Frontiers in Business, Economics and Management
ISSN: 2766-824X | Vol. 23, No. 2, 2026

Research on the Layout Optimization of the Production Area in an Auto Parts Manufacturing Enterprise Based on SLP

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Abstract: At present, in the field of production layout in the automotive parts industry, the overall situation still mainly follows the traditional functional zoning model. The organization of logistics and the spatial configuration of operation units are rather rough, and a highly efficient and coordinated systematic layout system has not yet been formed, which is at odds with the industry's demands for intelligence and flexibility. This paper takes D enterprise, which specializes in automotive parts production, as a case to analyze and optimize this issue. Currently, the Z-type automotive sensor production plant of D enterprise is confronted with problems such as high logistics costs and long logistics distances between production operation units, which are due to an unreasonable layout. To address this issue, this paper adopts the Systematic Layout Planning (SLP) method as an optimization approach. Specifically, this paper first comprehensively analyzes the logistics relationships, non-logistics relationships, and comprehensive logistics relationships within the plant, and explores the positional relationships among various operation units. On this basis, in combination with the actual production situation, a set of scientific and feasible workshop layout optimization plan is formulated. This plan not only effectively achieves the dual goals of cost savings and efficiency improvement, but also provides reliable theoretical support for similar enterprises in optimizing their workshop layouts. Through this research, the production efficiency of D enterprise has been significantly improved, and it also provides a reference for other enterprises in the industry in optimizing their layouts.

Keywords: Automotive engine sensor, Layout optimization, System Layout Planning (SLP).

1. Introduction

At present, the production facility layout in the automotive parts industry is still mainly based on the traditional functional zoning model. The factory is divided into independent sections such as raw material storage, component processing, and semi-finished product assembly. Each section has clear boundaries and lacks organic linkage. Most enterprises still follow the layout concepts of "large and comprehensive" or "small and comprehensive", without precisely optimizing based on product characteristics, production efficiency, and logistics costs. At the same time, the spatial configuration of the operation units is unreasonable, with issues such as unscientific equipment placement, remote auxiliary operation units, and inflexible workstation configuration. The logistics organization method is also relatively loose. Moreover, the information islands at each link are serious, and no efficient and coordinated systematic layout system has been formed. These layout-level problems are far from the industry's requirements for intelligence and flexibility, and have restricted the improvement of production efficiency and the high-quality development of the industry. This article takes D Company, which focuses on automotive parts production, as a case to analyze and optimize this issue [1].

D Company was established in 2006 and is an enterprise specializing in vehicle sensor manufacturing. With the rapid expansion of market demand and increasingly fierce industry competition, the company has expanded twice and introduced advanced production lines, increasing its production scale by approximately three times. However, the third expansion was limited by the basic building area, and it was unable to further increase production capacity through expansion. The original production system in the workshop could no longer meet the actual needs, and it urgently needed to enhance competitive advantages by optimizing the factory layout and improving production efficiency.

The main reason for the low production efficiency is the waste of logistics and human resources [2]. Studies show that in manufacturing enterprises, non-processing process costs such as storage and material movement account for 20% to 50% of the total production costs, while the material processing time only accounts for 10% of the entire production time, and the remaining 90% is in a stagnant or transporting state [3]. Therefore, the planning of factory production facilities plays an important role in reducing logistics losses and improving the utilization rate of the factory.

This article uses the classic facility planning method - System Layout Method (SLP) to optimize the layout of D Company's Z-type automotive sensor production factory. This method was proposed by Mueser [4], and its core lies in analyzing the density of interrelationships between operation units for reasonable layout. Through the analysis of the Z-type sensor production process, the interrelationships between operation units and the existing layout, the SLP method is used for calculation and improvement proposals are put forward [5]. This plan can effectively reduce the distance of material transportation and logistics volume, increase the proportion of effective production time, and help D Company maximize the utilization of limited land resources, break through production bottlenecks, and gain core competitiveness. At the same time, it also provides a powerful argument for the practice of IE theory [6, 7].

