

# Spatial Layout Optimization of Express Transit Warehouse F Based on SLP

Jie Gao<sup>1</sup>, Tao Mi<sup>2</sup>, Le Yu<sup>3\*</sup>

1. Department of Economics and Management, Yuncheng University, Yuncheng, Shanxi, 044000, China

2. Performance Business Department, Shanxi Sankuai Network Technology Co.,Ltd., Taiyuan, Shanxi, 030032, China

3. Storage Department, Yuansai Weixin Life Science (Hangzhou) Co.,Ltd., Hangzhou, Zhejiang, 311200, China

\*Corresponding author: Le Yu, yule03930@163.com

**Copyright:** 2026 Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY-NC 4.0), permitting distribution and reproduction in any medium, provided the original author and source are credited, and explicitly prohibiting its use for commercial purposes.

**Abstract:** To address the problems of unreasonable functional area configuration and intersecting logistics routes in express transit warehouses, Warehouse F was taken as the research object and the Systematic Layout Planning (SLP) was adopted to optimize its spatial layout. Basic data, including the area of each operating unit, logistics volume, handling distance, and operational relationships, were collected through field observations and interviews. Based on QQRST analysis, logistics and non-logistics relationships among the operating units were established. A weighting ratio of 3:1 was then assigned to the logistics and non-logistics relationships to determine the comprehensive closeness ratings. An activity relationship diagram and a space relationship diagram were designed to generate the optimized layout. The results show that the optimized scheme places highly related operating units in closer spatial proximity, provides a clearer separation between major logistics operating areas and auxiliary functional areas, and reorganizes the main parcel flow into a more continuous and clearly structured process, thereby reducing unnecessary detours and intersections. The optimized layout improves the consistency between the spatial configuration of functional areas and the actual parcel flow process and provides a reference for the layout optimization of similar express transit warehouses.

**Keywords:** Express Transit Warehouse; Systematic Layout Planning; Logistics Relationship; Layout Optimization

**Published:** Oct 7, 2026

**DOI:** <https://doi.org/10.62177/chst.v3i3.1776>

## 1. Introduction

With the rapid development of e-commerce and the express logistics industry, the volume of express parcels handled by logistics facilities has continued to increase. As key nodes responsible for parcel collection, distribution, sorting, and transshipment, transit warehouses depend heavily on an appropriate internal layout, which directly affects parcel handling distances and overall operating efficiency. Particularly during peak periods, poorly configured functional areas can lead to circuitous logistics routes, intersecting flows, and aisle congestion. Therefore, it is important to optimize the spatial layout of transit warehouses according to the logistics and functional relationships among different operating areas.

A substantial body of research has investigated the layout optimization of warehouses and logistics facilities. In terms of methodology, Systematic Layout Planning (SLP) integrates both logistics and non-logistics relationships and has been widely applied to layout optimization in warehouses, distribution centers, and other facilities. Building on SLP, previous studies have further incorporated genetic algorithms, the Analytic Hierarchy Process (AHP), and mathematical programming to

improve the layout alternatives<sup>[1-4]</sup>. Hu and Chuang optimized the functional-area layout of an e-commerce warehouse using SLP and a genetic algorithm together<sup>[5]</sup>. Yang et al. introduced AHP to generate a multi-criteria evaluation of alternative layouts designed using SLP<sup>[6]</sup>. Lin and Wang further integrated SLP with fuzzy AHP for facility layout design and alternative evaluation<sup>[7]</sup>. An integrated facility layout optimization approach was developed by combining SLP, AHP, and nonlinear programming<sup>[8]</sup>. These studies show that SLP can serve not only as a fundamental method for facility layout but also as a framework that can be integrated with multi-criteria decision-making methods to support the optimization of complex facility layouts. In terms of practical applications, previous studies have examined various scenarios, including fresh-food distribution centers, e-commerce warehouses, value-added processing area, and so on<sup>[9-11]</sup>, demonstrating the wide applicability of SLP to logistics facility layout optimization. However, different types of logistics facilities vary considerably in their operating processes, parcel types, and fluctuations in business volume. Express transit warehouses are characterized by high parcel volumes, continuous operating processes, and pronounced fluctuations during peak periods. Therefore, it is necessary to study the layout optimization of express transit warehouses combining both logistics and non-logistics relationships.

Warehouse F is an important regional node for the collection, distribution, and transshipment of express parcels. It handles approximately 1.1 million parcels per day on average. Field investigations revealed several problems in its existing layout, including insufficient spatial proximity, circuitous and intersecting logistics routes, aisle congestion during peak periods, and inadequate buffering capacity. To address these problems, this study takes Express Transit Warehouse F, hereafter referred to as Warehouse F, as the research object. Based on data collected through field investigations and interviews, SLP is applied to analyze the logistics and non-logistics relationships among its operating units, and a relationship diagram and a space relationship diagram are designed. Finally, the optimized layout is evaluated from two aspects: spatial configuration and logistics flow.

