and B-600mm), manual rear windows, power rear windows, and washing products. The Workshop in the H Company adopts a rectangle layout, which has a length of 40 meters, together with a width of approximate 30 meters, and covers an area of about 1200 square meters.

Due to lacks of necessary plans and effective analysis, there are many shortcomings using the initial design for the workshop facility layout, such as unreasonable layout, poor production process, exorbitant cost for raw material transportation, and relatively low productivity.

3.1. Overall Plane Layout for Its Workshop Operation Units

There is a large workshop in the H Company. The layout of the workshop is determined by functional requirements in the production process. Besides, the overall plane layout can be divided into 15 sub-regions or operation units, as shown in Figure 1, where logistics transportation routes are marked with arrow lines, and abbreviations are defined as follows.

Stamp. Area: Stamping Area, Stamp. Process: Stamping Process, Assem. Area: Assembly Area, Integr. Area: Integrated Area, Wareho.: Warehouse, Mater. Area B: Material Area B, C. Prod. M. Area: Curtain Product Manufacturing Area, W. Prod. M. Area: Washing Product Manufacturing Area, Inspect. Area: Inspection Area, and Mater. Area A: Material Area A.

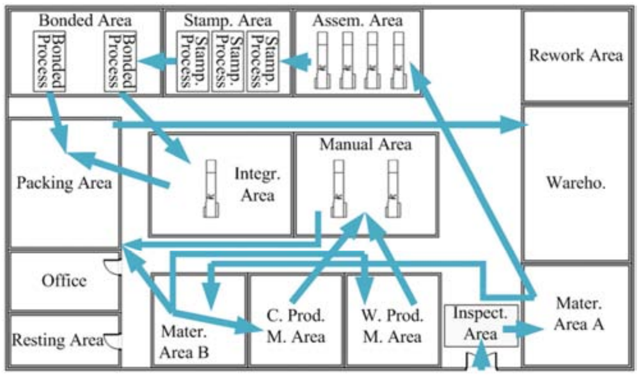

Figure 1. *The overall plane layout for the workshop in the H Company.*

3.2. Operation Process Chart

Through elaborate analyses on logistics transportation routes in Figure 1, an operation process chart for chief products of the H Company could be derived, as shown in Table 1, where Mod.: A-xxx mm inculdes A-350mm, A-400mm, A-450mm, A-475mm, A-550mm, A-600mm, A-650mm, and Mod.: B-xxx mm includes B-450mm, B-550mm, B-600mm.

Table 1. *The operation process chart for chief products of the H Company.*

Operation Process	Mod.: A-xxx mm	Mod.: B-xxx mm	Manual Rear Windows	Power Rear Windows	Washing Products
Inspect. Area	①	①	①	①	①
Mater. Area A	②	②			
Assem. Area	③	③			
Stamp. Area	④	④			
Bonded Area	⑤	⑤			
Integr. Area		⑥			
Mater. Area B			②	②	②
C. Prod. M. Area			③	③	
C. Prod. M. Area					③
Manual Area				④	④
Packing Area	⑥	⑦	④	⑤	⑤
Wareho.	⑦	⑧	⑤	⑥	⑥

3.3. Present Logistics Situation

There are mainly two logistics transportation routes for all kinds of spare parts in the workshop of the H Company. Specifically,

(1) Inspect. Area→Mater. Area A→Assem. Area→Stamp. Area→Bonded Area→Packing Area→Wareho.

(2) Inspect. Area→Mater. Area B→C. Prod. M. Area、W. Prod. M. Area→Manual Area→Packing Area→Wareho.

Through a careful observation and analysis of the present logistics situation of the H Company, we can discover several major issues. Specifically,

(3) The distance between Mater. Area B and Inspect. Area is too large, resulting in an inconvenient and time-consuming transportation.

(4) Material transportation becomes circulating, intersecting, and twisting, which reduces seriously logistics efficiency.

(5) Partial transport passages are not commodious enough for transportation. Besides, collisions between wheelbarrows and machines or products in the workshop are prone to take place, which will bring significant losses.

It can be concluded that the present workshop facility layout design of the H Company is unreasonable. As a result, how to optimize its layout, improve its material delivery process, and use effectively its original area, would be key issues in the workshop facility layout design.