2. The Current Layout of The Production Area For Z-Type Sensors of Enterprise D

2.1. Current Layout and Logistics Sequence

Enterprise D is a foreign-funded manufacturing enterprise in Jiangsu Province. It was established in April 1997 and mainly produces vehicle sensors. It holds significant influence in the related sensor field and has an annual production capacity of 45,766 units. The research object is the supporting production area for one of Enterprise D's main products, the Z-type crankshaft position sensor (magnetic-electric induction type: the rotation angle of the crankshaft is sensed and monitored by the sensor to ensure the position of the piston in the cylinder, and based on this, the fuel injection time and ignition timing are determined). The total area of this production area is approximately 7,600 square meters. It is divided into 10 working areas including the raw material warehouse, measurement room, original part cutting workshop, assembly workshop, forming workshop, bending/bridge cutting workshop, welding workshop, magnetizing workshop, packaging workshop, and finished product warehouse, as well as 3 auxiliary service departments such as the office service building, equipment maintenance workshop, and parking lot, and they are numbered accordingly to form as shown in Figure 1.

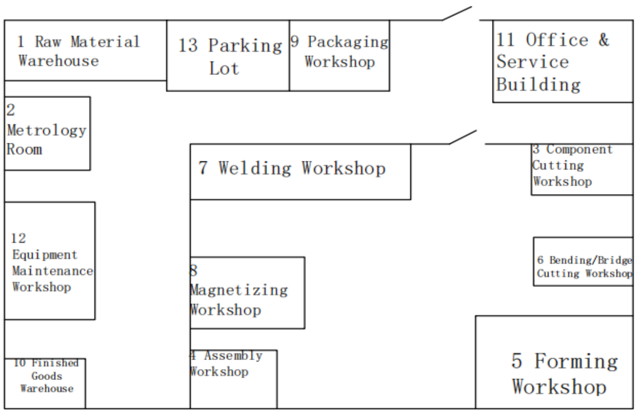

Figure 1. Layout of the original production plant area

The production process of the Z-type sensor is as follows: ICs are retrieved from the raw material warehouse and transported to the component cutting machine in the ESS production workshop to cut the ICs; the magnet and the component are assembled in the magnet installation unit, and then the semi-finished product is moved to the bracket forming machine for sub-module formation; it is transported by manpower to the terminal insertion machine to complete the terminal insertion, and then moved to the terminal bending/bridge cutting machine for IC bending and bridge cutting; subsequently, it is sent to the terminal/electronic component welding machine to complete the IC welding, and then secondary forming is carried out in the body forming machine after adding resin; subsequently, it goes through the magnetizing machine and the bridge cutting machine to complete the hammer cutting programming, and the finished product is obtained. After being inspected by the function inspection machine in the measurement room and found to be qualified, it is packaged and transported to the finished product warehouse for storage, and then waits for delivery.

2.2. Analysis of Layout Issues

As shown in Figure 1, there are three major problems in the production area: Firstly, the production process is not seamless. Through process and layout analysis, it was found that the production units closely related, such as the raw material warehouse and the processing workshop, the assembly and forming workshop, etc., are scattered and distributed. The daily output of 2,000 pieces of raw materials requires frequent handovers, and transportation is regularized, resulting in waste of production efficiency, increased load on transportation media, and affecting the production of other sensors. Secondly, the transportation distance is too far. The layout of related production units is unreasonable. The transportation distance between the raw material warehouse and the assembly and forming workshop, the packaging workshop and the finished product warehouse, etc., exceeds the average level, and there is a phenomenon of round-trip transportation. Thirdly, there are many path intersections, which may cause congestion during production, reducing production efficiency and posing a certain threat to safety production [8].

3. Comprehensive Analysis of Production Plant Interrelationships

3.1. Analysis of Logistics Relationships in The Factory Area

By recording the data of the entire process of producing a standard batch (107 pieces) of Z-type sensors for the enterprise, the logistics distance situation among each operation area before optimization is shown in Table 1; and the data on the transfer volume between areas obtained through actual production scenarios is presented in Table 2.

Table 1. Distance between work units before improvement: from – to

	1	2	3	4	5	6	7	8	9	10	Sum
1			50	73	70						193
2									41		41
3				47							47
4					39	41					80
5				39				40			79
6		52					40				92
7					47						47
8						39					39
9										66	66
10											0
Sum	0	52	50	159	156	80	40	40	41	66	

Table 2. Quantity of Worked Materials by Work Unit (from to)

	1	2	3	4	5	6	7	8	9	10	Sum
1			50	16	6						72
2									52		52
3				24							24
4					35	40					75
5				35				48			83
6		52					39				91
7					42						42
8						55					55
9										70	70
10											0
Sum	0	52	50	75	83	95	39	48	52	70	

The analysis of the strength of logistics relationships needs to be achieved through specific calculations of the logistics intensity between different regions. Logistics intensity, as the core indicator for measuring the degree of logistics association between regions, reflects the comprehensive manifestation of the distance and the volume of goods movement between different regions.