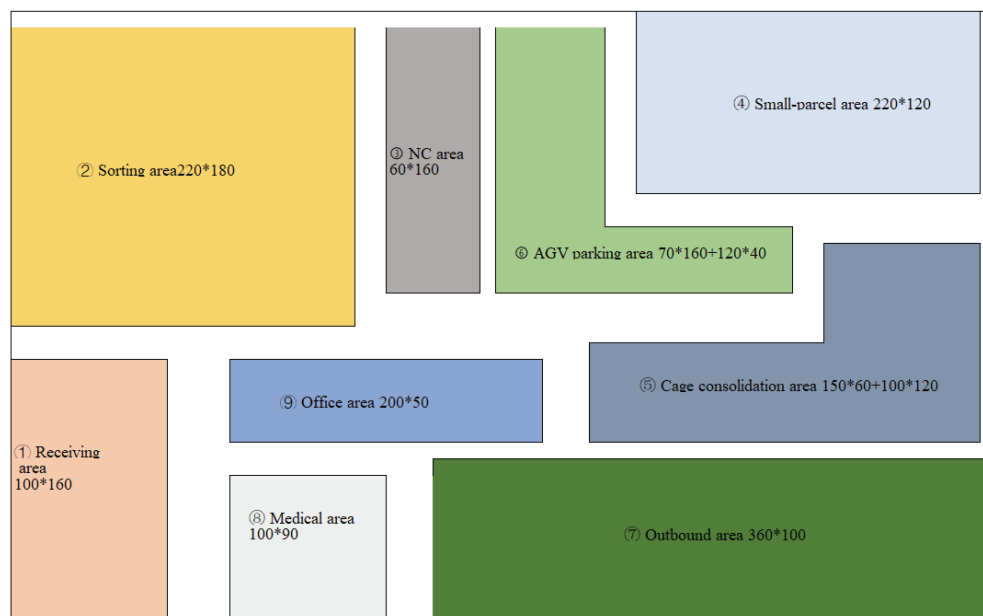
## 2. Overview and Data of Warehouse F

### 2.1 Basic Information on Warehouse F

Warehouse F is in Xiuzhou District, Jiaxing, Zhejiang Province. The area is 268 mu, approximately 0.179 km<sup>2</sup>, with a total floor area over 230,000 m<sup>2</sup>, 630 meters long and 370 meters wide. The facility is equipped with two loop cross-belt sorting systems and one dedicated cyclone sorting system.

According to its functions and operational characteristics, the warehouse is divided into nine operating units: the receiving area, sorting area, NC area, small-parcel area, cage consolidation area, AGV parking area, outbound area, medical area, and office area. The NC area is mainly responsible for handling irregular and special parcels; the cage consolidation area is used for the consolidation, temporary storage, and subsequent transfer of sorted parcels. The original layout of Warehouse F is shown in Figure 1.

Figure 1. Original Layout of Warehouse F (Scale: 1:1000)



The parcel handling process follows receiving, sorting, and outbound operations as its main flow. After unloading, parcels enter the sorting area and are routed to different processes and areas according to parcel type, including regular parcels, small parcels, and NC parcels. Some parcels are consolidated into cages for verification and dispatch. The warehouse handles approximately 1.1 million parcels per day on average, with daily throughput reaching up to 3 million parcels during peak periods. Depending on the movement of different parcel types, several major logistics routes are formed, including receiving–sorting–outbound, receiving–sorting–cage consolidation–outbound, receiving–sorting–NC–AGV–outbound and so on.

## 2.2 Field Investigation and Data Summary

Field observations and online interviews were used to obtain information about Warehouse F. Field observations were conducted from October 31 to November 12, 2025. The investigation focused on the nine operating units and recorded their spatial locations, adjacency relationships, parcel flows, logistics volumes and so on. Interviews were conducted with warehouse managers and frontline operators, from November 15 to November 22, 2025, resulting in 17 valid interviews. The interviewees included the site manager, dispatch supervisor, and team leaders responsible for each area, as well as experienced operators, and AGV operation and maintenance personnel.

To account for differences in handling difficulty among parcel types, logistics volumes were converted into standardized logistics volumes. Regular parcels were converted at a ratio of 1:1, NC parcels at 1:2, and small parcels at 2:1. After conversion, the standardized logistics volumes of the major logistics routes were approximately 440,000, 275,000, 200,000, 130,000, 60,000, and 50,000 parcels, respectively. These data provide the basis for the subsequent analysis of logistics relationships and non-logistics relationships among the operating units. The details of information are presented in Table 1.

*Table 1. Major Operating Units and Basic Data of Warehouse F*

| Code | Operating Unit          | Main Operations                                                     | Area (m <sup>2</sup> ) | Average Daily Processing Volume (10,000 parcels) |
|------|-------------------------|---------------------------------------------------------------------|------------------------|--------------------------------------------------|
| ①    | Receiving area          | Vehicle unloading, parcel scanning, and temporary receiving storage | 16,000                 | 110.0                                            |
| ②    | Sorting area            | Sorting of all parcel categories                                    | 39,600                 | 110.0                                            |
| ③    | NC area                 | Handling of irregular and special parcels                           | 9,600                  | 16.5                                             |
| ④    | Small-parcel area       | Automated sorting and processing of small parcels                   | 26,400                 | 22.0                                             |
| ⑤    | Cage consolidation area | Parcel consolidation, cage loading, and temporary storage           | 21,000                 | 44.0                                             |
| ⑥    | AGV parking area        | AGV charging, parking, and maintenance                              | 16,000                 | 16.5                                             |
| ⑦    | Outbound area           | Cage loading onto vehicles and dispatch verification                | 36,000                 | 110.0                                            |
| ⑧    | Medical area            | Equipment maintenance and exception-parcel handling                 | 9,000                  |                                                  |
| ⑨    | Office area             | Administrative operations and dispatch coordination                 | 10,000                 |                                                  |

Note: The Medical area and office area do not directly process parcels; therefore, their average daily processing volumes are not reported.

## 3. Problems with the Existing Layout of Warehouse F

(1) Insufficient alignment between the spatial configuration of functional areas and logistics relationships.

Under the existing layout, some operating areas with frequent logistics interactions are not located sufficiently close to each other. The office area is in the central part of the main operating area of the warehouse, creating a spatial barrier to some parcel flows and requiring parcels to take detours when transferred between operating units. In addition, there is insufficient buffer space between the receiving and sorting areas. During peak periods, concentrated parcel arrivals can therefore lead to accumulation, affecting subsequent sorting and transfer operations.

(2) Circuitous logistics routes and intersecting flows.

Different types of parcels follow different handling processes within the warehouse. NC parcels need to pass through the NC area and be transferred by AGVs, while some large parcels require secondary handling. Under the existing layout, AGV transport routes intersect with parcel flows associated with other operating areas, increasing handling distances and aisle occupancy. Field observations showed that during peak periods, the effective width of some aisles can be reduced to less than 2 m, restricting the normal movement of parcels and handling equipment.

(3) Aisle congestion and insufficient buffering capacity during peak periods.

