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A Functional Area Layout Model of Agricultural Products Logistics Park Based on PSO Algorithm

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Abstract

This paper proposes a functional area layout model for an agricultural products logistics park based on particle swarm optimization (PSO). Targeting the the layout planning of an agricultural products logistics park in C County, a multi-objective planning model is established ,considering the total material handling cost, land area utilization rate, and the comprehensive correlation of functional areas. The PSO algorithm is employed to solve the model and obtain the optimal layout scheme. Through field research and data analysis, the validity and practicability of the model are verified. The results indicate that the model can significantly enhance the operational efficiency and service quality of agricultural products logistics parks, reduce logistics costs, and promote the sustainable development of the agricultural products logistics industry.

Keywords: PSO; agricultural products logistics park; functional area layout

1. Introduction

Advanced technologies (Internet, IoT, big data) have accelerated the digital transformation of agricultural logistics, enhancing traceability through e-commerce and cold-chain systems. However, China's 20%-30% circulation attrition rate (vs. $< 5\%$ in developed nations) reveals systemic issues: fragmented infrastructure, poor node coordination, and inadequate multi-objective optimization. As critical supply chain hubs, agricultural logistics parks require layout designs balancing geographical constraints, functional correlations, costs, and sustainability—challenging traditional static methods lacking global optimization capacities. As the core hub of the agricultural product supply chain network, the logistics park plays a key role in reducing circulation costs, minimizing spoilage, and promoting balanced regional economic development by integrating core functions such as warehousing, processing, and transportation. However, the layout planning of agricultural product logistics parks involves multi-objective and multi-constraint complex system optimization problems. It is necessary to consider multi-dimensional factors such as geographical location, functional relevance, operating costs, and environmental sustainability.

Domestic and foreign scholars have carried out a lot of research on the layout optimization of logistics park functional areas. Early studies were mainly based on the system layout design (SLP) method. For example, Wang and Xu (2024) discussed that the joint research of SLP and Flexsim can promote the leanness of warehouse layout. Kutsenko et al. (2019) utilized the SLP method to optimize logistics center layouts, and verified the improvement effect of process layout on operation efficiency. Yang (2016), Gao (2018) domestic scholars also use SLP method to conduct empirical

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research on the layout of Chongqing Luohuang Logistics Park and D port functional area. Driven by the “dual carbon” objective, ” low-carbonization has become the core issue of logistics park layout optimization. Peng et al. (2025) established a dynamic matching model of climate adaptive photovoltaic, validating the efficacy of renewable energy integration in mitigating the carbon footprint of these parks. Lin and Hu (2024) constructed a carbon accounting system and a cost optimization model, subsequently proposing a functional area restructuring strategy predicated on green technology innovation. While Liu et al. (2024) advanced a low-carbon pathway for multimodal transport logistics parks, their work did not fully address the dynamic interaction mechanisms inherent in functional area design. Guo et al. (2023) further introduced carbon emission constraints and proposed a low-carbon-oriented multi-objective layout model of logistics parks. The field of intelligent algorithms presents significant technical iteration characteristics. Zhang and Jiang (2024) optimized the layout of ZJ ’s logistics park by integrating SLP and enhanced genetic algorithm, showing the adaptability of the algorithm in complex scenarios. Chen (2024) developed a cosine adaptive genetic algorithm, which enhances the comprehensive correlation among functional areas. Although the CIFS-CODAS fuzzy decision method proposed by Eren and Murat (2024) innovatively quantifies the correlation strength of functional areas, its spatial optimization granularity requires further refinement. It is worth noting that the existing research mostly focuses on the industrial logistics scene, and there is a theoretical gap in the special needs of agricultural product logistics, such as perishable and multi-temperature layers. While the case study of Yang (2024) involves the planning of agricultural product logistics parks, it lacks a quantitative model capable of addressing seasonal variability and stringent time constrain. Addressing the existing gap between theory and practical application, this study proposes a functional area layout model of agricultural product logistics park based on improved particle swarm optimization (PSO), aiming to solve the planning problem under multi-objective and multi-constraint conditions. The theoretical contribution of this study is to expand the application boundary of intelligent algorithms in the field of agricultural product logistics. At the practical level, the agricultural product logistics park in C County is taken as the empirical object, and the key data such as logistics flow and functional area correlation matrix are obtained through field investigation to verify the validity and practicability of the model. It provides a scientific decision-making tool for the cost reduction, efficiency increase and sustainable development of regional agricultural product supply chain, and has important policy reference value.

