Multi-objective logistics park functional block layout based on genetic algorithm

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Abstract. At present, the construction of logistics parks has become an indispensable part of the modern logistics system. Scientific and reasonable layout planning of the logistics parks not only effectively saves logistics costs, but also promotes the efficient operation of the entire logistics. This article uses a combination of qualitative analysis and quantitative analysis to analyze the layout structure of the functional areas, build a multi-objective mathematical model with the largest degree of adjacency and the smallest transportation cost, and set the functional blocks in horizontal and vertical modes to make the layout more rational. Using genetic algorithm to solve the model with Matlab software, and verify the rationality and effectiveness of the model through examples, providing a new idea for the layout of modern logistics parks.

Keywords: genetic algorithm, multi-objective, logistics park, functional block layout.

1. Introduce

Domestic and foreign scholars have conducted a series of studies on the layout of logistics parks. Richard Muther (1961) [1] based on system analysis and first proposed SLP, which combines logistics relations with non-logistics relations, and aims at the lowest logistics cost to solve the layout problem. Lee [2] et al. (2005) described the interrelationship of functional areas as an adjacency graph through an improved genetic algorithm, and applied Dijkstra algorithm to calculate the shortest distance between each functional area. Šulgan (2006) [3] through SWOT analysis and research on the corporate market, proposed a new strategy for planning and layout based on the characteristics of logistics transportation and distribution. Hernández Gress [4] et al. (2011) used an improved genetic algorithm and applied binary variables to solve the layout of functional blocks without equal area. Xiao [5] et al. (2012) proposed a low-carbon SLP improvement method to plan and design the layout site, which improved the logistics status of the workplace. Hosseini SS [6] et al. (2014) applied an improved SLP method to solve multi-level layout planning. Chen [7] et al. (2015) applied slice structure technology to determine the final layout of all irregular functional areas. Yan SUN [8] et al. (2017) used genetic algorithm to solve the layout problem considering the transportation network of the park. J F Liu [9] et al. (2020) applied a heuristic algorithm based on Pareto optimization and niche technology to solve the multi-objective irregular facility layout.

In this paper, with the goal of maximizing the degree of relationship and minimizing transportation cost, the functional areas are set horizontally and vertically, and entrance and exit constraints are set. The final layout is obtained through genetic algorithm.
2. Modern logistics park model construction

2.1. Build model assumptions
This article mainly considers the compact layout of each functional area as the principle. Since the shape of the functional area in real life is mostly rectangular, and for the convenience of calculation, the following assumptions are made:

1. The shape of each functional area is a rectangle with known length and width, and its boundary is parallel to the boundary of the logistics park, and the area and quantity are known.
2. The center of each functional area is located at its geometric center. The flow of material is generated from its center.
3. There is a fixed road interval between each functional area.
4. There is an exit and an entrance in the logistics park. The entrances are located on the boundary of the park to ensure the convenience of entering and exiting vehicles.

2.2. Model construction:

\[
\begin{align*}
\min Z_1 &= \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} C_{ij} Q_{ij} d_{ij} \\
\max Z_2 &= \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} K_{ij} b_{ij} \\
\text{s.t.} & \quad |x_i - x_j| \geq \frac{1}{2} [l_i d + h_i (1 - l) + l_j d + h_j (1 - l)] + P \\
& \quad |y_i - y_j| \geq \frac{1}{2} [h_i d + l_i (1 - l) + h_j d + l_j (1 - l)] + P \\
& \quad \frac{1}{2} [l_i d + h_i (1 - l)] + w \leq x_i \leq A - \frac{1}{2} [l_i d + h_i (1 - l)] - w \\
& \quad \frac{1}{2} [h_i d + l_i (1 - l)] + w \leq y_i \leq B - \frac{1}{2} [h_i d + l_i (1 - l)] - w \\
& \quad 1 \leq \theta_i \leq \theta_{max} \\
& \quad y_k = 0 \text{ or } B, x_k \in [0, A] \\
& \quad x_k = 0 \text{ or } A, y_k \in [0, B]
\end{align*}
\]