During evening peak periods, parcel cages are temporarily placed in aisles. Field observations showed that approximately 15–20 cages are frequently stored in this manner, occupying aisle sections of up to approximately 30 m. Meanwhile, temporary AGV parking, waiting, and avoidance maneuvers further occupy aisle space. Because the main operating areas lack flexible buffer spaces capable of accommodating fluctuations in business volume, concentrated parcel arrivals over short periods can easily result in parcel accumulation and aisle congestion.

(4) Operational coordination requires further improvement.

AGVs frequently experience waiting and avoidance during operation, while the processing of NC parcels is also affected by factors such as mis-sorting, forklift delivery, and information transmission. The investigation found that mis-sorting in the NC area and forklift delivery errors can prolong subsequent processing time, while intersecting logistics flows further interference among different operating activities. Therefore, it is necessary to redefine the spatial adjacency relationships among the operating units according to their logistics intensity and functional relationships and to optimize the existing warehouse layout.

## 4. Layout Optimization of Warehouse F

### 4.1 Analysis of Basic Elements

According to the SLP method, facility layout design primarily considers five basic elements: product (P), quantity (Q), routing (R), supporting services (S), and time (T). Based on the actual operational characteristics of Warehouse F, these five elements are analyzed as follows.

In terms of product (P), parcels are classified into three categories according to their actual operating classifications and handling methods in Warehouse F: regular parcels, small parcels, and NC parcels. Regular parcels mainly refer to regularly packaged parcels with dimensions of no less than 30 cm × 30 cm × 30 cm, a maximum side length of no more than 60 cm, and a weight of 3–20 kg, which can enter the conventional sorting process. Small parcels mainly include packages and documents with both height and width below 30 cm and a weight not exceeding 3 kg, which are processed through the automated small-parcel sorting system. NC parcels mainly include irregularly shaped parcels, parcels requiring special handling, and parcels weighing more than 20 kg or with a side length exceeding 60 cm that cannot directly enter the automated sorting line. These parcels must be processed in the NC area and handled using equipment such as pallet trucks, forklifts, or AGVs. Because the three parcel categories differ in handling methods, routing, and handling intensity, their logistics volumes are subsequently calculated separately and converted into standardized logistics volumes.

In terms of quantity (Q), Warehouse F handles approximately 1.1 million parcels per day on average, while daily throughput can reach 3 million parcels during peak periods such as e-commerce promotional events. Different parcel types generate different logistics volumes among the operating units. Their actual and standardized logistics volumes provide the basis for the subsequent analysis of logistics relationships.

In terms of routing (R), parcels enter the sorting area through the receiving area and are subsequently routed to different operating processes according to parcel type and handling requirements. After sorting, regular parcels are transferred either directly to the outbound area or to the cage consolidation area before outbound processing. Small parcels are processed in the small-parcel area and then transferred to either the cage consolidation area or the outbound area. NC parcels enter the NC area for special handling and are subsequently transported by AGVs to either the cage consolidation area or the outbound area. These processes form multiple logistics routes within the warehouse.

In terms of supporting services (S), the office area and medical area do not directly participate in the regular flow of parcels. The office area is mainly responsible for administrative management, dispatch coordination, and information processing, while the medical area performs auxiliary functions such as equipment maintenance, problem-parcel handling, and exception management. The AGV parking area is primarily used for AGV charging, parking, and maintenance and is also associated with the transfer of NC parcels. Although these auxiliary service areas do not directly generate major parcel flows, their spatial locations affect the coordination among the main operating areas and the arrangement of logistics aisles.

In terms of time (T), Warehouse F operates on a two-shift system. The day shift runs from 06:30 to 18:30, while the night shift runs from 18:30 to 06:30 the following day. Peak parcel-processing periods are concentrated between 21:00 and 23:00 and between 03:00 and 05:00. The warehouse therefore experiences pronounced temporal fluctuations in business volume, and concentrated parcel arrivals during peak periods can lead to localized parcel accumulation and aisle congestion. Consequently, in addition to routine logistics relationships among the operating units, the layout optimization should also account for parcel flows and temporary buffering requirements during peak periods.

## 4.2 Logistics Relationship Analysis

Logistics relationships provide an important basis for determining the relative locations of operating units in SLP analysis. In Warehouse F, parcels continuously flow through receiving, sorting, special handling, consolidation, and outbound operations, while considerable differences exist in logistics volumes and handling distances among the operating units. To characterize the logistics relationships among the operating units under the existing layout, a distance from-to chart and a logistics-volume from-to chart were first developed based on the actual warehouse layout and parcel handling routes. Logistics intensity between operating units was then calculated to determine the closeness of their logistics relationships.

First, based on the existing layout of Warehouse F and the actual handling routes of different parcel types, the handling distances between operating units with direct logistics flows were measured. The values in the distance from-to chart represent the actual distances traveled when parcels are transferred from one operating unit to another. Operating-unit pairs without direct logistics flows are not included. The results are presented in Table 2.

Table 2. Distance From-to Chart of Warehouse F (Unit: m)

| From/To | ① | ②   | ③   | ④  | ⑤   | ⑥  | ⑦   | ⑧ | ⑨ |
|---------|---|-----|-----|----|-----|----|-----|---|---|
| ①       |   | 200 |     |    |     |    |     |   |   |
| ②       |   |     | 100 | 80 | 180 |    | 300 |   |   |
| ③       |   |     |     |    |     | 50 |     |   |   |
| ④       |   |     |     |    | 100 |    | 220 |   |   |
| ⑤       |   |     |     |    |     |    | 50  |   |   |
| ⑥       |   |     |     |    | 150 |    | 120 |   |   |
| ⑦       |   |     |     |    |     |    |     |   |   |
| ⑧       |   |     |     |    |     |    |     |   |   |
| ⑨       |   |     |     |    |     |    |     |   |   |

Second, logistics volumes between operating units were determined according to the operating processes of different parcel types. Considering the differences among regular, small, and NC parcels in parcel specifications, handling methods, and handling difficulty, the standardized logistics-volume conversion method described above was adopted to improve comparability across parcel types. Regular parcels were converted at a ratio of 1:1, NC parcels at 1:2, and small parcels at 2:1. The parcel volumes associated with different operating routes were then allocated to the corresponding operating-unit pairs, resulting in the logistics-volume from-to chart shown in Table 3.