2. Model construction

2.1. Basic assumptions

When constructing the multi-objective planning model of the functional area layout of the agricultural product logistics park, it is necessary to make reasonable assumptions first, and determine the constraints and objective functions accordingly. This study aims to comprehensively optimize the total cost of material handling within the park, the utilization rate of land area and the comprehensive correlation of functional areas. Combined with the characteristics of agricultural product logistics parks, considering the constraints such as the layout of roads inside and outside the park and the setting of entrances and exits in functional areas, the following assumptions are proposed:

(1) Each functional area is set as a rectangle, and its length-width ratio needs to meet the preset range to ensure the rationality and flexibility of the layout.

(2) The entrances and exits of the functional area are located at the midpoint of the edge, which is convenient for efficient logistics operations.

(3) The overall planning of the logistics park is rectangular, and the boundary of each functional area is parallel to the boundary of the park to keep the layout neat and standardized.

(4) Functional areas are set independently and do not overlap with each other to ensure the independence and integrity of each regional function.

(5) Reserve roads and logistics operation space in the functional area to ensure the smooth progress of logistics operations.

(6) The functional interval distance is calculated by Manhattan distance, and the starting and ending points of the logistics volume are the geometric centers of each functional area to improve the accuracy and practicability of the layout.

Function design Considering the total cost of material handling, the utilization rate of land area and the comprehensive correlation degree of functional areas, a multi-objective model is established.

(1) Objective function

(a) The total cost of material handling is the smallest

$$\min C_1 = \sum_{i=1}^{n}\sum_{j=1}^{n} c_{ij} q_{ij} d_{ij} \tag{1}$$

Among them, c_{ij} is the cost per unit of goods per unit distance between function area i and function area j; q_{ij} is the logistics volume between function area and function area j; d_{ij} is the distance between function area i and function area j, $d_{ij} = |x_i - x_j| + |y_i - y_j|$.

(b) The land area rate is the largest

$$\max C_2 = \sum_{i=1}^{n} \frac{S_i}{L \times W} \tag{2}$$

Among them, S_i is the area of functional area i; L is the length of the park; W is the width of the park.

(c) The comprehensive correlation is the largest

$$\max C_3 = \sum_{i=1}^{n}\sum_{j=1}^{n} R_{ij} K_{ij} \tag{3}$$

Among them, R_{ij} is the comprehensive correlation between functional area i and functional area j ;K_{ij} is the adjacency correlation between functional area and functional area j, and the specific values are shown in Table 1.

Table 1: Adjacency correlation between functional areas

Manhattan distance	Adjacency correlation degree K_{ij}
$[0, d_{\max}/6]$	1.0
$[d_{\max}/6, d_{\max}/3]$	0.8
$[d_{\max}/3, d_{\max}/2]$	0.6
$[d_{\max}/2, 2d_{\max}/3]$	0.4
$[2d_{\max}/3, 5d_{\max}/6]$	0.2
$[5d_{\max}/6, d_{\max}]$	0