The specific calculation formula for logistics intensity is as follows: Logistics intensity = Distance × Volume

The theory of system layout planning is based on the size of logistics intensity and divides it into 5 grades, corresponding to the symbols A, E, I, O, and U. The criteria for classifying the logistics intensity levels for each grade are detailed in Table 3 [9].

Based on the formulas for calculating logistics distance and transportation volume as shown in Tables 1 and 2, the comprehensive logistics intensity between each unit was calculated by multiplying the distance data from Table 1 and the transportation volume data from Table 2, and the results were summarized in Table 4.

Based on Tables 3 and 4, we sorted and rated the logistics paths by their logistics intensity, resulting in Table 5. Then, we drew the relevant graphs of the logistics intensity of the operation units according to Table 5, as shown in Figure 2.

Table 3. Classification Table of Logistics Intensity Levels

Logistics intensity level	symbol	Undertake logistics proportion(%)	Logistics route proportion(%)
Ultra-high logistics intensity	A	40	10
Extraordinarily high logistics intensity	E	30	20
High logistics intensity	I	20	30
General logistics intensity	O	10	40
Negligible logistics intensity	U	——	——

Table 4. Improvement Before: Logistics Intensity of the Operating Unit from Table

	1	2	3	4	5	6	7	8	9	10	sum
1			2500	1168	420						4088
2									2132		2132
3				1128							1128
4					1365	1640					3005
5				1365				1920			3285
6		2704					1560				4264
7					1974						1974
8						2145					2145
9										4620	4620
10											0
sum	0	2704	2500	3661	3759	3785	1560	1920	2132	4620	

Table 5. Summary Table of Logistics Intensity Ranking

number	logistics path	logistics intensity	Logistics intensity level
1	9-10	4620	A
2	4-5 5-4	2730	E
3	6-2	2704	E
4	1-3	2500	E
5	8-6	2145	I
6	2-9	2132	I
7	7-5	1974	I
8	5-8	1920	I
9	4-6	1640	O
10	6-7	1560	O
11	1-4	1168	O
12	3-4	1128	O
13	1-5	420	O

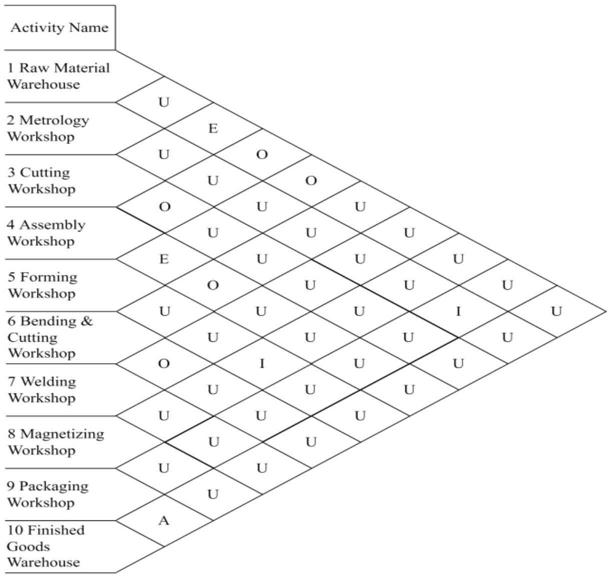

Figure 2. Correlation diagram of logistics intensity of operation units

3.2. Analysis of Non-Logistics Relationships in The Factory Area

In the SLP analysis, in addition to conducting logistics analysis, other non-logistics factors in reality also need to be considered. In fact, non-logistics factors can influence key characteristics of an enterprise such as safety production, work comfort, and management convenience. For instance, certain flammable materials stored in the raw material warehouse should be kept away from the welding workshop because they are prone to catching fire. Or, the office reception area should be located away from workshops with many noise sources such as the cutting workshop and the welding workshop because it requires a quieter environment for handling clients and processing documents. The analysis should be conducted from multiple perspectives in connection with the actual production situation of the enterprise. The non-logistics influencing factors are summarized as shown in Table 6 below.