Table 3. Logistics-Volume From-to Chart of Warehouse F (Unit: 10,000 standardized parcels/day)

| From/To | ① | ②     | ③    | ④    | ⑤    | ⑥    | ⑦    | ⑧ | ⑨ |
|---------|---|-------|------|------|------|------|------|---|---|
| ①       |   | 115.5 |      |      |      |      |      |   |   |
| ②       |   |       | 33.0 | 11.0 | 27.5 |      | 44.0 |   |   |
| ③       |   |       |      |      |      | 33.0 |      |   |   |
| ④       |   |       |      |      | 5.0  |      | 6.0  |   |   |
| ⑤       |   |       |      |      |      |      | 45.5 |   |   |
| ⑥       |   |       |      |      | 13.0 |      | 20.0 |   |   |
| ⑦       |   |       |      |      |      |      |      |   |   |
| ⑧       |   |       |      |      |      |      |      |   |   |
| ⑨       |   |       |      |      |      |      |      |   |   |

Third, to jointly reflect the effects of logistics volume and handling distance on internal warehouse logistics operations, the standardized logistics volume between each pair of operating units was multiplied by the corresponding handling distance to calculate logistics intensity. The logistics intensity between operating units (i) and (j) is calculated as follows:  $L_{ij}=Q_{ij}*D_{ij}$ .

where  $L_{ij}$  denotes the logistics intensity between operating units (i) and (j);  $Q_{ij}$  denotes the standardized logistics volume between the two operating units; and  $D_{ij}$  denotes the actual handling distance between them.

Using the above method, logistics intensity was calculated for each operating-unit pair with a direct logistics relationship. For example, the standardized logistics volume between the receiving area ① and sorting area ② is 1.155 million standardized parcels/day, and the handling distance is 200 m. The resulting logistics intensity is therefore  $23,100 \times 10,000$  standardized parcel·m/day. The same calculation was applied to the remaining operating-unit pairs, resulting in the logistics-intensity from-to chart shown in Table 4.

Table 4. Logistics-Intensity From-to Chart of Warehouse F (Unit: 10,000 standardized parcel·m/day)

| From/To | ① | ②     | ③    | ④   | ⑤    | ⑥    | ⑦     | ⑧ | ⑨ |
|---------|---|-------|------|-----|------|------|-------|---|---|
| ①       |   | 23100 |      |     |      |      |       |   |   |
| ②       |   |       | 3300 | 880 | 4950 |      | 13200 |   |   |
| ③       |   |       |      |     |      | 1650 |       |   |   |
| ④       |   |       |      |     | 500  |      | 1320  |   |   |
| ⑤       |   |       |      |     |      |      | 2275  |   |   |
| ⑥       |   |       |      |     | 1950 |      | 2400  |   |   |
| ⑦       |   |       |      |     |      |      |       |   |   |
| ⑧       |   |       |      |     |      |      |       |   |   |
| ⑨       |   |       |      |     |      |      |       |   |   |

A higher logistics intensity indicates a stronger combined effect of parcel-handling volume and handling distance between the corresponding operating units and therefore a higher priority for spatial proximity in warehouse layout optimization. Based on the calculated logistics intensities, the operating-unit pairs were further ranked and classified to determine the closeness of their logistics relationships and to construct the logistics relationship diagram.

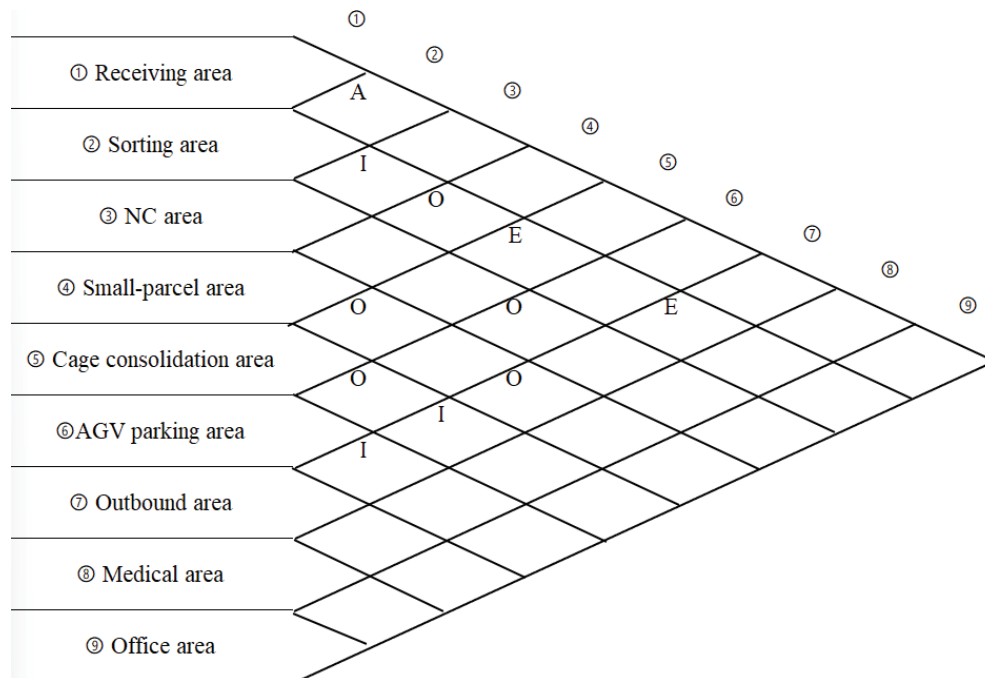
Finally, logistics relationships were classified primarily according to logistics intensity. A higher logistics intensity indicates a closer logistics relationship between two operating units. Accordingly, the logistics relationships were classified into five

levels: A (Absolutely Important), E (Especially Important), I (Important), O (Ordinary), and U (Unimportant or zero logistics intensity), with corresponding quantitative scores  $M_{ij}$  of 4, 3, 2, 1, and 0, respectively. In principle, A, E, I, and O were assigned to approximately 10%, 20%, 30%, and 40% of the non-U operating-unit pairs, respectively. The resulting logistics relationship classifications are presented in Table 5, and the corresponding logistics relationship diagram is shown in Figure 2.

