Application of Improved Genetic Algorithm Based on Multi-objective Optimization in the Layout of Intelligent Logistics Park

Nana Wang*

School of Liberal Education, Liaoning University of International Business and Economics, Dalian 116052, China
*Corresponding author: wangnana124@aliyun.com

Abstract: This paper constructs a layout model for intelligent logistics parks through literature research, breaking the traditional limitation of focusing only on fixed costs. It innovatively integrates a multi-objective optimization mechanism that considers logistics distribution and operating costs. The fitness function, encoding and decoding schemes, genetic algorithm operators, and parameter configurations are carefully designed. By introducing and improving the genetic algorithm, the planning and layout problems of the park are effectively solved, significantly reducing redundant encoding and greatly improving computational efficiency. The experimental results show that this method can obtain the optimal layout solution in a short time, providing strong support for the scientific planning and efficient operation of intelligent logistics parks, achieving dual optimization of cost and efficiency.

Keywords**:** Intelligent logistics; Multi-objective optimization; Fitness function; Genetic algorithm

1. Introduction

The Genetic Algorithm is an optimization algorithm based on the principles of natural selection and genetics, with strong global search capabilities and robustness. It can effectively handle multi-objective and multi-constraint optimization problems. In the planning of intelligent logistics parks, we need to consider multiple objectives such as transportation costs, construction costs, and operating costs, as well as various constraints such as traffic flow, spatial constraints, and functional area associations. These objectives often have complex trade-offs, and the constraints make the solution space more complicated.

Abdallah et al conducted layout analysis of logistics parks with the aim of reducing carbon emission costs, combining a carbon-sensitive model[1]. Zhao et al.constructed a bi-objective integer model considering carbon emissions and logistics costs based on the logistics characteristics of different industries, and successfully applied it to the layout optimization of logistics parks[2]. Lin et al.established an optimization model with the goal of minimizing carbon emission costs and uncertain demand as a stochastic constraint, effectively guiding the layout planning of logistics parks[3]. Zhao et al. considered environmental cost factors and conducted a systematic layout planning analysis of logistics parks based on the SLP method from aspects such as products and output[4]. Tao et al.explored the layout planning problem of logistics parks with total cost and total carbon emissions as the objective functions[5]. Sun et al.constructed a layout set division model for functional areas of logistics parks based on a grid data structure, with the goal of minimizing carbon emission and transportation costs[6]. In summary, the planning and layout model of intelligent logistics parks based on the improved genetic algorithm proposed in this paper comprehensively considers three core objectives: economic cost, operating efficiency, and environmental impact[7]. By constructing a multi-objective optimization model, the key parameters of the location and area of each functional area within the park are used as decision variables, and corresponding constraint conditions are designed to ensure the feasibility and practicality of the model. By simulating natural selection and genetic mechanisms, we seek the global optimal solution with a view to achieving the optimization of the park layout and improving operational efficiency. At the same time, by studying the improvement strategies of the genetic algorithm, the convergence speed and solution accuracy of the algorithm are improved, providing an effective tool for the scientific planning of intelligent logistics parks and promoting the sustainable development of the logistics industry.

2. Constructing a model based on an intelligent logistics park

The planning and layout of intelligent logistics parks is a complex optimization problem, involving trade-offs among multiple objectives such as economic cost, operational efficiency, and environmental impact. This paper proposes an improved optimization model based on the Genetic Algorithm (GA) to achieve efficient and sustainable park layouts.

2.1 Problem Modeling

In the planning of intelligent logistics parks, the objective function usually includes the following three dimensions:

Minimization of Economic Cost:This encompasses construction costs, operational costs, and transportation costs. Construction costs are related to the area and unit cost of each facility within the park. Operational costs involve personnel salaries, equipment maintenance, etc., while transportation costs are related to the distance and methods of goods transportation within the park.Maximization of Operational Efficiency:This focuses on the turnover speed of goods and order processing efficiency. The turnover speed of goods is affected by storage and transportation time, while order processing efficiency is related to the complexity of the process and the degree of automation. Minimization of Environmental Impact: This primarily concerns energy consumption and carbon emissions during park operations.