Table 6. Non-logistics influencing factors between operation units

number	influencing factors
1	The continuity of the production process
2	flammable and explosive
3	The connectivity among personnel
4	Frequency of work contact
5	Impacts such as vibration, noise, and smoke pollution
6	serve production

Compared to the logistics relationship level, the correlation level of non-logistics relationships has an additional X (negative correlation degree), indicating that there is a significant adverse mutual influence between the two operation units, and they should be kept as far apart as possible. The classification table is shown in Table 7.

Table 7. Classification of Non-logistics Relevance Levels

closeness	symbol	assignment	percentage (%)
absolutely important	A	4	2~5
especially important	E	3	3~10
important	I	2	5~15
general	O	1	10~25
not important	U	0	48~80
negative association degree	X	-1	——

Based on the actual production situation and Tables 6 and 7, a comprehensive analysis of the non-logistics relationship intensity within the production area was conducted, as shown in Table 8 and Figure 3.

Table 8. Benchmark correlation

level	A pair of work units	Reasons for the degree of closeness in relationships
A	Raw material warehouse 1 and assembly workshop 4	1, 3, 4,6
	Packaging workshop 9 and finished product warehouse 10	1, 3, 4,6
	Assembly workshop 4 and molding workshop 5	1, 3, 4,6
E	Parking lot 13 and office service building 11	3, 4, 6
	Magnetizing Workshop 8 and Bending and Cutting Workshop 6	1, 3, 4
I	Disconnect workshop 3 and bending and cutting workshop 6	3, 6
O	Measurement room 2 and finished product warehouse 10	6
	Measurement room 2 and various processing workshops 3, 4, 5, 6, 7, 8	6
	Welding workshop 7, bending and cutting workshop 6, and forming workshop 5	1
	Equipment maintenance workshop 12 and various processing workshops 3, 4, 5, 6, 7, 8	6
U	Between other operational units	——
X	Office service building 11, cutting workshop 3, and welding workshop 7	5
	Welding workshop 7 and raw material warehouse 1	2

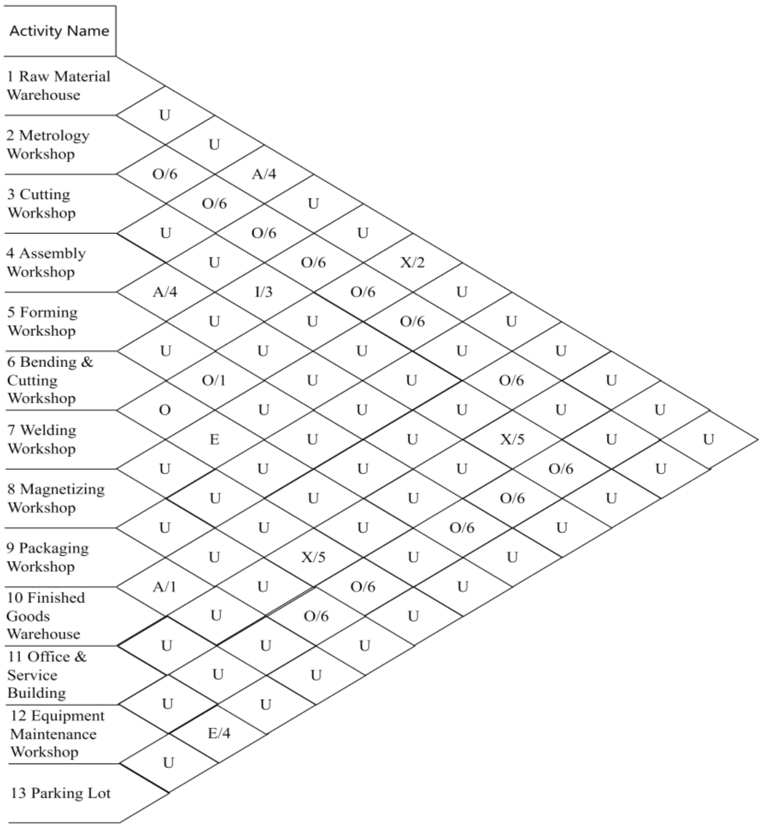

Figure 3. Interrelationship diagram of non-logistics among operational units

3.3. Analysis of the Comprehensive Interrelationships of The Work Units

Taking into account the actual situation of the enterprise, it should be handled as follows: the relationship between logistics and non-logistics is more important than the other relationship. Therefore, in this study, the weights of the logistics and non-logistics relationships are set as 2:1;