Table 5. Non-logistics Closeness Ratings among Operating Units

| Operating-unit pair | Logistics-Intensity | Closeness rating | Operating-unit pair | Logistics-Intensity | Closeness rating |
|---------------------|---------------------|------------------|---------------------|---------------------|------------------|
| ①- ②                | 23100               | A                | ⑤- ⑥                | 1950                | I                |
| ②- ⑦                | 1320                | A                | ③- ⑥                | 1650                | A                |
| ②- ⑤                | 4950                | E                | ④- ⑦                | 1320                | E                |
| ②- ③                | 3300                | E                | ②- ④                | 880                 | E                |
| ⑥- ⑦                | 2400                | I                | ④- ⑤                | 500                 | I                |
| ⑤- ⑦                | 2275                | A                |                     |                     |                  |

Figure 2. Logistics Relationship Diagram



### 4.3 Non-logistics Relationship Analysis

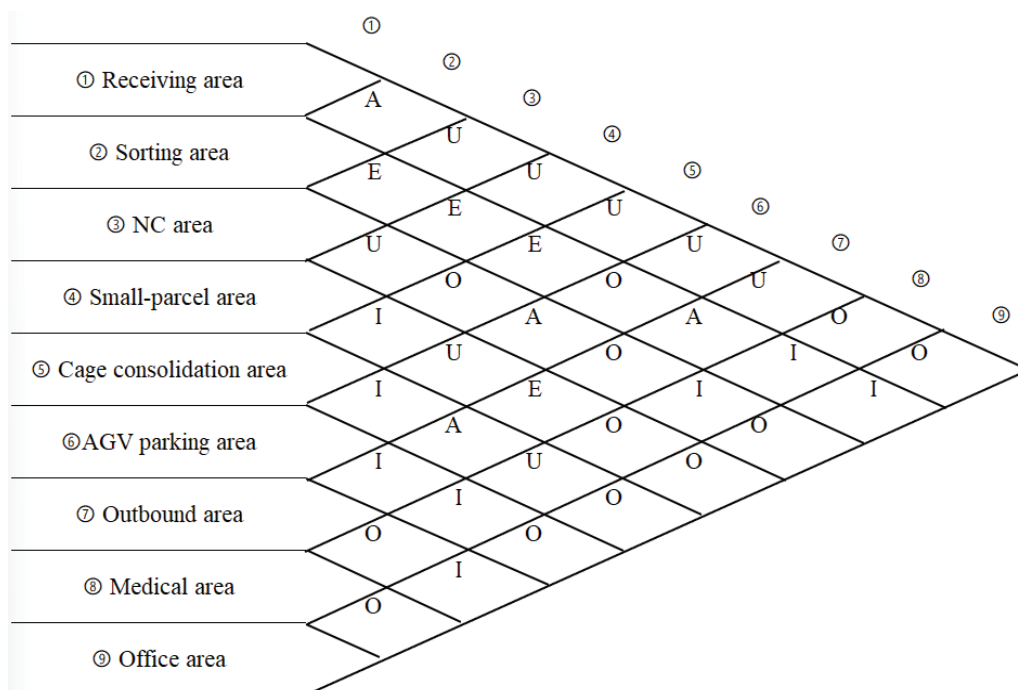
The non-logistics relationships among the operating units were evaluated based on factors such as process continuity, similarity in operational functions, convenience of information management and so on. Following the SLP closeness-rating system, the non-logistics relationships were classified into six levels: A (Absolutely Necessary), E (Especially Important), I (Important), O (Ordinary), U (Unimportant), and X (Undesirable), with corresponding quantitative scores  $N_{ij}$  of 4, 3, 2, 1, 0, and -1, respectively.

Based on the actual operations of Warehouse F, seven factors were identified for evaluating non-logistics relationships: (a) process continuity; (b) similarity or functional relationship between operations; (c) frequent operational coordination; (d) personnel interaction; (e) information and dispatch coordination; (f) safety and equipment support; and (g) no specific adjacency requirement. Field investigations indicated that no pair of operating units exhibited significant safety conflicts or functional incompatibilities requiring complete spatial separation; therefore, no operating-unit pair was assigned an X rating. The resulting non-logistics closeness ratings are presented in Table 6, and the corresponding non-logistics relationship diagram is shown in Figure 3.

Table 6. Non-logistics Closeness Ratings among Operating Units

| Operating-unit pair | Closeness rating | Reason(s) | Operating-unit pair | Closeness rating | Reason(s) |
|---------------------|------------------|-----------|---------------------|------------------|-----------|
| ①- ②                | A                | a、c       | ③- ⑦                | O                | a         |
| ①- ③                | U                | g         | ③- ⑧                | I                | b、f       |
| ①- ④                | U                | g         | ③- ⑨                | O                | c、e       |
| ①- ⑤                | U                | g         | ④- ⑤                | I                | a、c       |
| ①- ⑥                | U                | g         | ④- ⑥                | U                | g         |
| ①- ⑦                | U                | g         | ④- ⑦                | E                | a、c       |
| ①- ⑧                | O                | b、f       | ④- ⑧                | O                | b、f       |
| ①- ⑨                | O                | c、e       | ④- ⑨                | O                | e         |
| ②- ③                | E                | a、c       | ⑤- ⑥                | I                | a、c       |
| ②- ④                | E                | a、c       | ⑤- ⑦                | A                | a、c       |
| ②- ⑤                | E                | a、c       | ⑤- ⑧                | U                | g         |
| ②- ⑥                | O                | b、c       | ⑤- ⑨                | O                | e         |
| ②- ⑦                | A                | a、c       | ⑥- ⑦                | I                | a、c       |
| ②- ⑧                | I                | b、f       | ⑥- ⑧                | I                | b、f       |
| ②- ⑨                | I                | c、e       | ⑥- ⑨                | O                | c、e       |
| ③- ④                | U                | g         | ⑦- ⑧                | O                | b、f       |
| ③- ⑤                | O                | a         | ⑦- ⑨                | I                | c、e       |
| ③- ⑥                | A                | a、b、c     | ⑧- ⑨                | O                | c、e       |