4. Facility Layout of Workshop based on SLP

4.1. Logistics Analysis

4.1.1. From-To Chart of Total Logistics

As shown in Table 2, we can calculate the average daily output of chief products through field investigation and analysis with considering production planning table and demand table of H Corporation.

Table 2. *Daily output of chief products of the H Company.*

Categories	Chief Products	Daily Output (Sets)	Weight for Each Set (kg)	Overall Wei. (kg)	Overall Wei. for Ea. Ca.(kg)
Windshield Wipers	Mod.: A-350mm	720	0.08	57.6	3599.8
	Mod.: A-400mm	960	0.1	96	
	Mod.: A-450mm	1500	0.14	210	
	Mod.: A-475mm	960	0.16	153.6	
	Mod.: A-550mm	3600	0.18	648	
	Mod.: A-600mm	1260	0.2	252	
	Mod.: A-650mm	540	0.25	135	
	Mod.: B-450mm	1520	0.38	577.6	
	Mod.: B-550mm	2150	0.42	903	
	Mod.: B-600mm	1260	0.45	567	
Rear Windows	Manual Rear Windows	420	0.8	344.4	1880.4
	Power Rear Windows	960	1.6	1536	
Washing System	Washing Products	1800	2.8	5040	5040

According to the output of each product, the relative weight and the various raw materials moving distance between each operating units, the total amount of logistics can be calculated. Table 3 shows the from-to form of Total Logistics.

Table 3. *From-To form of total logistics.*

From	To	1 Office	2 Resting Area	3 Inspect. Area	4 Mater. Area A	5 Assem. Area	6 Stamp. Area	7 Bonded Area	8 Integr. Area	9 Mater. Area B	10 C. Prod. M. Area	11 W. Prod. M. Area	12 Manual Area	13 Rework Area	14 Packing Area	15 Wareho.
1	Office															
2	Resting Area															
3	Inspect. Area				25984					194940						
4	Mater. Area A					30383	28000	9984	27048							
5	Assem. Area						11610							500		
6	Stamp. Area							20250						190		
7	Bonded								11100					980	14900	

	To	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
From		Office	Resting Area	Inspect. Area	Mater. Area A	Assem. Area	Stamp. Area	Bonded Area	Integr. Area	Mater. Area B	C. Prod. M. Area	W. Prod. M. Area	Manual Area	Rework Area	Packing Area	Wareho.
	Area															
8	Integr. Area													240	18990	
9	Mater. Area B										5850	39780	13140			
10	C. Prod. M. Area												8200	480	5120	
11	W. Prod. M. Area												34240	1920		
12	Manual Area													1680	78120	
13	Rework Area			6050											3480	
14	Packing Area															298220
15	Wareho.															

4.1.2. Logistics Strength Grade

The logistics strength of the operation units are sorted, and then divided into five levels according to the strength between operation units, with the symbol A,E, I, O, U. There are twenty-eight pairs of operation units, which includes three pairs of level A about 10%,six pairs of level E about 20%,eight pairs of level I about 30%,eleven pairs of level O about 40%. And then we can get the Logistics strength analysis form, as shown in Table 4.

Table 4. *Logistics strength analysis form.*

SN	SN Pairs of Operation Units	Name Pairs of Operation Units	Logistics Strength	Logistics Strength Grade
28	14--15	Packing Area—Wareho.	298220	A
2	3--9	Inspect. area – Mater. Area B	194940	A
25	12--14	Manual Area -- Packing Area	78120	A
17	9--11	Mater. Area B --W. Prod. M. Area	39780	E
22	11--12	W. Prod. M. Area-- Manual Area	34240	E
3	4--5	Mater. Area A – Assem. Area	30383	E
4	4--6	Mater. Area A – Stamp. Area	28000	E
6	4--8	Mater. Area A – Integr. Area	27048	E
1	3--4	Inspect. area – Mater. Area A	25984	E
9	6--7	Stamp. Area -- Bonded Area	20250	I
15	8--14	Integr. Area -- Packing Area	18990	I
13	7--14	Bonded Area -- Packing Area	14900	I
18	9--12	Mater. Area B -- Manual Area	13140	I
7	5--6	Assem. Area – Stamp. Area	11610	I
11	7--8	Bonded Area – Integr. Area	11100	I
5	4--7	Mater. Area A -- Bonded Area	9984	I
19	10--12	C. Prod. M. Area-- Manual Area	8200	I
26	13--3	Rework Area—Inspect. area	6050	O
16	9--10	Mater. Area B --C. Prod. M. Area	5850	O
21	10--14	C. Prod. M. Area-- Packing Area	5120	O
27	13--14	Rework Area -- Packing Area	3480	O
23	11--13	W. Prod. M. Area-- Rework Area	1920	O
24	12--13	Manual Area -- Rework Area	1680	O
12	7--13	Bonded Area -- Rework Area	980	O
8	5--13	Assem. Area -- Rework Area	500	O
20	10--13	C. Prod. M. Area-- Rework Area	480	O
14	8--13	Integr. Area -- Rework Area	240	O
10	6--13	Stamp. Area -- Rework Area	190	O