Thus, \( n \) is the number of functional blocks in the logistics park; \( i \) and \( j \) represent functional blocks \( i \) and \( j \); \( C_{ij} \) is the unit transportation cost between \( i \) and \( j \) of the functional blocks; \( Q_{ij} \) is the average logistics volume between functional blocks \( i \) and \( j \); \( d_{ij} \) is the cargo transportation distance between functional areas \( i \) and \( j \); this article assumes that the flow between each functional area is generated from the center, \( d_{ij} \) is the absolute distance on the horizontal axis and the vertical axis; \( K_{ij} \) represents functional area \( i \), The comprehensive correlation coefficient between \( j \); \( b_{ij} \) represents the close value between functional areas \( i \) and \( j \), which can be obtained by dividing \( d_{max} \). \( A \) and \( B \) indicate the length and width of the park respectively. Set the functional area horizontal and vertical two modes, the aspect ratio of the functional area must be greater than or equal to 1.

\[
I_i = \begin{cases} 
1, & \text{the functional area is placed horizontally} \\
0, & \text{the functional area is placed vertically}
\end{cases}
\]

Constraint (3) and (4) ensure that each functional area does not overlap in the horizontal axis direction and the vertical axis direction; \( l \) and \( h \) respectively represent the length and width of each functional area; \( P \) represents the fixed distance between each functional area.

Constraint (5) and (6) indicate that all functional areas cannot exceed the boundaries of the park in the horizontal and vertical directions. Constraint (7) expresses the aspect ratio of the functional block. In order to prevent the functional block from being too long or too narrow, it is more conducive to the actual use of space. Constraint (8) and (9) respectively represent the entrance and exit constraints of the park, and they are set at the boundary of the park to ensure that goods enter and exit the logistics park normally. Constraint (10) indicates the horizontal and vertical setting of the functional area.
3. Model solving

3.1. Chromosome coding
According to the construction of the model, this paper uses a combination of floating-point coding and binary coding, and uses positive integers \( \{1, 2, 3, 4, \ldots, n\} \) to represent the number of the logistics center functional area, using \( \{0, 1\} \) indicates the orientation of the functional area. So the chromosome can be expressed as \( A_i = \{f_1, f_2, f_3, \ldots, f_n, I_1, I_2, I_3, \ldots, I_n\} \), where \( f_n \) represents the number of the \( n \)th functional area, and \( I_n \) indicates the placement direction.

3.2. Other operation
First, the population is initialized when the constraints are met, then the two objective functions are normalized, and the second objective function is converted to the minimum value through the penalty function method.

\[
\text{min } Z_2' = M - \sum_{i=1}^{n} \sum_{j=i+1}^{n} K_{ij} b_{ij} \tag{11}
\]

where \( M \) is a very large number, and then the fitness function value is generated,

\[
\text{fitness} = w_1 \frac{Z_1 - \min Z_1}{\max Z_1 - \min Z_1} + w_2 \frac{Z_2 - \min Z_2}{\max Z_2 - \min Z_2} \tag{12}
\]

where \( w_1 \) and \( w_2 \) respectively represent the weights of the two objective functions; \( \min Z_1 \) and \( \max Z_1 \) are the minimum and maximum values of formula (1); \( \min Z_2 \) and \( \max Z_2 \) are the minimum and maximum values of formula (2) respectively. Then, we use the roulette method of selection for selection operators. The chromosomes are crossed in a single-point crossover mode. Some gene values in the individual chromosome coding string are replaced with other alleles of the locus to achieve mutation. A new individual maintains the diversity of the population while preventing premature convergence.

4. Case analysis

4.1. Determination of basic parameters
A local government plans to build a logistics park measuring 450m×330m. The required area of each functional area is shown in Table 1.

According to the predicted logistics volume and cargo operation process of each functional area of the logistics park, the daily average logistics volume \( Q_{ij} \) of each function area of the logistics park is obtained. The unit transportation distance cost \( C_{ij} \) is 0.03. Then according to the logistics intensity between the functional areas of the logistics park, set the minimum spacing of each functional section to 10.

| number | Functional area         | Demand area /m² | length /m | width /m |
|--------|-------------------------|-----------------|-----------|----------|
| 1      | warehouse               | 16200           | 180       | 90       |
| 2      | processing areas        | 20000           | 200       | 100      |
| 3      | Temporary storage areas | 8000            | 100       | 80       |
| 4      | distribution area       | 6000            | 100       | 60       |
| 5      | parking                 | 8625            | 115       | 75       |
| 6      | integrated service area | 8500            | 100       | 85       |
| 7      | entrance                | 32              | 8         | 4        |
| 8      | exit                    | 32              | 8         | 4        |