Figure 3. Non-logistics Relationship Diagram



#### 4.4 Comprehensive Relationship Analysis

Based on the logistics and non-logistics relationship analyses, the two types of relationships were integrated to determine the overall closeness among the operating units. As Warehouse F is a typical express transit facility, parcel handling and transfer efficiency are major factors affecting its overall operational performance, while non-logistics relationships associated with operational coordination and management were also considered. A weighting ratio of 3:1 was assigned to logistics and non-logistics relationships. The comprehensive closeness score was calculated as follows:  $C_{ij}=3M_{ij}+N_{ij}$ , where  $C_{ij}$  denotes the comprehensive closeness score between operating units (i) and (j),  $M_{ij}$  denotes the logistics closeness score, and  $N_{ij}$  denotes the non-logistics closeness score.

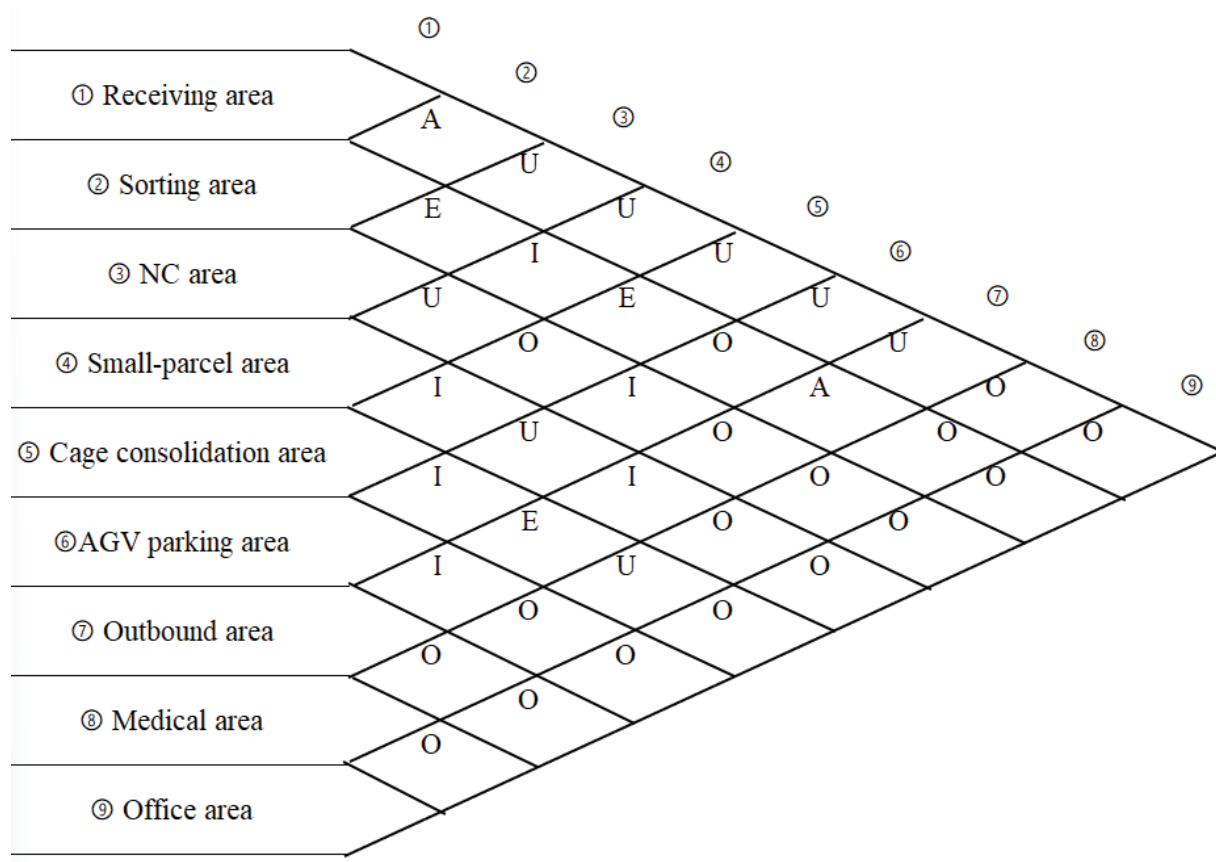
Based on the results presented in Tables 5 and 6, the comprehensive closeness scores were calculated, as shown in Table 7. The comprehensive relationships among the operating units were then classified into six closeness ratings: A (Absolutely Necessary), E (Especially Important), I (Important), O (Ordinary), U (Unimportant), and X (Undesirable). The resulting comprehensive relationship diagram is shown in Figure 4.