And when the number of operation units is N, the total number of operation units P can be calculated using the following formula. That is:

$$P = \frac{N(N-1)}{2}$$

Since there are 13 operation units in the factory area, it can be known that there are 78 pairs of operation units. In addition, the general proportion of the relationship levels needs to be divided according to Table 9.

Table 9. General proportion of comprehensive correlation level and division

symbol	meaning	Operational unit comparison ratio (%)	linear
A	absolutely important	1~3	4 parallel lines
E	especially important	2~5	3 parallel lines
I	important	3~8	2 parallel lines
O	General level of intimacy	5~15	1 straight line
U	not important	20~85	—
X	Do not approach	0~10	1 dotted line

If a comprehensive analysis of the interrelationships between units is required, it is necessary to link the logistics-related relationships and non-logistics-related relationships, assign weights, and determine the overall score to assess the comprehensive grade. The table for analyzing the comprehensive interrelationships of enterprise operation units is shown in Table 10.

Table 10. Analysis of comprehensive interrelationships among operation units

number	job unit pair	relationship level				comprehensive relationship	
		Logistics relationship Weighted value: 2		Weighted value of non-logistics relationship: 1			
		level	score	level	score	score	level
1	1-3	E	6	U	0	6	I
2	1-4	O	2	A	4	6	I
3	1-5	O	2	U	0	2	O
4	1-7	U	0	X	-1	-1	X
5	2-3	U	0	O	1	1	U
6	2-4	U	0	O	1	1	U
7	2-5	U	0	O	1	1	U
8	2-6	E	6	O	1	7	E
9	2-7	U	0	O	1	1	U
10	2-8	U	0	O	1	1	U
11	2-9	I	4	U	0	4	I
12	2-10	U	0	O	1	1	U
13	3-4	O	2	U	0	2	O
14	3-6	U	0	I	2	2	O
15	3-11	U	0	X	-1	-1	X
16	3-12	U	0	O	1	1	U
17	4-5	E	6	A	4	10	E
18	4-6	O	2	U	0	2	O
19	4-12	U	0	O	1	1	U
20	5-7	I	4	O	1	5	I
21	5-8	I	4	U	0	4	I
22	5-12	U	0	O	1	1	U
23	6-7	O	2	O	1	3	O
24	6-8	I	4	E	3	7	E
25	6-12	U	0	O	1	1	U
26	7-11	U	0	X	-1	-1	X
27	7-12	U	0	O	1	1	U
28	8-12	U	0	O	1	1	U
29	9-10	A	8	A	4	12	A
30	11-13	U	0	E	3	3	O

3.4. Plant Layout Optimization Plan

Based on the comprehensive interrelationships presented in Table 10, an intuitive representation is made and a comprehensive interrelationship diagram is drawn, as shown in Figure 4.

Using the comprehensive interrelationship diagram in Figure 4 and different levels and different scores, the total score of an operation unit is obtained by adding them together. When facing the same score for different units, it is necessary to analyze the degree of the highest proximity between them to distinguish the rankings. Then, a comprehensive proximity degree ranking table is drawn, as detailed in Table 11.

Analyzing the data of the comprehensive proximity degree ranking, different rating evaluation type symbols for different proximity degrees are divided. According to the feasibility principle of the layout adjustment of the factory area, a location-related diagram is drawn, as shown in Figure 5.

To meet the final goal of production optimization, the location-related diagram needs to be linked with the actual layout requirements of the factory area and combined to obtain the operation unit-related diagram of the factory area. Based on the operation unit-related diagram and the actual situation and optimization goals of D enterprise, a detailed layout improvement scheme diagram is designed. During the design process, it is necessary to ensure that the overall area of the factory remains the same, but the areas of each operation zone can be appropriately adjusted. Ultimately, the entire related diagram should be arranged within the limited factory area. Based on the functional requirements of different operation zones, the operation unit-related diagram is reasonably planned, and the factory layout improvement scheme is drawn as shown in Figure 6.