Because the optimization direction and dimension of the three functions of the total handling cost function, the land area utilization function and the comprehensive correlation function are different, and the order of magnitude is quite different, the direct addition and subtraction will produce large errors. Therefore, it is necessary to add the normalization factor α_1, α_2 to normalize it. Finally, the total objective function expression can be obtained as follows :

$$\min C = \alpha_1 b_1 C_1 - b_2 C_2 - \alpha_2 b_3 C_3 = \alpha_1 b_1 \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} q_{ij} d_{ij} - b_2 \sum_{i=1}^{n} \frac{S_i}{L \times W} - \alpha_2 b_3 \sum_{i=1}^{n} \sum_{j=1}^{n} R_{ij} K_{ij} \quad (4)$$

Among them, $\alpha_1 = \frac{1}{\sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} q_{ij} d_{\max}}$; $\alpha_2 = \frac{1}{\sum_{i=1}^{n} \sum_{j=1}^{n} R_{ij} (K_{ij})_{\max}}$; $b_1 + b_2 + b_3 = 1$; b_1 is the weight of total handling cost; b_2 is the weight of land area utilization rate; b_3 is the comprehensive correlation weight.

(2) Constraint conditions

(a) The maximum lateral distance constraint of all functional area layouts

$$x_{max} = \sum_{i=1}^{n} (l_i + r_x) \leq L \quad (5)$$

Here, l_i is the length of the functional area i in the X-axis direction ; r_x is the distance between the two adjacent functional areas in the X-axis direction; n is the total number of functional areas.

(b) The maximum longitudinal distance constraint of all functional area layouts

$$y_{\max} = \sum_{i=1}^{n} (w_i + r_y) \leq W \quad (6)$$

Here, w_i is the length of the functional area i in the Y-axis direction; r_y is the distance between the adjacent two functional areas in the X-axis direction.

(c) The entrance and exit constraints of each functional area

The center coordinate of the functional area i is (x_i, y_i), the length is l_i, and the width is w_i. Then the entrance and exit coordinates (M_i, N_i) on the functional area i are: $(M_i, N_i) = \left(x_i, y_i - \frac{w_i}{2}\right)$ or $\left(x_i, y_i + \frac{w_i}{2}\right)$ or $\left(x_i - \frac{l_i}{2}, y_i\right)$ or $\left(x_i + \frac{l_i}{2}, y_i\right)$.

(d)The non-overlapping constraint of adjacent functional areas is $|x_i - x_j| - r_x \geq \frac{l_i + l_j}{2}$, $|y_i - y_j| - r_y \geq \frac{w_i + w_j}{2}$.

(e) The constraint that the boundary of each functional area cannot exceed the boundary of the park area is $\frac{l_i}{2} \leq x_i \leq L - \frac{l_i}{2}$, $\frac{w_i}{2} \leq y_i \leq W - \frac{w_i}{2}$.

(f) The length and width limit of each functional area is $\lambda_i = \frac{L_i}{W_i}$, $\lambda_{i\min} \leq \lambda_i \leq \lambda_{i\max}$.

2.2. Mathematical model

According to the above formula and content, the functional area layout model of agricultural product logistics park in C county is expressed as:

$$\min C = \alpha_1 b_1 C_1 - b_2 C_2 - \alpha_2 b_3 C_3 = \alpha_1 b_1 \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} q_{ij} d_{ij} - b_2 \sum_{i=1}^{n} \frac{S_i}{L \times W} - \alpha_2 b_3 \sum_{i=1}^{n} \sum_{j=1}^{n} R_{ij} K_{ij}$$