2.2 Improved Genetic Algorithm Design

To address the limitations of traditional genetic algorithms in solving complex optimization problems, this paper proposes the following improvement strategies:

Encoding Method:Real-number encoding is adopted, mapping the location and area of each functional area within the park to the genes of a chromosome, facilitating the direct representation of layout solutions.

Fitness Function:A multi-objective fitness function is designed, considering the above three objectives.

Selection Operation:A combination of roulette wheel selection and elite retention strategy is employed to ensure that superior individuals are passed on to the next generation.

Crossover Operation:The Simulated Binary Crossover (SBX) operator is used to effectively explore the solution space and maintain population diversity.

Mutation Operation:A polynomial mutation operator is adopted to randomly perturb the genes of chromosomes, increasing population diversity.

Termination Condition: The maximum number of iterations or the stagnation of the optimal solution for multiple consecutive generations is set as the termination condition.

Through these improvement strategies, the genetic algorithm proposed in this paper can more effectively balance economic cost, operational efficiency, and environmental impact when solving the planning and layout problems of intelligent logistics parks, achieving efficient and sustainable park layouts.

2.3 Model Construction

Considering the scale and agglomeration effects of logistics parks, as well as the processing costs of logistics parks and the transportation costs between logistics parks, the cost function is a concave function with a marginal transportation cost that decreases as the logistics volume increases, with its first derivative greater than zero and its second derivative less than zero, expressed mathematically as follows:

$$c_j(x) = a\left(\sum_i x_{ij}\right)^{\theta} \tag{1}$$

$$x_j = \sum_i x_{ij} \tag{2}$$

where a and θ are undetermined constants. Generally, the smaller the value of $0 \le \theta \le 1$, the greater the agglomeration effect. Let:

$$\frac{dc_j(x)}{dx_j} > 0 \quad , \qquad \frac{d^2\left(c_j(x)\right)}{dx^2{}_j} < 0 \tag{3}$$

Then the following inequality holds:

$$F(x) = \sum_{i=1}^{n} w_i \int (x_i) \tag{4}$$

The objective function is:

$$F(x)_{\max} = w_1 \int (x_1) + w_2 \int (x_2) + w_3 \int (x_3) \tag{5}$$

If the score is the highest, then the layout is optimal. The objective function for logistics intensity relationships is as follows:

$$\int (x_1)_{\min} = \gamma_1 \sum_{i=1}^{m} \sum_{j=1}^{n} M(x) x_{ij} + \gamma_2 \sum_{i=1}^{m} \sum_{j=1}^{n} N(x) x_{ij} \tag{6}$$

where γ_1 and γ_2 represent the importance weights, $\gamma_1 + \gamma_2 = 1$, $N(x)$ is the degree of correlation with the flow of goods, and $M(x)$ is the degree of storage capacity. The objective function for business processes is as follows:

$$\int (x_2)_{\max} = \beta_1 \sum_{i=1}^{m} \sum_{j=1}^{n} P(x) x_{ij} + \beta_2 \sum_{i=1}^{m} \sum_{j=1}^{n} Q(x) x_{ij} + \beta_3 \sum_{i=1}^{m} \sum_{j=1}^{n} R(x) x_{ij} \tag{7}$$

$$\int (x_3)_{\max} = \sum_{i=1}^{m} \sum_{j=1}^{n} H(x) x_{ij} \tag{8}$$

where $H(x)$ represents the degree of environmental impact.

3. Results Analysis and Discussion

Experiments show that the functional area layout method using the improved GA has significant advantages in reducing total material handling costs, increasing the correlation between functional areas, saving operation time, and land utilization rate. Its weighted total score is better than the score obtained using the relationship diagram method, demonstrating a certain degree of superiority and feasibility. Considering the actual situation, this paper analyzes the implementation technology, operating costs, and other factors, compares and evaluates each candidate solution, selects the best design plan, and then obtains the final layout plan. The rationality comparison of planning layouts for different models is shown in Figure 1.