4.1.3. Operation Units Logistics Correlogram

According to the structure and mode of from-to chart, we can draw a table to describe logistics relationship between each pair of operation unit, which is called as original logistics related table. In order to more concisely express the relationship among each operation unit, original logistics related Table will be adjusted and deformed into a triangular matrix, and then we can get the logistics correlogram, as shown in Figure 2.

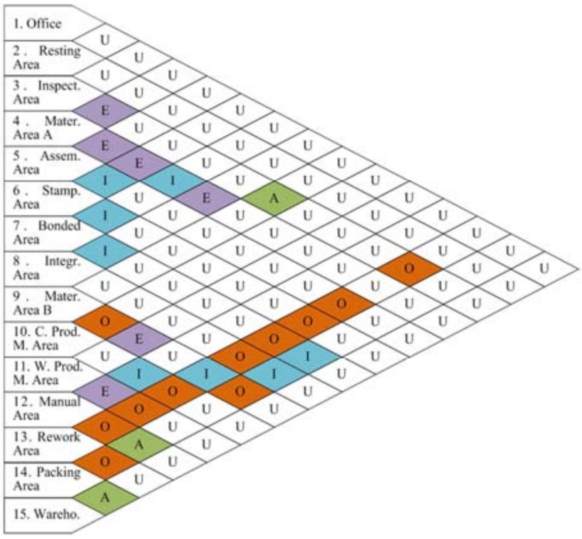

Figure 2. *Operation units logistics correlogram.*

4.2. Analysis on Non-Logistics Relationships

Material handling is s an important influencing factors to production workshop for a typical manufacturer. In actual production, there are parts of logistics relationship does not have important impact to production process. So, we should carry on analyzing non-logistics relationships.

According to reciprocity close degree between different operation unit, the SLP method divide them into six grades, with the symbol A, E, I, O, U, X.

As shown in Table 5, we could get reasons of relationship grades about different production workshop operation units, after the calculation about related logistics quantity and with the help of work experience.

By referring the Table 5, and with considering the actual situation of the production workshop about H Company as well as relationships between each operation unit and production process of all kinds of products, then we can carry on drawing non-logistics correlogram of each operation unit, as shown in Figure 3.

Table 5. *Reasons of relationship grades among operation units.*

SN	Reasons to Consider
1	Continuity of work flows
2	Transportation of materials
3	Convenience of management
4	Service condition of equipments and facilities
5	Convenience of communications and contacts
6	Level of noise and pollution

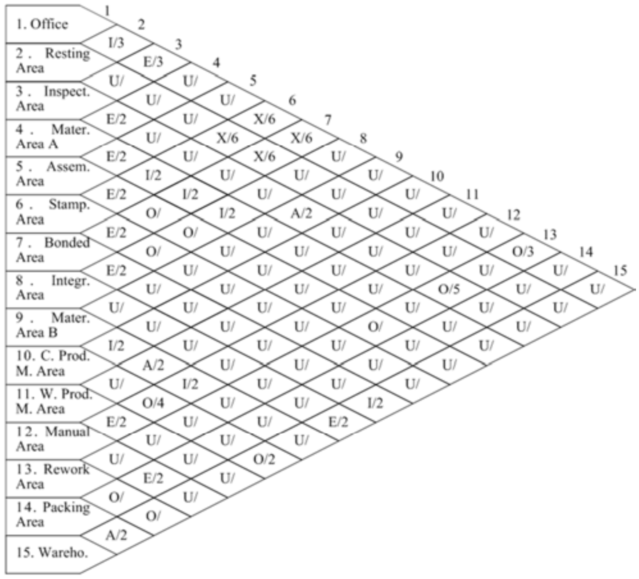

Figure 3. *Non-logistics correlogram of each operation unit.*

4.3. Analysis on Comprehensive Relationships between Each Operation Unit

In the production workshop of most manufacturing enterprises in China, each operation unit not only includes logistics factor, but also includes non-logistics factor. Therefore, in the design of SLP, it is important to consider the relationships include logistics and non-logistics, which is call as comprehensive relationship.