$$
s.t. \begin{cases}
x_{\max} = \sum_{i=1}^{n} (l_i + r_x) \leq L & \\
y_{\max} = \sum_{i=1}^{n} (w_i + r_y) \leq W & i = 1, 2, ..., n \\
(M_i, N_i) = \left(x_i, y_i - \frac{w_i}{2}\right) \cup \left(x_i, y_i + \frac{w_i}{2}\right) \cup \left(x_i - \frac{l_i}{2}, y_i\right) \cup \left(x_i + \frac{l_i}{2}, y_i\right) & i = 1, 2, ..., n \\
|x_i - x_j| - r_x \geq \frac{l_i + l_j}{2} & i = 1, 2, ..., n \\
|y_i - y_j| - r_y \geq \frac{w_i + w_j}{2} & i, j = 1, 2, ..., n, i \neq j \\
\frac{l_i}{2} \leq x_i \leq L - \frac{l_i}{2} & i, j = 1, 2, ..., n, i \neq j \\
\frac{w_i}{2} \leq y_i \leq W - \frac{w_i}{2} & i = 1, 2, ..., n \\
\lambda_i = \frac{L_i}{W_i} \lambda_{i\min} \leq \lambda_i \leq \lambda_{i\max} & i = 1, 2, ..., n \\
 & i = 1, 2, ..., n
\end{cases} \tag{7}
$$

3. Empirical analysis

3.1. Data sources

As a typical agricultural county in China, C County takes the cultivation of fruits and vegetables, grains and characteristic agricultural products as the leading industry, with an annual agricultural output exceeding 2 million tons. However, limited by the lagging logistics infrastructure and decentralized circulation mode, the circulation loss rate of agricultural products has been maintained at more than 25% for a long time, and the cold chain coverage rate is less than 15%, which seriously restricts the high-quality development of regional agricultural economy. This study takes the comprehensive agricultural product logistics park planned and constructed in C County as the object, with a total area of 225 mu. According to the above assumptions, the whole area of the logistics park is regarded as a rectangle, and the south side of the logistics park is regarded as the X axis, and the west side is regarded as the Y axis. A plane rectangular coordinate system is established, with the southwest corner of the logistics park as the origin, and the length and width of the park are 500 meters and 300 meters respectively. In this area, the layout planning of 10 functional areas, such as receiving area, storage area, circulation processing area, product exhibition and sales area, transit distribution area, waste recycling area, comprehensive service area, business office area, parking area and reserved development area, is carried out, along with the establishment of roads and greening areas within the park.

The data come from the statistical annual report of the Agricultural and Rural Bureau of C County, the operation records of logistics enterprises and field research. The relevant known data is input into MATLAB, that is, the minimum interval distance between each functional area is 6 meters; the range of length-width ratio of functional area is [1/3,3]. The unit distance handling cost of goods in the park is set to 0.02 yuan; the weights of cargo handling cost, land utilization rate and comprehensive correlation were 0.4, 0.3 and 0.3, respectively.

3.2. Model parameter

Based on the improved PSO algorithm, the particle swarm size is set to 100, and the maximum number of iterations is 200 times. The parameters for the model were configured as detailed in Table 2.

Table 2: Layout Model Parameter Settings

Parameter	Numerical Value
Population size	100
Iteration times	200
Inertia weight	0.8
c_1	0.5
c_2	1.5
Spatial dimensions	2
$V_{\max}$	10 % of the area value

3.3. Algorithm implementation

MATLAB is used to solve the problem, and the layout planning model of the logistics park is obtained. The iterative process of the algorithm is shown in Figure 1.

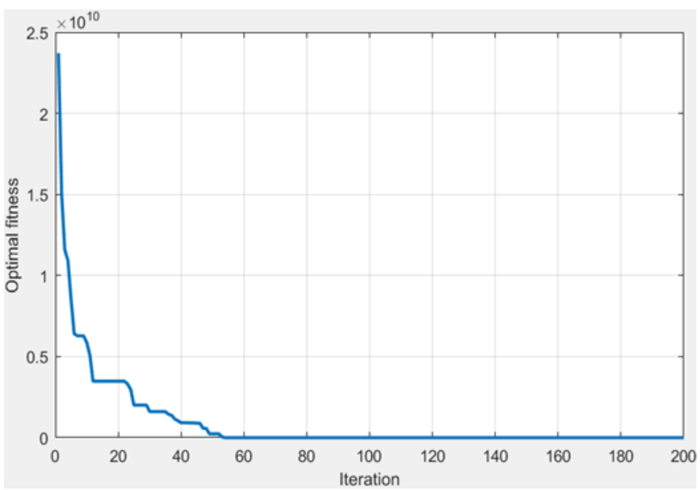

Figure 1: Particle Iteration Process

3.4. Optimal results

It can be seen from Figure 1 that the function is relatively stable when running to about the 55 th time, and the result is approximately the optimal solution. The particle swarm optimization algorithm layout diagram at this time is shown in Figure 2.