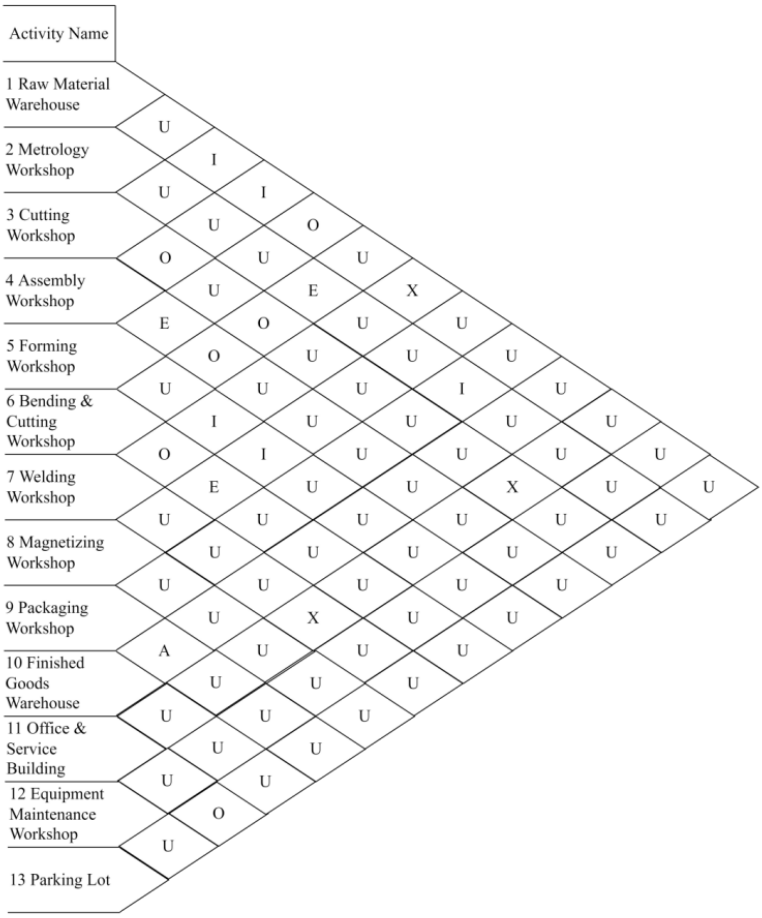

Figure 4. Comprehensive Interrelationship Diagram of Production Plant Area

Table 11. Ranking Table of Comprehensive Proximity of Operation Units

Operation unit number	1	2	3	4	5	6	7	8	9	10	11	12	13
1		U/0	I/2	I/2	O/1	U/0	X/-1	I/2	U/0	U/0	U/0	U/0	U/0
2	U/0		U/0	U/0	U/0	E/3	U/0	U/0	I/2	U/0	U/0	U/0	U/0
3	I/2	U/0		O/1	U/0	O/1	U/0	U/0	U/0	U/0	X/-1	U/0	U/0
4	I/2	U/0	O/1		E/3	O/1	U/0	U/0	U/0	U/0	U/0	U/0	U/0
5	O/1	U/0	U/0	E/3		U/0	I/2	I/2	U/0	U/0	U/0	U/0	U/0
6	U/0	E/3	O/1	O/1	U/0		O/1	E/3	U/0	U/0	U/0	U/0	U/0
7	X/-1	U/0	U/0	U/0	I/2	O/1		U/0	U/0	U/0	X/-1	U/0	U/0
8	I/2	U/0	U/0	U/0	I/2	E/3	U/0		U/0	U/0	U/0	U/0	U/0
9	U/0	I/2	U/0	U/0	U/0	U/0	U/0	U/0		A/4	U/0	U/0	U/0
10	U/0	U/0	U/0	U/0	U/0	U/0	U/0	U/0	A/4		U/0	U/0	U/0
11	U/0	U/0	X/-1	U/0	U/0	U/0	X/-1	U/0	U/0	U/0		U/0	O/1
12	U/0	U/0	U/0	U/0	U/0	U/0	U/0	U/0	U/0	U/0	U/0		U/0
13	U/0	U/0	U/0	U/0	U/0	U/0	U/0	U/0	U/0	U/0	O/1	U/0	
Comprehensive proximity	6	5	3	7	8	9	1	7	6	4	-1	0	1
sort	6	7	9	4	2	1	10	3	5	8	13	12	11