Table 7. Comprehensive Closeness Scores and Ratings among Operating Units

| Operating-unit pair | $M_{ij}$ | $N_{ij}$ | $C_{ij}$ | Rating | Operating-unit pair | $M_{ij}$ | $N_{ij}$ | $C_{ij}$ | Rating |
|---------------------|----------|----------|----------|--------|---------------------|----------|----------|----------|--------|
| ①-②                 | 4        | 4        | 16       | A      | ③-⑦                 | 0        | 1        | 1        | O      |
| ①-③                 | 0        | 0        | 0        | U      | ③-⑧                 | 0        | 2        | 2        | O      |
| ①-④                 | 0        | 0        | 0        | U      | ③-⑨                 | 0        | 1        | 1        | O      |
| ①-⑤                 | 0        | 0        | 0        | U      | ④-⑤                 | 1        | 2        | 5        | I      |
| ①-⑥                 | 0        | 0        | 0        | U      | ④-⑥                 | 0        | 0        | 0        | U      |
| ①-⑦                 | 0        | 0        | 0        | U      | ④-⑦                 | 1        | 3        | 6        | I      |
| ①-⑧                 | 0        | 1        | 1        | O      | ④-⑧                 | 0        | 1        | 1        | O      |
| ①-⑨                 | 0        | 1        | 1        | O      | ④-⑨                 | 0        | 1        | 1        | O      |
| ②-③                 | 2        | 3        | 9        | E      | ⑤-⑥                 | 1        | 2        | 5        | I      |
| ②-④                 | 1        | 3        | 6        | I      | ⑤-⑦                 | 2        | 4        | 10       | E      |
| ②-⑤                 | 3        | 3        | 12       | E      | ⑤-⑧                 | 0        | 0        | 0        | U      |
| ②-⑥                 | 0        | 1        | 1        | O      | ⑤-⑨                 | 0        | 1        | 1        | O      |
| ②-⑦                 | 3        | 4        | 13       | A      | ⑥-⑦                 | 2        | 2        | 8        | I      |
| ②-⑧                 | 0        | 2        | 2        | O      | ⑥-⑧                 | 0        | 2        | 2        | O      |
| ②-⑨                 | 0        | 2        | 2        | O      | ⑥-⑨                 | 0        | 1        | 1        | O      |
| ③-④                 | 0        | 0        | 0        | U      | ⑦-⑧                 | 0        | 1        | 1        | O      |
| ③-⑤                 | 0        | 1        | 1        | O      | ⑦-⑨                 | 0        | 2        | 2        | O      |
| ③-⑥                 | 1        | 4        | 7        | I      | ⑧-⑨                 | 0        | 1        | 1        | O      |

Note: The comprehensive closeness ratings were classified according to the following criteria: A, ( $C_{ij} > 12$ ); E, ( $8 < C_{ij} \leq 12$ ); I, ( $4 < C_{ij} \leq 8$ ); O, ( $0 < C_{ij} \leq 4$ ); and U, ( $C_{ij} = 0$ ).

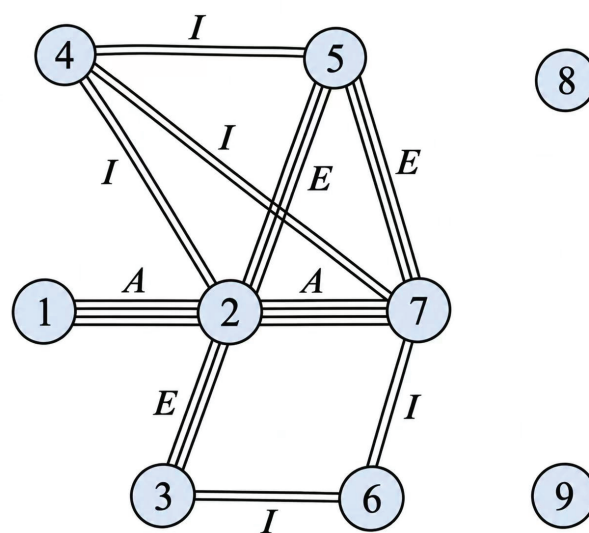
Figure 4. Comprehensive Relationship Diagram



#### 4.5 Activity Relationship Diagram

Based on Table 7 and Figure 4, an activity relationship diagram was developed to represent the relative spatial positions of five operating units, as shown in Figure 5. To improve the clarity of spatial relationships, only A-, E-, and I-rated relationships are connected in Figure 5, whereas O- and U-rated relationships are not shown.

Figure 5. Activity Relationship Diagram (Scale: 1:1000)



#### 4.6 Space Relationship Diagram

Further, the areas of the nine operational units are considered, and the resulting space relationship diagram of Warehouse F is shown in Figure 6.

Figure 6. Space Relationship Diagram of Warehouse F



## 5. Analysis of Layout Optimization Effects of Warehouse F

Based on the results of the logistics relationship, non-logistics relationship, and comprehensive relationship analyses, the functional areas of the F express transit warehouse were reconfigured. To evaluate the rationality of the proposed optimization scheme, the original and optimized layouts are compared from two perspectives: spatial layout and logistics flow.

### 5.1 Spatial Layout Optimization Effects

In the original layout, some operational units with close relationships were spatially dispersed, such as sorting area and small-parcel area. Auxiliary functional areas, such as the office area and medical area, were interspersed among the major logistics operation areas. This arrangement fragmented the main operational space to some extent.

In the optimized scheme, the functional areas were rearranged primarily according to the strength of the comprehensive relationships among operational units. The receiving area is located adjacent to the sorting area, allowing inbound parcels to enter the sorting process more directly. As the core area for parcel distribution, the sorting area is positioned close to the NC area and small-parcel area. The cage consolidation area and outbound area are arranged together to create a relatively continuous space for downstream dispatch operations. Meanwhile, the NC area maintains close spatial proximity to the AGV parking area to facilitate equipment use during the transfer of NC parcels. Auxiliary functional areas, including the office area and medical area, are appropriately separated from the major logistics operation areas to reduce their fragmentation of the core operational space.

After optimization, the warehouse forms a spatial layout centered on the major logistics operational units, including inbound handling, sorting, classified processing, cage loading, and outbound operations, while the auxiliary functional areas remain relatively independent. Compared with the original layout, operational units with strong relationships are located closer, the boundaries between major logistics operation areas and auxiliary functional areas are clearer, and the correspondence between the spatial configuration of functional areas and actual operational relationships is improved.

### 5.2 Logistics Flow Optimization Effects

In the original layout, the transportation paths of different types of parcels involved a certain degree of detouring and intersection. Parcel flows could also lead to temporary occupation of aisles by cages, as well as waiting and avoidance by AGVs, thereby increasing interference among different logistics activities.