This article believes that the importance of logistics relations and non-logistics relations are equal, and the comprehensive relationship matrix between the functional areas is calculated based on the closeness between the them, as shown in Table 2.
Table 2. Comprehensive relationship matrix between functional areas.

| Number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|--------|---|---|---|---|---|---|---|---|
| 1      | 0 | 6 | 1 | 0 | 0 | 1 | 5 | 3 |
| 2      | 6 | 0 | 0 | 0 | 0 | 2 | 5 | 1 |
| 3      | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| 4      | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 1 |
| 5      | 0 | 0 | 1 | 1 | 0 | 3 | 0 | 2 |
| 6      | 1 | 2 | 1 | 2 | 3 | 0 | 0 | 2 |
| 7      | 5 | 5 | 1 | 0 | 0 | 0 | 0 | -1|
| 8      | 3 | 1 | 1 | 1 | 2 | 2 | -1| 0 |

4.2. GA algorithm solution

NP=1000, crossover probability Pc=0.7, mutation probability Pm=0.1, and the maximum number of iterations is 600. The distance between the functional area and the boundary is \( w = 7 \). The function block is placed horizontally and vertically according to Table 3.

Table 3. Pseudo code of functional area horizontally and vertically.

```plaintext
for i=1:L
    if BB(i)==1%Set the function block horizontally to 1
        Devicesize new(1,i)=Devicesize(1,i);
        Devicesize new(2,i)=Devicesize(2,i);
    else
        Devicesize new(1,i)=Devicesize(2,i);
        Devicesize new(2,i)=Devicesize(1,i);
    end
end
```

In this paper, the mathematical software Matlab is used to solve the model, and the layout structure shown in Figure 1 is obtained. The calculation time is 15.323 seconds and the objective function value is 3.187969. Solving the model that does not set the functional area horizontally and vertically obtains Figure 2, and the calculation time is 14.675 seconds. The objective function value is 3.804786. By comparison and according to the adjacency of the functional areas, the layout structure of Figure 2 is not conducive to the scheduling of vehicles in the park, and the value of the objective function is higher than the target value of the model in the text. In summary, by setting the horizontal and vertical modes of functional areas, the layout is more rationalization.

5. Conclusions and prospects

This paper uses an improved SLP method to establish a multi-objective function with the goal of maximizing the comprehensive relationship of each functional area and minimizing the transportation
cost, setting the horizontal and vertical placement modes of the functional blocks, and restricting the
e trance and exit of the logistics park to enhance logistics The circulation performance of the park is
solved by the genetic algorithm, which reduces the uncertainty of the influence of subjective factors on
the layout to a certain extent. Future research can make more considerations in models and algorithms.

Acknowledgement
This article is supported by Project JZW2020032 Logistics Park Layout Optimization and Operation
Process Simulation Research, China Society of Logistics.

References
[1] Muther R. Systematic layout planning. Boston, Industrial Education Institute, (1961)
[2] Lee, K. Y., Roh, M. I., & Jeong, H. S. An improved genetic algorithm for multi-floor facility
layout problems having inner structure walls and passages. Computers & Operations Research,
32(4), 879–899(2005)
[3] Šulgan, M. Logistics park development in Slovak Republic. Transport, 197-200. (2006)
[4] Hernández Gress ES, Mora-Vargas J, Herrera del Canto LE, et al. A genetic algorithm for optimal
unequal-area block layout design. Int J Prod Res 2183–2195(2011)
[5] Xiao Y, Cheng Y K , Jia Q H . Application of SLP in Plant Layout Based on Low Carbon
Logistics[J]. Advanced Materials Research, 314-317(2012)
[6] Hosseini SS, Wong KY, Mirzapour SA, et al. Multi-floor facility layout improvement using
systematic layout plan-ing. Adv Mater Res,532–537(2014)
[7] Chen Y, Jiang Y, Wahab MIM, et al. The facility layout problem in non-rectangular logistics
parks with split lines. Expert Syst Appl, 42 7768–7780(2015)
[8] Y SUN, YF Gao. The functional block layout of logistics park based on transportation
organization[J]. Journal of Tongji University, 45(3), 369-376(2015).
[9] JF LIU, J LIU, XM YAN, A heuristic algorithm combining Pareto optimization and niche
technology for muti-objective uneal area facility layout problem.[J].Engineering
Applications of Artificial Intelligence,(2020).