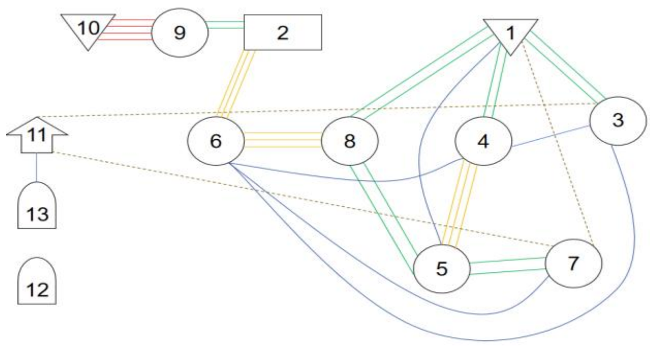

Figure 5. Relevant diagram of operation unit locations in the production plant area

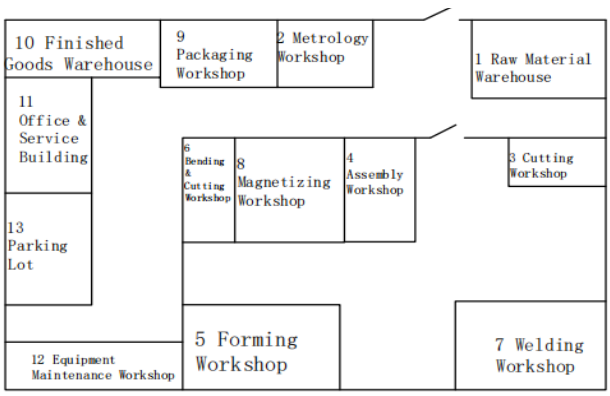

Figure 6. Improvement Plan for Plant Layout

Based on the improved CAD diagram, all transportation routes are connected, and the improved distances are measured and summarized as shown in Table 12.

Table 12. Distance from - to table after improvement

	1	2	3	4	5	6	7	8	9	10	sum
1			18	39	54						111
2									23		23
3				31							31
4					20	21					41
5				20				11			31
6		53					39				92
7					10						10
8						13					13
9										24	24
10											0
sum	0	53	18	90	84	34	39	11	23	24	

After obtaining the data in Table 12, when compared with the distance between the operation units before improvement as shown in Table 1, it can be found that the logistics distance between each operation unit has decreased. Among them, the distance between operation unit 7 and operation unit 5 has been optimized the most significantly.

At the same time, by combining the logistics volume table 2 showing the logistics volume for producing one standard batch (107 pieces), the logistics intensity after improvement can be calculated as shown in Table 13 below:

Table 13. Logistics Intensity from - to after Improvement

	1	2	3	4	5	6	7	8	9	10	sum
1			900	624	324						1848
2									1196		1196
3				744							744
4					700	840					1540
5				700				528			1228
6		2756					1521				4277
7					420						420
8						715					715
9										1680	1680
10											0
sum	0	2756	900	2068	1444	1555	1521	528	1196	1680	

By comparing the logistics intensity before and after improvement in Tables 13 and 4, it can be observed that the layout of the Z-type sensor production area optimized using the SLP method has significantly reduced the logistics intensity during the production process. Before the optimization, the intensity was 26,641 kg/m, while after the layout was adjusted, it decreased to 13,648 kg/m. This not only alleviated the pressure on the logistics routes and workers but also reduced the logistics costs for production and improved the production efficiency.

4. Conclusion

Based on the three major current problems identified in the analysis of D Enterprise's Z-type sensor production, the layout of the factory area was improved through the calculation and research using the SLP method. The production was optimized as follows:

(1) The logistics intensity of the factory area decreased by 48.7%, the distance of logistics movement between operation units was reduced, logistics costs were decreased, and production efficiency was improved;

(2) By re-arranging the operation units, the connection between processes was strengthened, making the production layout more reasonable;

(3) The congestion problem on the transportation routes in the factory area was improved, the intersection of paths was reduced, which was conducive to safe production and improving the actual production efficiency.

The solution process of D Enterprise's production problems provides a scientific basis for enterprises in the automotive parts production field with similar problems, and has certain academic significance and reference value.

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