In the optimized scheme, the major logistics nodes were reorganized according to the actual operational process, forming an overall logistics flow of “inbound handling–sorting–classified processing–cage loading/outbound.” Consecutive operational units are located closer to each other. Auxiliary functional areas are separated from the main logistics areas. This reduces unnecessary detours and intersections among different logistics flows. At the same time, this arrangement makes the flow directions of different parcel types clearer.

After optimization, the consistency between the main parcel flow directions and the spatial arrangement of functional areas is strengthened. The logistics flow changes from a relatively dispersed and intersecting pattern to a more continuous and clearly organized structure. Necessary logistics aisles and operational spacing are also maintained between functional areas. Overall, the optimized scheme improves not only the static spatial configuration but also the connections among major logistics operation.

## Conclusion

Based on the SLP method and the actual operational processes of Warehouse F, this study analyzes the logistics relationships, non-logistics relationships, and comprehensive relationships among different operational units and proposes an optimized layout while considering the space requirements of each functional area and the physical constraints of the warehouse. The results show that the original layout is characterized by the spatial dispersion of highly related operational units, a mismatch between the spatial configuration of functional areas and actual operational relationships, and detours and intersections in logistics paths. After optimization, highly related operational units are located closer to one another, the spatial separation between major logistics operation areas and auxiliary functional areas becomes clearer, and the overall logistics flow is reorganized along the sequence of “inbound handling–sorting–classified processing–cage loading/outbound,” thereby improving the coordination between the spatial configuration of functional areas and the actual parcel flow process. The results show that the optimized layout improves the arrangement of functional areas and makes logistics flows more direct. Meanwhile, this proposed layout can also provide a reference for similar express transit warehouses.

This study is subject to several limitations due to data availability. The layout optimization is mainly based on routine operational data and field investigation results and does not fully account for the dynamic effects of substantial fluctuations in business volume during peak periods, such as major e-commerce promotional events. In addition, the proposed optimization scheme remains primarily at the layout design stage and has not yet been further validated through simulation. Future research could incorporate more comprehensive dynamic operational data and employ simulation tools such as FlexSim and AnyLogic to evaluate and further refine the proposed layout under different operational scenarios.

## Funding

This research was supported by the Philosophy and Social Sciences Research Project of Shanxi Province (No. 2025YB216), 2026 Annual Major Decision-Making Consultation Project of the People’s Government of Shanxi Province (No. ZB3012), 2025 Annual Special Research Project on High-Quality Financial and Economic Development of Shanxi Province (No. SXCJGZLZS2503), and Yuncheng University Doctoral Research Start-up Project.

## Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

## Reference

- [1] Rahmadani M I, Diansari B N, Waluyono G F. (2025). Redesigning the Production Facility Layout Using the Systematic Layout Planning (SLP) Method: A Case Study at CV. Vyo Factory[J]. SAINTEKBU, 17(01):61-71. doi: <https://doi.org/10.35794/emba.v6i3.20232>.
- [2] Zaeni Z S, Juniani A I, Zammi K A F Z. (2025). The Re-Layout Design of the Production Machine Through Blocplam and Systematic Planning (SLP) Method[J/OL]. MEIN : Journal of Mechanical, Electrical & Industrial Technology, 2(1):17-24. DOI:10.35991/mein.v2i1.20.
- [3] Lopes R, Pinto A G, Pinto I M, Pereira M T, Gavina A, Figueiredo I, Viamonte A J. (2026). Using Systematic Layout Planning together with Analytic Hierarchy Process to Define a New Industrial Layout in the Automotive Industry: A Nov-

- el Approach[J/OL]. *Journal of Mechanical Engineering and Manufacturing*, 2(1):6. DOI:10.53941/jmem.2026.100006.
- [4] Ji-Hyland C, White D, Khaydarov R. (2025). The impact of circular economy practices on sustainable logistics performance[J/OL]. *International Journal of Logistics Research and Applications*, 28(10):1220-1246. DOI:10.1080/13675567.2025.2465579.
- [5] Hu X, Chuang Y F. (2023). E-commerce warehouse layout optimization: systematic layout planning using a genetic algorithm[J/OL]. *Electronic Commerce Research*, 23(1):97-114. DOI:10.1007/s10660-021-09521-9.
- [6] Yang T, Su C, Hsu Y. (2000). Systematic layout planning: a study on semiconductor wafer fabrication facilities[J/OL]. *International Journal of Operations & Production Management*, 20 (11):1359-1371. DOI:10.1108/01443570010348299.
- [7] Lin Q, Wang D. (2019). Facility Layout Planning with SHELL and Fuzzy AHP Method Based on Human Reliability for Operating Theatre[J/OL]. *Journal of Healthcare Engineering*, 1-12. DOI:10.1155/2019/8563528.
- [8] Singla V. (2025). An integrated systematic layout planning, analytical hierarchy process and nonlinear programming approach to facility layout design[J/OL]. *International Journal of Operational Research*, 52(1): 128-145. DOI:10.1504/IJOR.2025.143960.
- [9] Zhao D, Yang J, Zhou H. (2020). Layout Design of Warehouse Based on Systematic Layout Planning and GA-ACO Algorithm[C/OL]//2020 Chinese Automation Congress (CAC). Shanghai, China: IEEE, 7101-7104. <https://ieeexplore.ieee.org/document/9327612/>. DOI:10.1109/CAC51589.2020.9327612.
- [10] Yang M, Wang T, Yao J, Qiu P, Gong G. (2025). Model based planning and layout optimization for multilevel express processing centers through A case study of air express sorting center[J/OL]. *Scientific Reports*, 15(1):33961. DOI:10.1038/s41598-025-11113-8.
- [11] Liu Y, Zhao Q.(2015). Research on Logistics Center Layout Based on SLP[M/OL]//Logistics Engineering Institution, CMES. *Proceedings of China Modern Logistics Engineering*: 286. Berlin, Heidelberg : Springer Berlin Heidelberg:17-28. [https://link.springer.com/10.1007/978-3-662-44674-4\\_2](https://link.springer.com/10.1007/978-3-662-44674-4_2). DOI:10.1007/978-3-662-44674-4\_2.