In this paper, the production workshop operation units are divided into five different grades, which give the corresponding scores. Table 6 shows grade-score relationships.

Table 6. *Grade-score relationships.*

Grades	Corresponding Scores
A	4
E	3
I	2
O	1
U	0
X	-1

Firstly, we should determine the importance degree of logistics and non-logistics in the workshop. Because of the large amount of the material handing in production workshop of the H Company, which means logistics relationships are the main factor. So weight ratio about logistics factor and non-logistics is set to 2:1. Then we can got the comprehensive grade-score relationship correlogram, as shown in Figure 4.

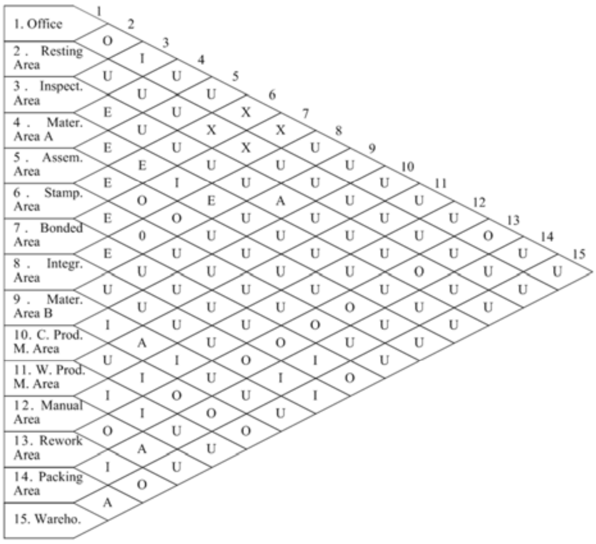

Figure 4. *Comprehensive grade-score correlogram.*

4.4. Design and Adjust of Layout Scheme

4.4.1. Area Independent Block Diagram

Then we carry on drawing the operating unit of the comprehensive correlogram of operating units after determine the logistics and non-logistics relationship between the units base on SLP theory. And then quantize the six grades relationships by using Tompkins's relational Table method, and finally we can draw the area independent block diagram, as shown in Figure 5.

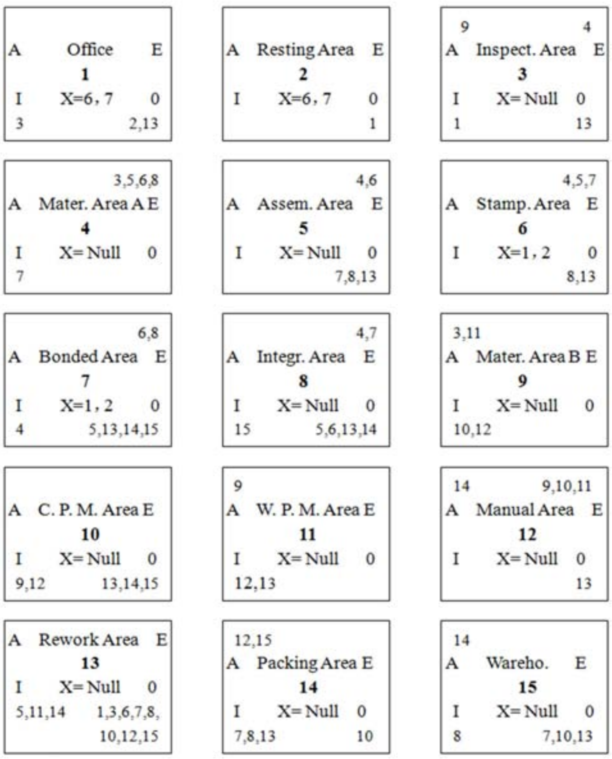

Figure 5. *Area independent block diagram.*

4.4.2. Placement and Evaluation about Area Independent Block

According to the rules of the Tompkins, the four kinds of area independent block schemes can be obtained, as shown in Figure 6.