The relevant data of each functional area of this layout are shown in Table 3.

The layout results obtained by the particle swarm optimization algorithm are theoretically optimal, but in fact, it is necessary to combine the local actual situation to determine whether it is

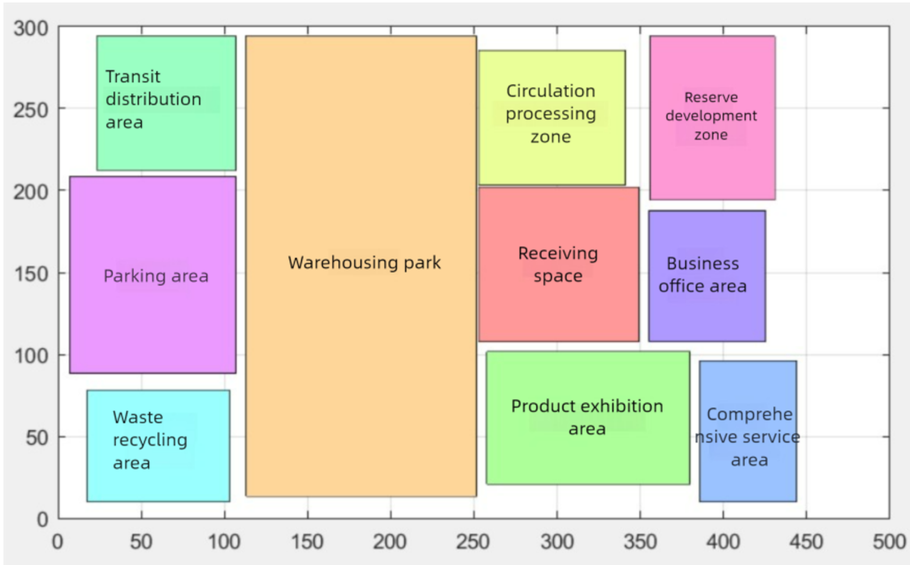

Figure 2: Layout of Particle Swarm Optimization Algorithm

Table 3: Center coordinates and dimensions of each functional area

Functional Area	Center Coordinates	X-axis length (length/m)	Y-axis length (width/m)
Consignment area	(300.8,154.9)	96.4	94.5
Storage area	(184.1,156.5)	138.6	280.4
Circulation processing zone	(296.8,247.1)	88.4	82.4
Product exhibition area	(318.7,62.2)	122.1	80.6
Transit distribution area	(63.3,255.1)	83.8	81.5
Waste recycling area	(62.2,46.9)	85.3	68.4
Integrated Service Area	(413.9,53.2)	58.1	86.3
Business office area	(389.1,148.5)	70.0	80.0
Parking area	(57.0,148.4)	100.0	120.0
Reserved Development Zone	(393.2,245.8)	75.0	100.0

the optimal result. Therefore, the scheme is adjusted according to the factors not considered in the model. At the same time, considering the road setting and greening distribution inside the park, the final functional area layout scheme is obtained as shown in Figure 3.

