# Path Optimization in Different Road Sections Based on Improved Ant Colony Algorithm

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Abstract: The traditional ant colony algorithm has certain limitations to solve the path optimization problem, and its effect is relatively unsatisfactory. In the context of sustainable development, low-carbon logistics has become an inevitable trend in the development of the modern logistics industry. Traditional logistics and distribution often ignore the environmental impact of transportation, resulting in wasted energy and increased CO2 emissions. In order to meet this challenge, researchers and logistics companies are looking for innovative solutions, and intelligent algorithms provide an efficient way. This paper will focus on how to optimize low-carbon logistics paths in different road sections through improved ant colony algorithms.

## 1 INTRODUCTION

As a highly cooperative creature in nature, ants' ability to search for food inspired computer scientists to simulate their behavior, and then developed the famous Ant Colony Optimization (ACO) algorithm (Zhou and Xu, 2023). In the field of logistics, the algorithm is used to solve the Vehicle Routing Problem (VRP) to reduce logistics costs and improve efficiency (Zhao, 2021). However, in pursuing low-carbon goals, we must not only focus on cost and efficiency, but also on the carbon footprint of the entire distribution process (Li Yanzhen,2023).

## 2 RELATED CONCEPTS

### 2.1 Improved Mathematical Description of the Ant Colony Algorithm

In response to this demand, an improved ant colony algorithm came into being. The core of the algorithm is to simulate the behavior of ants releasing pheromones, so that the concentration of pheromones on the optimal path is gradually increased, and the subsequent ants are guided to choose these paths, so as to find the optimal solution (Zhang and Huang, 2021). The improved ant colony algorithm adds the consideration of carbon emissions on the basis of the traditional model (Liu and Gu, et al. 2023), so that the algorithm not only considers the length of the path and the economic cost, but also takes into account the environmental benefits.

$$\lim_{x\to\infty}(y_i \cdot t_{ij}) = \frac{-b \pm \sqrt{b^2-4ac}}{2a} y_{ij} \geq \max(t_{ij} \div 2) \quad (1)$$

The judgment of outliers is shown in Equation (2).

$$\max(t_{ij}) = \partial(t_{ij}{}^2 + 2 \cdot t_{ij}) \succ \frac{1}{2}\frac{n!}{r!(n-r)!}(\sum t_{ij} + 4)\mathrm{N} \quad (2)$$

Specifically, the improved algorithm introduces a carbon footprint assessment function into the pheromone update mechanism, and comprehensively calculates the carbon emissions of each road section according to the traffic conditions, road slopes, vehicle types and other factors of different road sections (Zhang and Wu, et al. 2022). In the process of algorithm execution, it is more inclined to choose those path segments with low carbon emissions, so as to gradually screen out the logistics routes with the smallest overall carbon emissions (Jiang and Gao, et al. 2021). In addition, the algorithm can dynamically adjust the rate of pheromone evaporation and accumulation to adapt to changing road conditions and environmental requirements.



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$$F(d_i) = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \sum t_i \bigcap \xi \cdot \sqrt{2} \rightarrow \int y_i \cdot' \quad (3)$$

## 2.2 Selection of Logistics Route Optimization Scheme

Through this intelligent method, logistics companies can effectively avoid high-pollution areas, reduce unnecessary detours, and choose greener driving routes on the premise of meeting the delivery timeliness (Wang, 2021). This not only helps enterprises establish the brand image of green logistics, but also has great significance for alleviating urban traffic pressure and improving urban air quality.

$$g(t_i) = \ddot{x} \cdot z_i \prod F(d_i) \frac{dy}{dx} - w_i K \frac{\Delta y}{\Delta x} \quad (4)$$

It is worth mentioning that the improved ant colony algorithm is also suitable for complex logistics networks with multiple warehouses and distribution points, which can flexibly deal with logistics path optimization problems of various scales and types, and provide a scientific basis for logistics planning.

$$\lim_{x \to \infty} g(t_i) + F(d_i) \leq \frac{dy}{dx} max(t_{ij}) \quad (5)$$

With the continuous iterative upgrading of algorithms, real-time dynamic optimization can even be realized in the future to respond to the needs of emergencies or temporary changes.

$$g(t_\iota)\widetilde{+F}(d_\iota) \leftrightarrow mean(\sum t_{ij} + 4) \quad (6)$$