According to the Tompkins Table method of scoring rules, we can abandon schemes C and D, for better schemes are A, B.

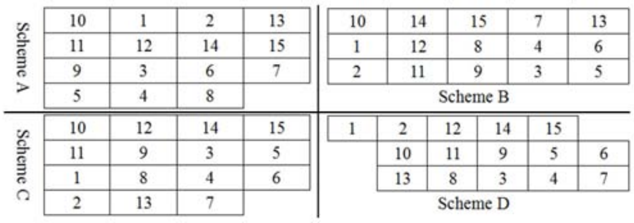

Figure 6. *Four kinds of area independent block schemes.*

4.4.3. Block Diagram Area Layout Design

There are two aspects should be considered when design the block diagram area layout. First, determine the basic shape of the building by analysis and determination of the area of each operation unit through actual processing demand. Then, assign the appropriate area for each correlation operation unit and draw block layout area diagram based on actual produce procedure demand area as well as area independent block diagram, as shown in Figure 7 and Figure 8.

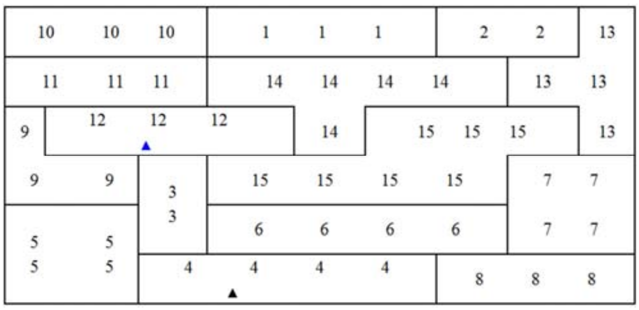

Figure 7. *Block layout area diagram for the Scheme A.*

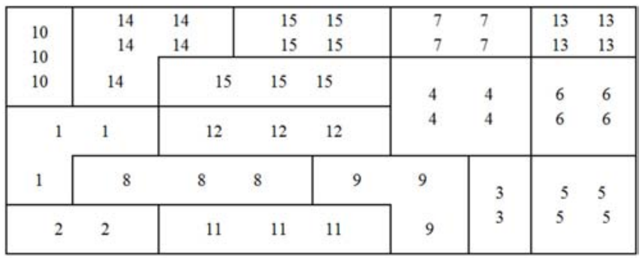

Figure 8. *Block layout area diagram for the Scheme B.*

Through field investigation and study of the workshop, then take grid layout of Figure 7 and Figure 8 into account. Finally we can succeed to obtain block layout area diagram, as shown in Figure 9 and Figure 10, which corresponds separately to scheme A and scheme B.

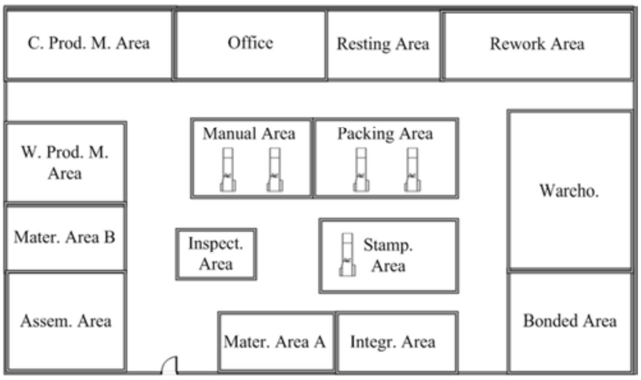

Figure 9. Block layout area diagram for the Scheme A.

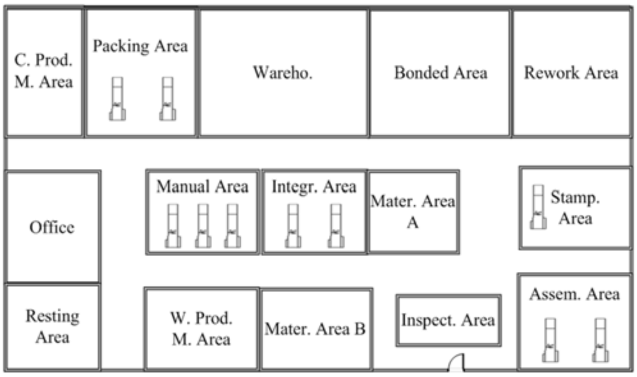

Figure 10. Block layout area diagram for the Scheme B.