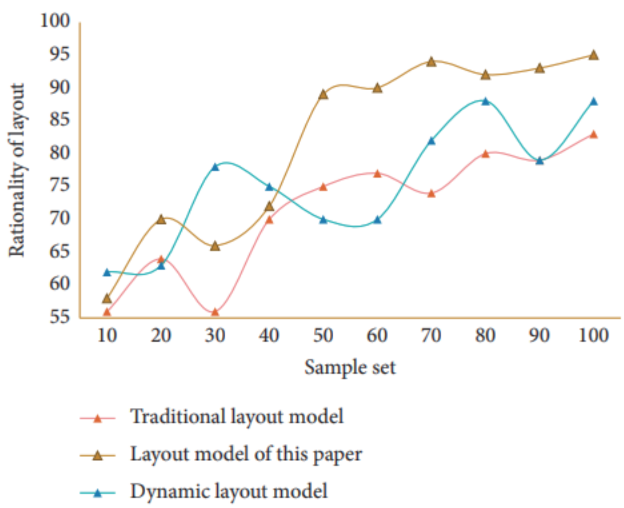

Figure 1. Comparison of rationality of planning and layout of dierent models.

From Figure 1, The experiments show that It can be observed that the intelligent logistics park planning and layout model proposed in this paper, based on an improved genetic algorithm, is capable of achieving a balance between economy, efficiency, and environmental friendliness in multi-objective optimization. By optimizing the encoding method, fitness function, and genetic operations, the model has shown significant improvements in both solution efficiency and global optimization capabilities, providing an effective tool for the scientific planning of smart logistics parks.

The genetic operations within the model, including selection, crossover, and mutation, have been refined to enhance the algorithm's exploration and exploitation capabilities. This fine-tuning ensures that the model can swiftly converge on high-quality solutions while maintaining a diverse population of potential layouts, thereby reducing the risk of premature convergence and local optima.

4. Conclusion

As the core node of the modern logistics system, the rationality of the planning and layout of intelligent logistics parks directly affects the operational efficiency, economic benefits, and environmental impact of the entire park. Aiming at this complex multi-objective optimization problem, this study proposes an improved genetic algorithm-based planning and layout model for intelligent logistics parks, comprehensively considering three core objectives: economic cost, operational efficiency, and environmental impact. By constructing a multi-objective optimization model, key parameters such as the location and area of each functional area within the park are taken as decision variables, and corresponding constraints are designed to ensure the feasibility and practicality of the model.

Acknowledgments

This work was supported by the project of China Society of Logistics (2025CSLKT3-028).

References

[1] ABDALLAH T, FARHAT A, DIABAT A, et al. Green supply chains with carbon trading and environmental sourcing: formulation and life cycle assessment [J]. Applied Mathematical Modelling, 2012, 36(9): 4271−4285.

[2] ZHAO Quanwu, YANG Qian. The location of city professional logistics centers on consideration of CO_2 emissions [J]. Chinese Journal of Management Science, 2014, 22(7): 124−130.

[3] LIN D S, ZHANG Z Y, WANG J X, et al. Lowcarbon logistics distribution center location with uncertain demand [J]. Control and Decisions,2020,35(2):492−500.

[4] ZHAO Jingyuan, LYU Nan. Layout of logistics park based on improved SLP method [J]. Journal of Chang'an University (Natural Science Edition),2020,40(3): 100−108.

[5] TAO Jinghui, GUO Xiaowei. The Co-location between logistics park and industrial park based on the total cost and carbon emission reduction [J]. Chinese Journal of Management Science,2018,26(12):124−134.

[6] SUN Liucheng, SUN Yan, ZHENG Wenjia. Model and algorithm on the layout problem of functional areas in irregular logistics parks [J]. Journal of Transportation Systems Engineering and Information Technology,2017,17(2):168−175.

[7] SUN W,HUANG C C. Predictions of carbon emission intensity based on factor analysis and an improved extreme learning machine from the perspective of carbon emission efficiency [J]. Journal of Cleaner Production,2022,338:130414.