## 2.3 Analysis of Logistics Path Optimization Scheme

In conclusion, the improved ant colony algorithm opens a path to green logistics for us. On this path, scientific and technological innovation and environmental protection go hand in hand and complement each other (Jin and He, et al. 2021). With the maturity of technology and the popularization of applications, we look forward to seeing more logistics companies join the ranks of low-carbon logistics, jointly promote the green development of the logistics industry, and create a more sustainable future.

$$No(t_i) = \frac{g(t_i) + F(d_i)}{mean(\sum t_{ij} + 4)} \sqrt{\frac{\partial^2 \Omega}{\partial u \partial v}} \quad (7)$$

$$\frac{g(t_i) + F(d_i)}{mean(\sum t_{ij} + 4)} \leq 1$$

Conclusion: Green logistics is not only related to the sustainable development of an enterprise, but also the embodiment of social responsibility and environmental friendliness.

$$Zh(t_i) = \bigcap \quad [\sum g(t_\iota)\widetilde{+F}(d_\iota)] \quad (8)$$

Through the improved ant colony algorithm, it has become possible to optimize low-carbon logistics routes, so that we can work together towards a more environmentally friendly logistics era, reduce the burden on the planet, and add greenery to the future.

$$accur(t_i) = \frac{min[\sum g(t_\iota)\widetilde{+F}(d_\iota)]}{\sqrt{a^2 + b^2} \sum g(t_\iota)\widetilde{+F}(d_\iota)} \times 100\% \quad (9)$$

In today's society that pursues sustainable development, reducing carbon emissions has become one of the goals of all walks of life. As the main source of global carbon dioxide emissions, the path optimization of transportation is not only related to logistics costs, but also closely related to environmental protection (Xing and Yan, et al. 2021). Traditional path optimization methods often ignore environmental factors, while modern intelligent algorithms, such as ant colony algorithms, provide a solution that is both energy-efficient and efficient (Wu and Hu, 2022). In this paper, we will discuss how to improve the ant colony algorithm to achieve low-carbon path optimization.

$$accur(t_i) = \frac{min[\sum g(t_\iota)\widetilde{+F}(d_\iota)]}{\sqrt{2} \sum g(t_\iota)\widetilde{+F}(d_\iota)} \quad (10)$$

First, we need to understand what ant colony algorithms are. Simulating the way ants find food paths in nature, this heuristic algorithm is able to evolve through a positive feedback mechanism to find the shortest path. Ants release pheromones as they travel, and other ants choose paths based on pheromone concentrations, resulting in an optimal path (Tang and Tang, et al. 2021). However, the traditional ant colony algorithm may fall into the local optimal solution when dealing with complex networks, and it has the disadvantage of low efficiency for multi-objective optimization problems.

# 3 OPTIMIZATION STRATEGY FOR LOGISTICS ROUTE OPTIMIZATION

To overcome these limitations, the researchers proposed an improved ant colony algorithm. These improvements include the introduction of heuristics to guide the search process, adaptive adjustment of pheromone evaporation rate, and reinforcement learning strategies (Chen and Liu, 202). These improvements allow the algorithm to find solutions in a wider search space, while speeding up convergence and reducing the risk of falling into local optimums (Wang, 2021).

## 3.1 Introduction to the Optimization of Logistics Routes

In low-carbon path optimization, we need to consider not only the length of the path, but also the energy consumption of the vehicle, the environmental impact of the route, and possible congestion.

Table 1: Logistics route optimization requirements.

| Scope of application | Grade | Accuracy | Logistics route optimization |
|---|---|---|---|
| Indra-city logistics | I | 87.21 | 91.16 |
| | II | 88.43 | 89.37 |
| Long-distance logistics and transportation | I | 89.18 | 89.25 |
| | II | 94.40 | 90.98 |
| Multi-modal logistics and transportation | I | 91.42 | 89.07 |
| | II | 93.16 | 87.44 |

The logistics route optimization process in Table 1 is shown in Figure 1.

The improved ant colony algorithm can take these factors into account and evaluate the comprehensive cost of different paths through multi-dimensional evaluation functions. For example, algorithms can give higher cost values to high-carbon emission pathways, thereby inducing the search process to favor low-carbon and environmentally friendly choices.