4.5. Layout Scheme Evaluation and Choice

The evaluation method is the logistics transportation cost comparison method, which carries on quantitative analysis on original facility layout scheme and the two optimized scheme, and appraise logistics handling cost about three schemes. And then we can calculate the amounts of the product of weight and distance about three schemes, as shown in Table 7.

Table 7. Amounts of the product of weight and distance for each scheme.

Layout Schemes	Product Amount: S	Relative
Original Layout Scheme	891379	/
Layout Scheme A	536883	39.77%
Layout Scheme B	481014	46.04%

As it can be seen from the Table 7, the amount of the product of weight and distance of scheme A reduce about 39.77% compare to the original scheme, while amount of the product of weight and distance of scheme B reduce about 46.04% compare to scheme A. Scheme B significantly shortens the material handling route, greatly reducing the material handling costs of the H Company's production workshop.

4.6. Detailed Layout Diagram

We can draw the detailed layout diagram of the workshop in the H Company once we have determined the optimal scheme, as shown in Figure 11.

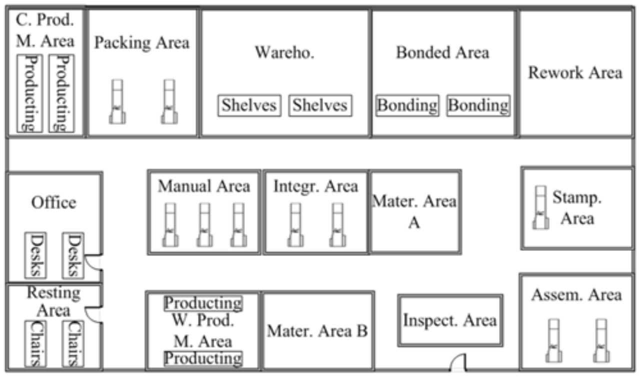

Figure 11. Detailed layout diagram of the workshop in the H Company.

5. Overall Evaluation of Layout Schemes Based on AHP Approach

This paper adopts one of the most well known system analysis engineering approaches, i.e., the AHP, to choose the best one from two candidate layout schemes after the optimization operations. The results show that the application of SLP approach in the H Company could enhance obviously the performance of its workshop facility layout.

5.1. Analytical Procedures Using AHP Approach

As one of the decision analysis approaches, the AHP is very efficient in solving complex decision making issues. Usually, the AHP includes three layers, which are upper layer, middle layer and bottom layer [11].

Once three layers in the AHP are built, all elements in each layer should be compared to corresponding element in higher layer using judgment matrices. Scales of those judgment matrices are defined in Table 8.

Table 8. Definitions for scales of judgment matrices when comparing element A with element B.

Scales	Implications
1	A is of equal importance with B
3	A is slightly more important than B
5	A is obviously more important than B
7	A is strongly more important than B
9	A is extremely more important than B
2, 4, 6, 8	Four medians among above five judgments

Seaty defined the Consistency Index (CI) as $CI = (\lambda_{\max} - n)/(n-1)$, and Consistency Ratio (CR) as $CR = CI/RI$ [12], where $\lambda_{\max}$ is the principal eigenvalue of a judgment matrix, n is the number of judgment alternatives, and RI is the average value of CI. Besides, the authors adopt the CR as an index for the rationality of those judgment matrices, where the consistency is satisfied when $CR < 0.1$. Available values of RI are shown in Table 9.

Table 9. Available values of RI.

n	1	2	3	4	5	6
RI	0	0	0.52	0.89	1.12	1.26

5.2. AHP Approach based Overall Evaluation for Layout Schemes

5.2.1. Establishing the Recursive Hierarchical Model

Firstly, a recursive hierarchical model can be derived, as shown in Figure 12, when three layers, i.e., the upper layer, the middle layer and the bottom layer, are determined from the workshop layout of the H Company.