Figure 3 presents the layout map obtained by reducing the proportion of each side of the agricultural product logistics park. Overall, the comprehensive planning goal of the park has been basically achieved. The plan includes two criss-cross main roads, which are designed to improve the efficiency of logistics operations and effectively alleviate traffic congestion within the park. For the design of entrances and exits, the park has adopted a strategy of diversion of people and vehicles and diversion of cargo damage, which not only optimizes the operating efficiency of the park, but also significantly improves safety. In the layout of the storage area and the receiving area, the two main areas are set in the central position of the park and are located at the intersection of the main roads, which facilitates the distribution of vehicles. Specifically, vehicles entering the park can form a natural diversion at the intersection. Vehicles with trading needs can directly enter the

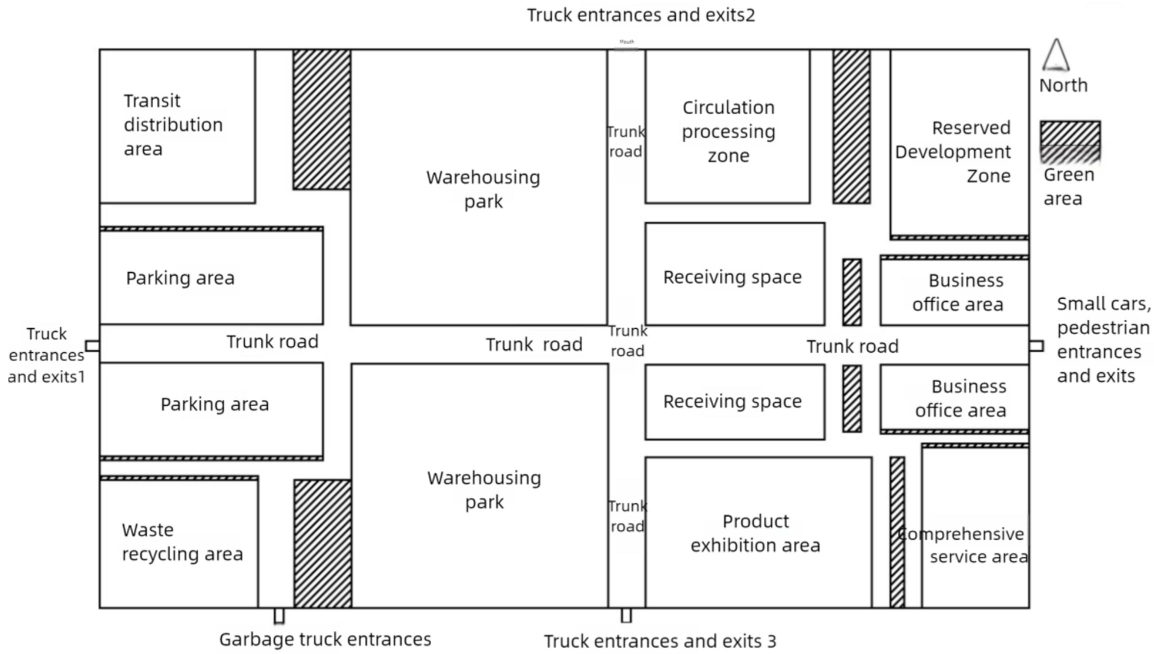

Figure 3: Functional Area Layout

receiving area on the south side, while vehicles that need to be processed enter the receiving area on the north side. This design not only improves the efficiency of the internal operation of the park, but also effectively reduces the operation cost, reflecting the scientific and practical nature of the park planning.

4. Conclusion

This paper proposes a functional area layout model for an agricultural products logistics park based on the Particle Swarm Optimization (PSO) algorithm. The study takes the agricultural products logistics park in County C as the research object and constructs a multi - objective planning model, which comprehensively considers factors such as material handling cost, land area utilization rate, and the comprehensive correlation of functional areas. The model is solved using the PSO algorithm to obtain the optimal layout scheme.However, the current work primarily validates algorithmic convergence through iterative trajectories rather than benchmarking against alternative optimization methods (e.g., genetic algorithms or simulated annealing). This limitation stems from the project's prioritized focus on tailoring PSO parameters to agricultural logistics specificity, including perishability constraints and seasonal demand variability. Future research will incorporate comparative algorithmic analyses and dynamic environmental factors to enhance generalizability.

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