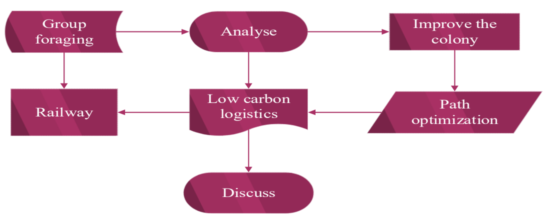


Figure 1: The analysis process of logistics route optimization.

## 3.2 Optimization of Logistics Routes

Furthermore, combined with real-time traffic data and weather forecast information, the improved ant colony algorithm can dynamically adjust the path planning to avoid additional energy consumption and delays caused by traffic congestion or bad weather. This dynamic adaptability is incomparable to traditional static path planning.

Table 2: The overall picture of the logistics route optimization scheme.

| Category | Random data | Reliability | Analysis rate |
|---|---|---|---|
| Indra-city logistics | 90.40 | 92.89 | 87.33 |
| Long-distance logistics and transportation | 90.63 | 90.27 | 90.04 |
| Multi-modal logistics and transportation | 88.17 | 88.98 | 89.91 |
| Mean | 92.23 | 89.64 | 89.18 |
| X6 | 87.82 | 91.11 | 91.99 |
| | | P=1.249 | |

## 3.3 Logistics Path Optimization and Stability

In addition, the improved ant colony algorithm can also be used for charging station planning for electric vehicles. By analyzing the user's driving habits and charging needs, the algorithm can arrange the most reasonable charging stations in the city, reduce the detour caused by the lack of battery life of electric vehicles, and reduce the overall carbon emissions at the macro level.

In the field of modern logistics, efficient path optimization is not only a key part of cost control, but also an important means to improve service quality and win market competitiveness. With the continuous development of artificial intelligence technology, more and more intelligent algorithms are applied to logistics route optimization.

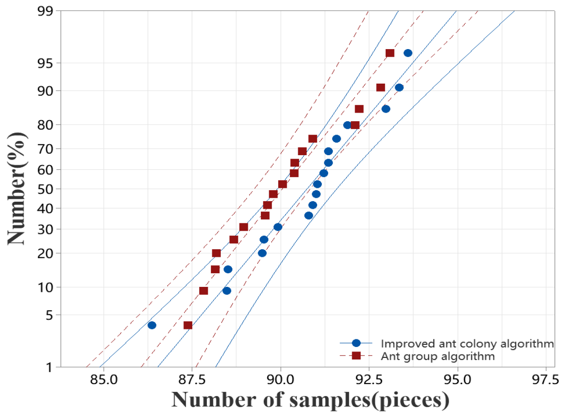


Figure 2: Logistics route optimization with different algorithms.

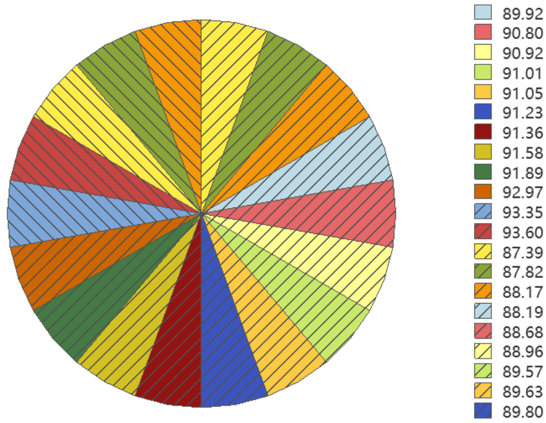


Figure 3: Improved logistics path optimization of ant colony algorithm.

Table 3: Comparison of the accuracy of logistics route optimization of different methods

| Algorithm | Survey data | Logistics route optimization | Magnitude of change | Error |
|---|---|---|---|---|
| Improving the ant colony algorithm | 93.35 | 89.80 | 91.80 | 90.46 |
| Ant colony algorithm | 91.36 | 88.68 | 91.95 | 89.40 |
| P | 92.97 | 87.39 | 91.73 | 92.63 |

In summary, through the improvement of the ant colony algorithm, we can achieve low-carbon path optimization more effectively. This not only helps to reduce environmental pollution and energy consumption, but also improves the efficiency of logistics and transportation. Of course, any algorithm has its limitations, and improved ant colony algorithms also need to be constantly tested and tuned in practice. In the future, with the continuous progress of computing technology and the increasing abundance of environmental data, we have reason to believe that the improved ant colony algorithm will play a more critical role in the field of low-carbon path optimization and contribute a green intelligent force to our earth.