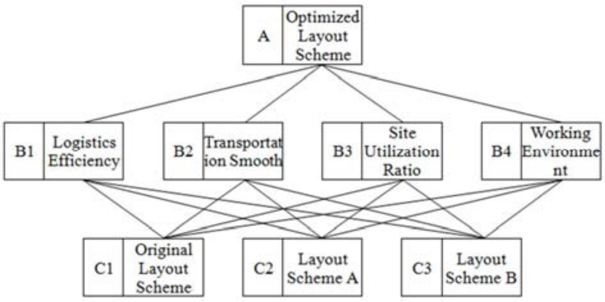

Figure 12. *The recursive hierarchical model.*

Once the recursive hierarchical model is derived, all judgment matrices can be obtained. Specifically,

(1) The judgment matrix between the middle layer the upper layer is:

$$A = \begin{bmatrix} & B1 & B2 & B3 & B4 \\ B1 & 1 & 3 & 5 & 3 \\ B2 & 1/3 & 1 & 3 & 1 \\ B3 & 1/5 & 1/3 & 1 & 1/3 \\ B4 & 1/3 & 1 & 3 & 1 \end{bmatrix}$$

(2) The judgment matrix between the bottom layer the middle layer is:

$$B1 = \begin{bmatrix} & C1 & C2 & C3 \\ C1 & 1 & 1/5 & 1/7 \\ C2 & 5 & 1 & 1/3 \\ C3 & 7 & 3 & 1 \end{bmatrix} \quad B2 = \begin{bmatrix} & C1 & C2 & C3 \\ C1 & 1 & 1/3 & 1/3 \\ C2 & 3 & 1 & 1 \\ C3 & 3 & 1 & 1 \end{bmatrix}$$

$$B3 = \begin{bmatrix} & C1 & C2 & C3 \\ C1 & 1 & 1/5 & 1/5 \\ C2 & 5 & 1 & 1 \\ C3 & 5 & 1 & 1 \end{bmatrix} \quad B4 = \begin{bmatrix} & C1 & C2 & C3 \\ C1 & 1 & 1/2 & 1/3 \\ C2 & 2 & 1 & 1/2 \\ C3 & 3 & 2 & 1 \end{bmatrix}$$

Table 10 shows the hierarchical consistency check results.

Table 10. *Results for hierarchical single order and consistency check.*

Index Consistency Check	*CI*	*CR*	Results
Middle Layer *w.r.t.* Upper Layer	0.014	0.016	Effective
Bottom Layer *w.r.t.* B1 Layer	0.032	0.062	Effective
Bottom Layer *w.r.t.* B2 Layer	0	0	Effective
Bottom Layer *w.r.t.* B3 Layer	0	0	Effective
Bottom Layer *w.r.t.* B4 Layer	0.005	0.009	Effective

5.2.2. Hierarchical Overall Order and Consistency Check

Table 11 shows results for synthetic weights between elements in each layer and the element in the upper layer.

Table 11. *Results for hierarchical overall order and consistency check.*

Middle Layer		B1	B2	B3	B4	Hierarchical Overall Order	Order Number
Weights		0.29	0.26	0.2	0.26		
Bottom Layer	C1	0.07	0.14	0.09	0.16	0.116	3
	C2	0.28	0.43	0.45	0.3	0.361	2
	C3	0.65	0.43	0.45	0.54	0.531	1

Based on the overall evaluation of above three layout schemes with the AHP approach, it can be concluded that the best layout scheme is C3 (namely optimized B), the second best one is C2 (namely optimized A), the worse one is C1 (namely original layout scheme), and B is far superior to C1 for the layout purpose. As a result, we choose scheme B as the best facility layout for the workshop in the H Company.

6. Conclusion

In this paper, SLP method is applied to analyze and study the layout of workshop facilities in H Company. Then three optimization schemes are proposed. Finally, AHP is used to analyze and compare these three optimization schemes, which proves the rational and scientific character of SLP method. The achievements of our work are as follows.

(1) After analyzing and summarizing workshop facilities layout and logistics system, eventually we conclude that scheme B is the best, because it not only effectively solves the problem of cycle, cross and tortuosity in the process of materials handling, but also raises the efficiency of logistics transportation by 46.04% and reduces the cost of logistics transportation.

(2) By researching logistics transportation and facilities layout of workshop in H Company, we reasonably design facilities layout that conforms to reality for H Company. The facilities layout can decrease distance between operational units and widen each transportation channel. As a result, the efficiency of transportation is effectively improved.

(3) AHP is applied to analyze and decide three alternative schemes of workshop facilities layout. Then scheme B is chosen as the best for H Company. Thereby, the rational and scientific character of SLP method is validated.

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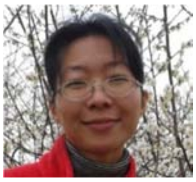
Biography



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