The core of the ant colony algorithm is to simulate the behavior of ants by releasing and sensing pheromones to find food sources and ultimately find the shortest path. In the process of logistics route optimization, we can consider the distribution point of goods as a food source, and the route of goods from the warehouse to each distribution point can be analogous to the path of ants looking for food. Each virtual "ant" represents a potential solution, they choose the path according to the intensity of the pheromone, and leave a certain amount of pheromone as they pass through the path, and over time, the pheromones on the shorter path will become stronger and stronger, thus guiding more "ants" to choose this path, forming a positive feedback process, gradually converging to the optimal or approximate optimal solution.

## 3.4 The rationality of Logistics Route Optimization

However, there are still some shortcomings in the practical application of the traditional ant colony algorithm, such as slow convergence speed and easy to fall into local optimum. Therefore, the improvement of the traditional ant colony algorithm is the key to improve its performance in logistics route optimization applications.

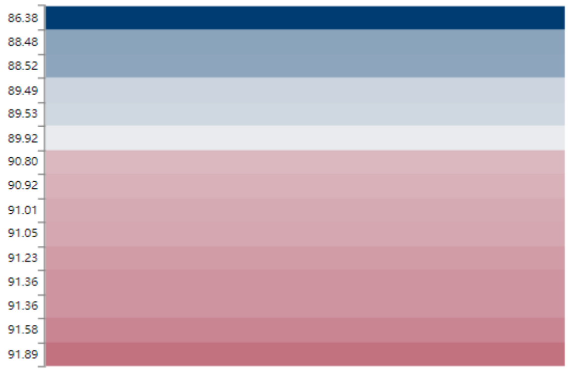


Figure 4: Logistics route optimization with different algorithms.

For example, we can introduce the crossover and mutation mechanisms from genetic algorithms into ant colony algorithms to increase search diversity and jump out of local optimal solutions. In addition, the hybrid algorithm strategy can be used to further improve the global search ability and efficiency of the algorithm by combining the advantages of particle swarm optimization and simulated annealing.

## 3.5 Effectiveness of Logistics Route Optimization

At the same time, according to the needs of specific logistics scenarios, the ratio of pheromone volatilization coefficient and heuristic information can also be customized to adapt to different optimization goals and constraints.

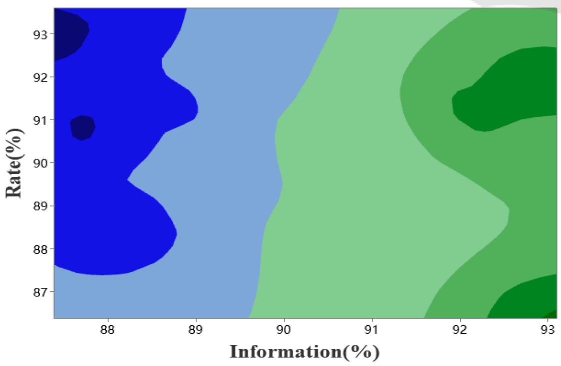


Figure 5: Logistics route optimization with different algorithms.

Improvement strategies typically include adjusting pheromone update rules, introducing heuristics to guide search directions, and incorporating other optimization algorithms.

Table 4: Comparison of the effectiveness of logistics route optimization of different methods.

| Algorithm | Survey data | Logistics route optimization | Magnitude of change | Error |
|---|---|---|---|---|
| Improving the ant colony algorithm | 86.38 | 93.10 | 92.94 | 87.83 |
| Ant colony algorithm | 88.52 | 90.91 | 88.00 | 90.37 |
| P | 89.53 | 89.57 | 90.08 | 89.46 |

In the context of big data and the Internet of Things, real-time dynamic optimization is possible. By collecting real-time data such as vehicle location, traffic conditions, and weather forecasts, the pheromone distribution can be dynamically adjusted, so that the ant colony algorithm can respond to real-time changes and provide a more flexible and accurate path optimization scheme. This real-time and dynamic application can not only reduce delays caused by unexpected situations such as traffic congestion, but also predict and avoid possible risks in the future to a certain extent, and ensure the efficiency and safety of logistics and transportation.



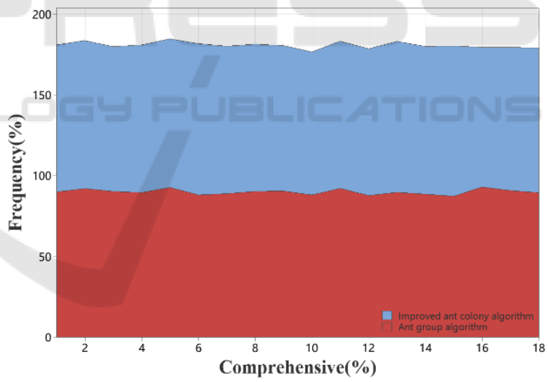


Figure 6: Improved ant colony algorithm logistics path optimization.

Among them, ant colony algorithm, as a heuristic algorithm that simulates the foraging behavior of ants in nature, has shown great potential and unique advantages in logistics path optimization with its unique pheromone communication mechanism and parallel search ability.

## 4 CONCLUSIONS

In conclusion, through the continuous improvement and innovation of traditional ant colony algorithms, we are expected to develop more efficient and intelligent logistics route optimization tools. These improvements not only improve the performance of the algorithm, but also broaden its application scenarios, so that the logistics industry can better adapt to the rapidly changing market demand, realize the optimal allocation of resources, and ultimately promote the progress and development of the entire industry.

## REFERENCES

Chen Jing, & Liu. (2021). Research on the optimization of cold chain logistics path based on ant colony algorithm. Transportation Technology and Economy, 23 (5), 7.

Li Yanzhen. (2023). Research on the optimization of the low-carbon distribution path of the fresh e-commerce cold chain based on the ant colony algorithm. Journal of Tianjin Vocational University, 32 (2), 76-83.

Liu Jianguo, Gu Xiaoyan, Chen Liang, & Chen Mengtong. (2023). Study on grazing path optimization based on an improved ant colony algorithm. computer simulation.

Jiang Fangtao, Gao Yajing, Zhang Chong, Jiang Haoyang, & Yang Naiyu. (2021). Optimization of cold chain logistics transportation path based on ant colony algorithm —— Take f company as an example. Computer Knowledge and Technology: Academic Edition.

Wang Zhiyi. (2021). Research on ship path planning technology based on improved ant colony algorithm. (Doctoral dissertation, Harbin Engineering University).

Jin Juting, He Weijie, Xu Changyuan, Zhang Junyao, & Dai Dan. (2021). Research on optimization of logistics distribution path based on improved ant colony algorithm. Shopping mall modernization (10), 3.

Xing Shubao, Yan Xiujuan, & Bai Zongwen. (2021). Planning and design of logistics distribution path in leather market based on ant colony algorithm —— Evaluation Research on optimization of Logistics Distribution System in Metropolitan isa. Leather Science and Engineering.

Wu Jiming, & Hu Changsheng. (2022). Study on optimization of intercity cargo transport path based on improved ant colony algorithm. Journal of Changchun Institute of Engineering: Natural Science Edition, 23 (4), 109-112.

Tang Huiling, Tang Hengshu, & Zhu Xingliang. (2021). Research on low-carbon vehicle path problem based on improved ant colony algorithm. Chinese Management Science (007), 029.

Wang Yu. (2021). Research on the optimization method of aviation logistics distribution path based on ant colony algorithm. Information Technology (011), 000.

Zhang Danlu, & Huang Xianghong. (2021). Research on logistics path optimization based on improved ant colony algorithm —— Take the logistics network in Henan Province as an example. Journal of Henan University of Technology (Social Science Edition), 037 (002), 56-60,96.

Zhang Guijun, Wu Chuxiong, Chen Chi, Sun Huzeng, Yuan Fengqiao, & Li Yuanfeng. (2022). A multi-distribution center vehicle path optimization method based on an improved ant colony algorithm. CN201910763723.X.

Zhao Jiangli. (2021). Optimize the site selection system design of the low-carbon logistics distribution center based on the improved ant colony algorithm. Modern electronic technology, 44 (13), 5.

Zhou Yuxuan, & Xu Wei. (2023). The application of improved ant colony algorithm in the optimization of low-carbon cold chain logistics path. Logistics technology, 42 (5), 105-110.